General Anatomy & Physiology

General Anatomy & Physiology

EDITED BY JULIA BROWN, MS ED, MS BIOLOGY

WISTECH OPEN

*General Anatomy & Physiology Copyright © 2026 by WisTech Open is licensed under a **Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License**, except where otherwise noted.*

Contents

Overview xi

Book Contributors xiv

How to Use This Book xvi

Accessibility Statement xvii

Competencies and Learning Objectives xix

About WisTech Open and Open RN xxviii

Faculty Resources xxx

Part I. Chapter 1 Introduction to the Human Body

1.1 Introduction 3

1.2 Anatomy and Physiology 5

1.3 Levels of Organization 8

1.4 Anatomical Position 13

1.5 Directional Terms 16

1.6 Major Planes 21

1.7 Major Body Regions and Their Subdivisions 23

1.8 Homeostasis and Feedback Systems 30

1.9 Learning Activity: Flashcards 35

1.10 Glossary 36

Part II. Chapter 2 Chemical Components of Living Things

2.1 Introduction to Chemical Components of Living Things 43

2.2 Elements and Compounds 45

2.3 Chemical Bonds 57

2.4 Organic and Inorganic Compounds 69

2.5 Learning Activity: Flashcards 100

2.6 Glossary 101

Part III. **Chapter 3 Structure and Function of Cells**

3.1 Introduction to Cells 109
3.2 Structure and Composition of the Cell Membrane 111
3.3 Transport Across the Cell Membrane 116
3.4 Cytoplasm, Organelles, and Cytoskeleton 130
3.5 Cell Cycle 143
3.6 Learning Activity: Flashcards 154
3.7 Glossary 155

Part IV. **Chapter 4 Structure and Function of Tissues**

4.1 Introduction 165
4.2 Categories of Tissues 167
4.3 Tissue Disorders 195
4.4 Learning Activity: Flashcards 199
4.5 Glossary 200

Part V. **Chapter 5 Integumentary System**

5.1 Introduction to the Integumentary System 209
5.2 Major Functions of the Integumentary System 211
5.3 Anatomy of the Integumentary System 213
5.4 Wound Healing 231
5.5 Skin Disorders 234
5.6 Career Connections Related to the Integumentary System 263
5.7 Learning Activity: Flashcards 265
5.8 Glossary 266

Part VI. **Chapter 6 Skeletal System**

6.1 Introduction to the Skeletal System 275
6.2 Major Functions of the Skeletal System 278
6.3 Anatomy of the Skeletal System 283

6.4 Bones of the Axial Skeleton 316
6.5 Bones of the Appendicular Skeleton 343
6.6 Joints 359
6.7 Skeletal System Disorders 374
6.8 Career Connections Related to the Skeletal System 394
6.9 Learning Activity: Flashcards 396
6.10 Glossary 397

Part VII. **Chapter 7 Muscular System**

7.1 Introduction to the Muscular System 413
7.2 Muscle Tissue 415
7.3 Skeletal Muscle 420
7.4 Cardiac Muscle 483
7.5 Smooth Muscle 486
7.6 Muscular System Disorders 489
7.7 Career Connections Related to the Muscular System 494
7.8 Learning Activity: Flashcards 496
7.9 Chapter Resources: Movements by Muscle 497
7.10 Glossary 525

Part VIII. **Chapter 8 Nervous System**

8.1 Introduction to the Nervous System 537
8.2 Major Functions of the Nervous System 539
8.3 Anatomy of the Nervous System 542
8.4 Autonomic Nervous System 596
8.5 Senses 604
8.6 Disorders of the Nervous System and Sense Organs 624
8.7 Career Connections Related to the Nervous System 650
8.8 Learning Activity: Flashcards 653
8.9 Glossary 654

Part IX. Chapter 9 Endocrine System

9.1 Introduction to the Endocrine System 675
9.2 Major Functions of the Endocrine System 677
9.3 Anatomy of the Endocrine System 678
9.4 Disorders of the Endocrine System 723
9.5 Career Connections Related to the Endocrine System 730
9.6 Learning Activity: Flashcards 733
9.7 Glossary 734

Part X. Chapter 10 Blood

10.1 Introduction to Blood 743
10.2 Functions of Blood 745
10.3 Characteristics of Blood 747
10.4 Components of Blood 748
10.5 Hemostasis 772
10.6 Hemopoiesis 777
10.7 Blood Types 778
10.8 Blood Disorders 785
10.9 Career Connections Related to Blood 792
10.10 Learning Activity: Flashcards 794
10.11 Glossary 795

Part XI. Chapter 11 Cardiovascular System

11.1 Introduction to the Cardiovascular System 803
11.2 Anatomy of the Heart 805
11.3 Conduction System of the Heart 834
11.4 Cardiac Cycle 840
11.5 Blood Vessels 848
11.6 Cardiovascular Disorders 935
11.7 Career Connections Related to the Cardiovascular System 959
11.8 Learning Activity: Flashcards 962
11.9 Glossary 963

Part XII. Chapter 12 Lymphatic System

12.1 Introduction to the Lymphatic System and Immune Systems 983
12.2 Functions of the Lymphatic System 985
12.3 Structure of the Lymphatic System 987
12.4 Immune System 999
12.5 Lymphatic System Disorders 1013
12.6 Career Connections Related to the Lymphatic System 1023
12.7 Learning Activity: Flashcards 1026
12.8 Glossary 1027

Part XIII. Chapter 13 Respiratory System

13.1 Introduction to the Respiratory System 1033
13.2 Functions of the Respiratory System 1035
13.3 Anatomy of the Respiratory System 1036
13.4 Pulmonary Ventilation (Breathing) 1054
13.5 Disorders of the Respiratory System 1065
13.6 Career Connections Related to the Respiratory System 1090
13.7 Learning Activity: Flashcards 1093
13.8 Glossary 1094

Part XIV. Chapter 14 Digestive System

14.1 Introduction to the Digestive System 1101
14.2 Functions of the Digestive System 1104
14.3 Anatomy of the Gastrointestinal System 1108
14.4 Metabolism and Nutrition 1158
14.5 Digestive System Disorders 1173
14.6 Career Connections Related to the Digestive System 1195
14.7 Learning Activity - Flashcards 1198
14.8 Glossary 1199

Part XV. Chapter 15 Urinary System

15.1 Introduction to the Urinary System 1211

15.2 Functions of the Urinary System 1215
15.3 Anatomy of the Urinary System 1218
15.4 Disorders of the Urinary System 1250
15.5 Career Connections Related to the Urinary System 1259
15.6 Learning Activity: Flashcards 1262
15.7 Glossary 1263

Part XVI. **Chapter 16 Reproductive System**

16.1 Introduction to the Reproductive System 1271
16.2 Functions of the Reproductive System 1273
16.3 Male Reproductive System Anatomy 1274
16.4 Male Puberty and Spermatogenesis 1287
16.5 The Female Reproductive System 1293
16.6 Female Puberty, Ovarian Cycle, and Menstrual Cycle 1302
16.7 Reproductive System Diseases and Disorders 1317
16.8 Career Connections Related to the Reproductive System 1335
16.9 Learning Activity: Flashcards 1338
16.10 Glossary 1339

Part XVII. **Chapter 17 Laboratory Methods and Safety Procedures**

17.1 Introduction to Laboratory Methods & Safety Precautions 1353
17.2 Anatomy and Physiology Lab Guidelines 1355

Acknowledgments 1361
Epilogue 1363

Overview

About *General Anatomy & Physiology*

General Anatomy & Physiology is a comprehensive textbook designed for community and technical college students, examining the basic concepts of human anatomy and physiology as they relate to health sciences. Using a body systems approach, the book emphasizes the interrelationships between structure and function at both the gross and microscopic levels of organization. It covers essential topics such as anatomical terminology, cellular biology, tissue organization, and the functions of major systems, including the integumentary, skeletal, muscular, nervous, endocrine, cardiovascular, respiratory, digestive, urinary, and reproductive systems. This textbook is intended to prepare healthcare professionals to apply foundational knowledge of anatomy and physiology to informed decision-making and effective communication with colleagues and patients. With a blend of theoretical concepts and practical applications, it serves as a vital resource for students pursuing careers in health sciences and provides the foundation for advanced studies in the field.

General Anatomy & Physiology is an open educational resource with **CC BY-NC-SA 4.0** licensing. Content is based on the Wisconsin Technical College System (WTCS) statewide curriculum for General Anatomy & Physiology (10-806-177) and serves as a foundation and prerequisite for Advanced Anatomy & Physiology (10-806-179). The content is grounded in scholarly research and evidence, and is carefully peer reviewed for accuracy and quality.

Licensing/Terms of Use

This textbook is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International (**CC BY-NC-SA 4.0**) license unless otherwise indicated. This means that you are free to:

- **SHARE** – copy and redistribute the material in any medium or format
- **ADAPT** – remix, transform, and build upon the material

Under the following terms:

- **Attribution** – You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.
- **NonCommercial** – You may not use the material for commercial purposes.
- **ShareAlike** – If you remix, transform, or build upon the material, you must distribute your contributions under the same license (CC BY-NC-SA 4.0).

  The licensor cannot revoke these freedoms as long as you follow the license terms.

- **No Additional Restrictions** – You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

Notice – You do not have to comply with the license for elements of the material in the public domain or where your use is permitted by an applicable exception or limitation.

No Warranties Are Given – The license may not give you all of the permissions necessary for your intended use. For example, other rights such as publicity, privacy, or moral rights may limit how you use the material.

Suggested Citation Statement

Unless otherwise noted, below is a suggested citation statement for this resource:

Brown, J. (Ed.). (2026). ***General Anatomy & Physiology***. Open RN | WisTech Open. https://wtcs.pressbooks.pub/anatphys/

Acknowledgment of Remixed Content

This textbook was made possible in part through the availability of high-quality open educational resources. Much of the content in *General Anatomy & Physiology* was developed by remixing, adapting, and building upon existing openly licensed materials, which are identified in the footnotes throughout this text.

We especially acknowledge *Anatomy and Physiology 2e* by OpenStax, which served as a major foundational source for anatomy and physiology content. We also acknowledge the Open RN resources *Medical Terminology 2e*, *Nursing Health*

Promotion, and *Health Alterations*, which contributed terminology, health science context, and clinical connections throughout the text.

The content from these sources has been reviewed, revised, reorganized, and adapted to support the Wisconsin Technical College System statewide curriculum for General Anatomy & Physiology and to meet the learning needs of students preparing for health science careers.

Report a Correction

We welcome your feedback! If you would like to suggest a correction, please let us know by filling out the form at **wistechopen.org/contact**. Your feedback helps us improve and advocate for WisTech Open—we appreciate your support!

Acknowledgment of Support and Disclaimer

This book was developed through the WisTech Open project and supported by funds from WTCS. However, this content does not necessarily represent the policy of the WTCS, and you should not assume endorsement by the state or federal government. More information about the WisTech Open project can be found at **wistechopen.org**.

Book Contributors

Editors

- Julia Brown, MS Biology, MS Education, Chippewa Valley Technical College
- Kimberly Ernstmeyer, MSN, RN, CNE, CHSE, APNP-BC

Author

The developing author remixed existing open educational resources and developed original content.

- Julia Brown, MS Biology, MS Education, Chippewa Valley Technical College

Reviewers

- Mary Bauer, MS, Faculty, Chippewa Valley Technical College
- Robert Duerst, MS Biology, MS Physics, Faculty, University of Wisconsin – Eau Claire
- Kellea Ewen, MSN, RN, Faculty, Lakeshore College
- Dr. Gerald Heins, BA, DC, Faculty, Northeast Wisconsin Technical College
- Jennifer Hinz, BSN, RN, Nurse, Manitowoc Public School District
- Dr. Thomas Kalluvila, PhD, Faculty, Milwaukee Area Technical College
- Angela Landry, MSN, RN, Waukesha County Technical College
- Brian Molini, DC, Faculty, Southwest Wisconsin Technical College
- Troy Moore, MA, DC, Northeast Wisconsin Technical College
- Claire Rueckheim, MS, Western Technical College
- Dr. Christine Ryan, PhD, Faculty/Department Chair, Milwaukee Area Technical College
- Jennifer Servais, MS, MA, Faculty, Western Technical College

- Diane Witt-Rose, MS, Chippewa Valley Technical College
- Dr. Clint Gosse, DC, Mid-State Technical College

WisTech Open Team

- Hannah Bryson, BA, Copy Editor
- Kelly Carpenter, MLIS, Librarian
- Dalton Gamroth, BA, Production
- Haley Mades, BA, Copy Editor
- Ashley McHose, MBA, MLIS, Instructional Design Librarian
- Louise Morgan, BA, Copy Editor
- Vince Mussehl, MBA, MLIS, Project Director
- Asia Yang, AAS, Project Assistant

How to Use This Book

Using the Digital Textbook

The following video provides a quick overview of how to navigate the digital version of the textbook:

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.



Accessibility Statement

At WisTech Open, excellence in education includes excellence in access.

We are committed to designing and publishing open textbooks that empower a wide range of learners. Accessibility is embedded in our development process from concept through revision. We apply established best practices and strive to meet WCAG 2.2 Level AA standards, including the foundational WCAG 2.0 principles of making content perceivable, operable, understandable, and robust.

To support these requirements, WisTech Open develops materials with:

- Structured headings so learners using screen readers can navigate efficiently.
- Meaningful alternative text for images, charts, and figures.
- Properly formatted tables with clear headers.
- Descriptive links that explain their destination or purpose.
- Readable color contrast that does not rely on color alone to communicate meaning.
- Captions and/or transcripts for multimedia.
- Files designed for compatibility with assistive technologies such as screen readers, keyboard navigation, text-to-speech tools, and screen magnification software.

We also recognize that learners engage with content in different ways. Whenever possible, WisTech Open provides materials in multiple formats—including accessible digital editions, optional print textbooks, and optional audiobook versions—to support varied learning preferences and accessibility needs.

Our commitment is active and ongoing. WisTech Open regularly conducts accessibility audits and engages qualified accessibility professionals to evaluate and strengthen our materials. These reviews may include checking document structure, alternative text, color contrast, table accessibility, link clarity, keyboard navigation, multimedia accessibility, and compatibility with assistive technologies. We treat accessibility as a continuous quality improvement process—one that evolves alongside technology, standards, and the needs of the communities we serve.

We acknowledge that accessibility is not a fixed endpoint, and no resource is ever perfect. If you encounter a barrier or have suggestions for improvement, we welcome your feedback. Please contact us at **wistechopen.org/contact**. We are committed to responding promptly and to providing alternative access whenever possible.

At WisTech Open, accessibility is not simply compliance—it is part of our responsibility to expand opportunity through open education.

Competencies and Learning Objectives

Competency 1: Apply descriptive, anatomical, physiological, and directional terminology to the human body and its organization

Learning Objectives

- Distinguish between anatomy and physiology
- Describe the anatomical position
- Describe the three major planes of the body or of an organ
- Identify the major body cavities and their subdivisions
- Identify the serous membranes that line the walls and cover the organs of each body cavity and the fluid found inside each cavity
- Describe two ways to subdivide the abdominal region
- Identify the quadrants of the abdominopelvic cavity
- Identify the nine abdominal regions
- Describe the axial and appendicular regions of the body and their subdivisions
- Use correct directional terms in the study of anatomy and physiology
- Describe the location of specific body organs
- Match locating terms with the correct descriptions
- Match body positions with the correct descriptions
- Define terms related to organization of the human body
- Define examples of homeostasis, negative and positive feedback systems
- Provide examples of homeostasis, negative and positive feedback systems

Competency 2: Classify the major chemical components of living things according to their structure and function

Learning Objectives

- Describe the structure of an atom
- Differentiate among an atom, molecule, compound, ion, and isotopes
- Describe the various types of chemical bonding
- List the body's inorganic compounds and their functions
- Explain the importance of water in living organisms
- Explain the importance of oxygen and carbon dioxide to living organisms
- Describe the body's major organic compounds and their functions
- Define enzymes
- Describe the role of enzymes in cellular metabolism

Competency 3: Characterize the basic structure and functions of the cell and its parts

Learning Objectives

- Define cytoplasm and organelle
- Describe the structure, function, and relationship of all cell organelles
- Describe the structure of the cell membrane
- Describe the different modes of transport of substances across cell membranes

Competency 4: Identify how cells store and use energy

Learning Objectives

- Define metabolism
- Distinguish between catabolic and anabolic pathways
- Contrast aerobic and anaerobic respiration
- Describe the role of mitochondria in cellular metabolism

Competency 5: Analyze the role of DNA in controlling cell functions

Learning Objectives

- Describe the structure and function of DNA, RNA, and chromosomes
- Describe the stages of a cell cycle
- Relate DNA replication to the cell cycle

Competency 6: Correlate the structure of tissues with their functions

Learning Objectives

- Identify the microscopic anatomy of body tissues
- List the characteristics of each tissue type
- List the functions of each tissue type
- Give examples of the locations of each tissue type in the body

Competency 7: Analyze how components of the integumentary system function in the body

Learning Objectives

- Compare the structures and functions of the layers of the skin
- Describe the events occurring during keratinization that produce a skin resistant to abrasion and water loss
- Explain the effects of ultraviolet radiation on the skin
- Describe the glands of the skin, their secretions, and the functions of these secretions, including surface film (acid mantle)
- Describe the way in which the integumentary system helps to regulate body temperature
- Describe the role of skin in sensation
- Explain the way in which skin responds to injuries and repairs itself

Competency 8: Analyze how components of the skeletal system function in the body

Learning Objectives

- Describe the functions of the skeletal system
- Describe the composition and organization of bone matrix
- List the three types of bone cells and their functions
- Give examples of each bone classification, according to their shape
- Describe how the features that characterize spongy and compact bones impact their function
- Describe bone growth
- Explain the role of bone in calcium homeostasis
- Explain how and when bone remodeling occurs
- Describe the different types of joints and how they work

- Apply movement terminology to joint functions
- Identify the components and functions of the axial and appendicular skeleton
- Relate the major landmarks on individual bones of the skeleton to their function
- Discuss the process of skull development
- Identify the differences in structure and function of the various vertebrae
- Describe the skeletal differences between males and females

Competency 9: Analyze how components of the muscular system function in the body

Learning Objectives

- Describe the characteristics and functions of muscular tissue
- Explain the organization of muscle at the tissue level
- Distinguish among the different types of muscle contractions
- Relate types of muscle fibers to muscular performance
- Identify the major human skeletal muscles and their actions
- Define origin, insertion, agonist and antagonist, prime mover and synergist

Competency 10: Analyze how components of the nervous system function in the body

Learning Objectives

- Describe the anatomical organization and general functions of the nervous system
- Distinguish between neurons and neuroglia by comparing their structures and functions
- Explain how the brain and spinal cord are protected
- Describe the major regions of the brain, their structure and functions

- Distinguish among the motor, sensory, and association areas of the cerebral cortex
- Discuss the structure and function of the spinal cord and spinal nerves
- Explain the role of white matter and gray matter in processing and relaying sensory and motor information
- Describe the process of a neural reflex
- Identify the principal sensory and motor pathways
- Differentiate between the somatic and autonomic divisions based on their respective structures and functions
- Identify the cranial nerves and their functions
- Contrast the functions of the sympathetic and parasympathetic divisions of the autonomic nervous system
- Discuss the receptors and processes involved in the senses of smell and taste
- Describe the structures of the ear and their roles in the process of hearing
- Describe the structures and processes involved in maintaining equilibrium
- Describe the structures of the eye and their functions
- Explain the mechanism of vision

Competency 11: Correlate the major organs of the endocrine system with their function in the body

Learning Objectives

- Explain the general functions of the endocrine system
- Differentiate between the two chemical families of hormones
- Explain the control mechanisms of hormonal secretion
- Identify the role of the hypothalamus in the endocrine system
- Describe the functions and effects of hyposecretion and hypersecretion of major hormones
- Compare the roles of the endocrine and nervous systems in maintaining homeostasis
- Describe the endocrine and nervous systems response to stress

Competency 12: Analyze how components of the cardiovascular system function in the body

Learning Objectives

- Identify the names and locations of the major parts of the heart
- Explain the function(s) of each of the major parts of the heart
- Trace the pathway of the blood through the heart and lungs
- Compare the structures and functions of the major types of blood vessels
- Describe the mechanisms that aid in returning venous blood to the heart
- Describe the general characteristics and functions of blood
- Distinguish among the types and functions of the formed elements of blood
- Explain the control of red blood cell production
- Explain the mechanisms that help to achieve hemostasis
- Define coagulation
- Describe the basis of blood typing, ABO, Rh compatibility, and transfusions
- Describe the general characteristics and functions of the lymphatic system
- Describe the location of the major lymphatic pathways
- Describe the formation of tissue fluid and lymph
- Explain lymphatic circulation maintenance and the consequences of an obstruction
- Describe major functions of the lymph nodes, thymus, and spleen
- Define immunity
- Relate the role of the lymphatic system to immunity

Competency 13: Analyze how components of the digestive system function in the body

Learning Objectives

- Describe the parts and functions of the digestive system organs
- Describe the functions of major digestive enzymes (e.g., pepsin, amylase, ptyalin, and lipase)
- Describe the mechanisms of swallowing, vomiting, and defecating

Competency 14: Analyze how components of the respiratory system function in the body

Learning Objectives

- Describe the locations, structures, and functions of the organs of the respiratory system
- Describe the mechanics of breathing
- Define respiratory air volumes and capacities
- Explain the mechanism of respiratory control and factors that may influence it

Competency 15: Analyze how the components of the urinary system function in the body

Learning Objectives

- Illustrate the gross anatomy of the urinary tract
- Describe general functions of the urinary system and its components
- Explain the functional processes of urine formation, including filtration, reabsorption, secretion, and excretion

Competency 16: Analyze how components of the reproductive systems function in the body

Learning Objectives

- Describe the parts and general functions of the male and female reproductive system
- Explain the way in which hormones control the activities of the reproductive organs and the development of secondary sexual characteristics
- Describe the similarities between the male and female reproductive system
- Explain the diploid and haploid cycle in human reproduction

Competency 17: Use appropriate laboratory methods and safety precautions

Learning Objectives

- Identify hazards and safety equipment in the lab
- Select appropriate personal protective equipment
- Follow all laboratory practice expectations of the college

About WisTech Open and Open RN

About WisTech Open



WisTech Open is a Wisconsin Technical College System (WTCS) consortium that supports the development and adoption of open educational resources (OER) across Wisconsin's technical colleges. WisTech Open works with faculty from technical/community colleges, universities, K-12, and industry partners to create high-quality, openly licensed textbooks and learning materials aligned with WTCS statewide curriculum.

By providing free and low-cost resources, WisTech Open helps reduce financial barriers for students while supporting teaching and learning with materials that are relevant, current, and adaptable. All WisTech Open resources are published with open licenses that allow instructors to retain, reuse, revise, remix, and redistribute content to better meet the needs of their students.

To learn more about WisTech Open, browse additional OER textbooks, or build custom supplementary resources, visit **wistechopen.org.**

About Open RN



The Open RN project was initially funded $2.5 million by the U.S. Department of Education – Open Textbook Pilot grant, to create five open educational resource nursing textbooks. The project grew to include several additional textbooks and virtual simulations, funded by HEERF, the Department of Labor, Wisconsin Technical College System, and the WiLS Ideas to Action award. Content is developed by faculty based on WTCS state nursing curriculum and NCLEX-RN test plan. In 2023, the Open RN approach was broadened to include other subject areas and disciplines, spurring the creation of WisTech Open.

To learn more about Open RN or view additional resources, visit **openrn.org**.

Faculty Resources

WisTech Open offers several, no-cost tools that can help you build out your course using open educational resources (OER). Whether you're starting from scratch or adapting an existing textbook, these resources can save time and add meaningful interaction for students.

WisTech Fusion: Supplementary Materials

Explore WisTech Fusion

WisTech Fusion is a new tool that's designed to help with one of the biggest challenges in OER—creating all the "extras" that usually come with a traditional textbook.

With Fusion, you can generate things like:

- Quizzes and assessments
- Slide decks
- Study guides
- Worksheets
- Case studies

Instead of building these from the ground up, Fusion gives you a starting point that you can edit and adapt for your course.

WisTechfusion
Fusing AI with WisTech Open

Wisc-Online Learning Objects

Browse Wisc-Online Learning Objects

Wisc-Online is a long-standing collection of interactive learning materials created by

Wisconsin educators. It's a great option when you want to add a little more engagement without creating something new yourself. Learning objects can be linked directly in your LMS.

You'll find:

- Short interactive activities
- Animations and visual explanations
- Practice exercises and self-checks
- Instructional videos

WisTech Open | Open RN YouTube

Browse YouTube Videos

The WisTech Open | Open RN YouTube channel provides free educational videos that instructors and students can use as supplemental resources to reinforce learning, review key concepts, and support accessible, media-rich instruction across disciplines.

Connecting Content into the LMS

Pressbooks is the platform used to create and host WisTech Open textbooks. If you're using one now, you're familiar with how it organizes content into chapters and sections. One of the biggest advantages of Pressbooks is how easily it fits into your LMS. You can:

- Link or embed specific chapters directly into modules

- Add interactive H5P activities that can be graded
- Keep everything accessible to students in one place

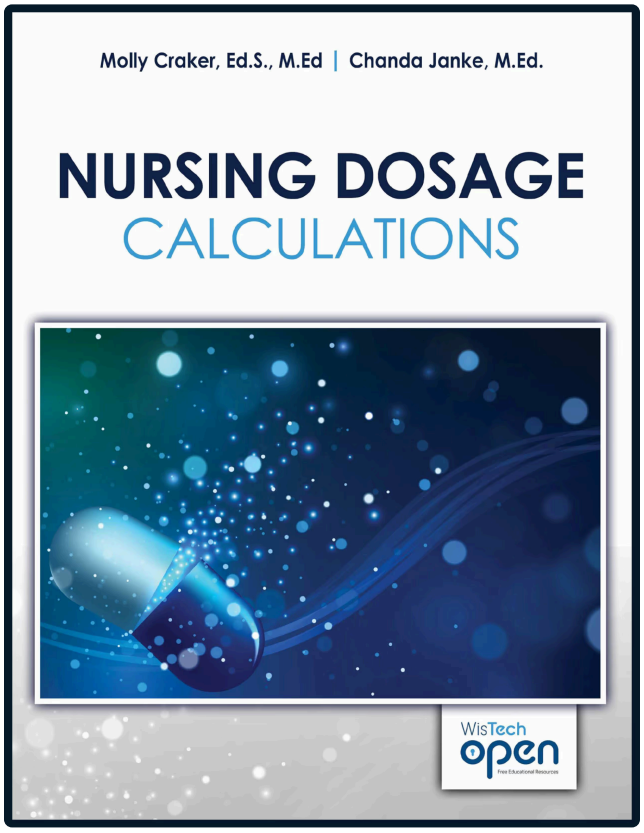
Below is a video of a quick overview:

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Nursing Dosage Calculations

View the Resource

Nursing Dosage Calculations is a practical and essential interactive resource designed to help nursing students master the critical skill of medication dosage calculations. This resource covers fundamental concepts such as unit conversions, dosage formulas, and safe medication administration practices. It includes step-by-step instructions, practice problems, and real-world scenarios to build confidence and accuracy in calculating dosages for various routes of administration, including oral, intravenous, and injectable medications. With a focus on patient safety and precision, this book prepares students to perform dosage calculations confidently in clinical settings. Ideal for nursing students and healthcare professionals, it is a must-have tool for ensuring safe and effective medication administration.


Molly Craker, Ed.S., M.Ed | Chanda Janke, M.Ed.
NURSING DOSAGE
CALCULATIONS
WisTech
open

PART I

CHAPTER 1 INTRODUCTION TO THE HUMAN BODY

1.1 Introduction

Chapter Competency

Apply descriptive, anatomical, physiological, and directional terminology to the human body and its organization.

Learning Objectives

- Include anatomical terminology for the anatomical positions used.
- Include directional terminology.
- Describe characteristics and sequences of homeostatic mechanisms.
- Describe the location, structure, and function of body cavities and linings.
- Identify body planes, sections, and regions.
- Accurately represent homeostatic mechanisms.

Imagine you are working as a paramedic, arriving at the scene of an accident. A patient is lying on the ground, unconscious. To assess their condition quickly and communicate clearly with other emergency responders, you must understand the body's anatomical position, directional terminology, and internal stability mechanisms. Where is the injury located? Is it anterior or posterior? Is it affecting a specific body cavity or organ system? How might the body's homeostatic systems respond to trauma?

These questions require a foundational knowledge of human anatomy and physiology. Understanding anatomical position and directional terminology is crucial for accurately describing the location of structures and injuries within the body. The mechanisms that maintain homeostasis play a vital role in regulating body functions and responding to internal and external changes.

In this chapter, you will explore the essential concepts used to describe the human body and its organization. You will learn how anatomical position provides a standard frame of reference, how directional terms describe relationships between body structures, and how body planes and sections are used to view and interpret anatomical

structures. You will also examine major body regions, body cavities, serous membranes, and the homeostatic mechanisms that help maintain internal balance.

By mastering these concepts, you will gain the language and framework needed to study anatomy and physiology. This foundation will help you communicate accurately, interpret medical scenarios, and understand how the body is organized and maintained throughout later chapters.

1.2 Anatomy and Physiology

Anatomy

Human **anatomy** is the scientific study of the body's structure. Some structures, such as cells, are very small and can only be observed using a microscope. Other structures, such as organs, can be easily seen and studied with the naked eye.

Like most sciences, anatomy has areas of specialization:

- **Gross anatomy** is the study of the large, easily visible parts of the body. It is usually studied by dissection.
  - *Macro-* means "large," so gross anatomy is also referred to as macroscopic anatomy.
- **Microscopic anatomy** is the study of structures seen only with the use of a microscope or other magnification.
  - *Micro-* means "small." Microscopic anatomy includes **cytology**, the study of cells, and **histology**, the study of tissues.

See Figure 1.1 for an image comparing gross anatomy and microscopic anatomy.[1]

1. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

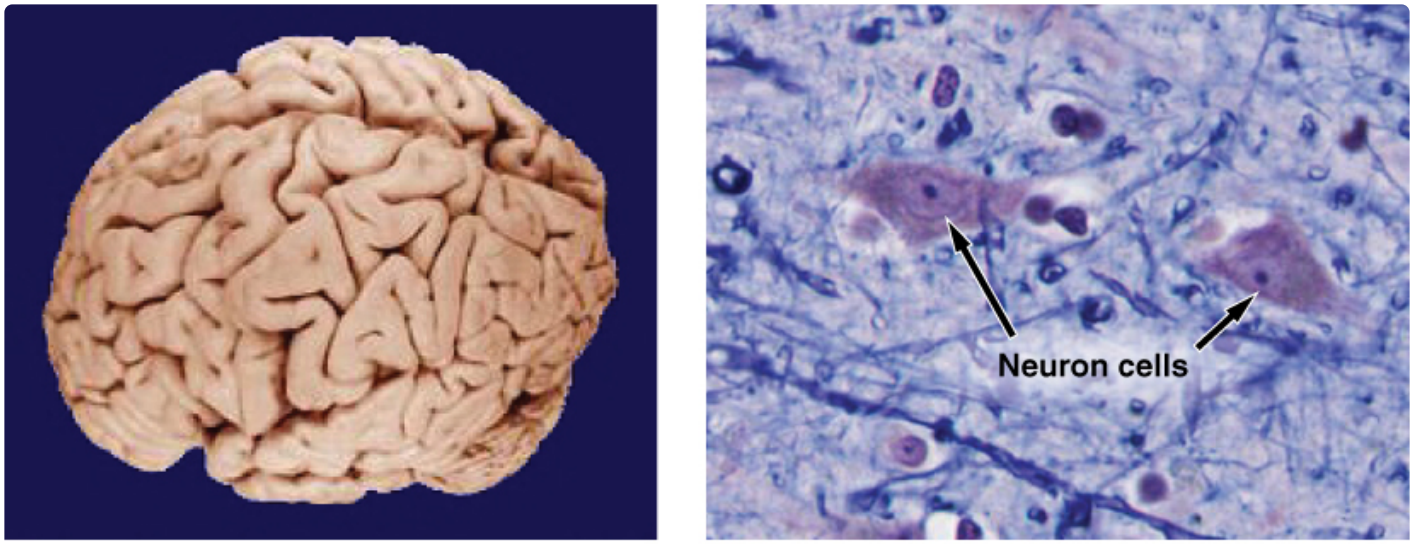


Figure 1.1 (a) Gross Anatomy of the Brain and (b) Microscopic Anatomy of Neuron Cells

Anatomists are scientists who study the structure of the human body. They use two basic categories of anatomy called regional and systemic anatomy:

- **Regional anatomy** is the study of the structures in a specific body region, such as the abdomen. Studying regional anatomy helps us learn the relationships between body structures, such as how the muscles, nerves, blood vessels, and other structures work together in the abdomen.
- **Systemic anatomy** is the study of the structures that make up a specific body system—a group of structures that work together to perform a specific function. For example, a systemic study of the muscular system would look at all the skeletal, cardiac, and smooth muscle of the body.

Physiology

Where anatomy studies the structure of the human body, physiology studies its function. Human **physiology** is the study of how body structures work to support life. Physiologists are scientists who study the functions of the human body. The study of physiology involves observations, manipulations, measurements, and carefully designed laboratory experiments that reveal the functions of the structures and chemicals in the human body.

Like anatomists, physiologists typically specialize in a particular branch of physiology.

For example, a physiologist may study the organ level (such as exploring what different parts of the brain do), whereas another physiologist may study the molecular level (such as exploring how signals travel along nerves). Neurophysiology is the study of the brain, spinal cord, and nerves, and how they work together to allow vision, movement, and thinking.

Much of the study of physiology centers on the body's tendency towards homeostasis. **Homeostasis** is a steady state of internal balance that the body works to maintain. It includes monitoring and adjusting many internal conditions, such as temperature, pulse, respiratory rate, heart rate, and hormone levels. For example, the human body maintains its internal temperature at roughly 98.6°F. A temperature of 102.5°F due to external sources is a disruption of that homeostasis, and the body will work to restore the temperature back to the normal temperature of 98.6°F [2]

2. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

1.3 Levels of Organization

The human body can be organized into many levels, ranging from simple to complex. These levels include atoms, molecules, cells, tissues, organs, organ systems, and the organism. Atoms and molecules form cells, cells group together to form tissues, tissues form organs, organs form organ systems, and organ systems make up an organism. See Figure 1.2[1] for an illustration of the levels of organization.

1. OpenStax. (2016). *101 levels of org in body*. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:101_Levels_of_Org_in_Body.jpg

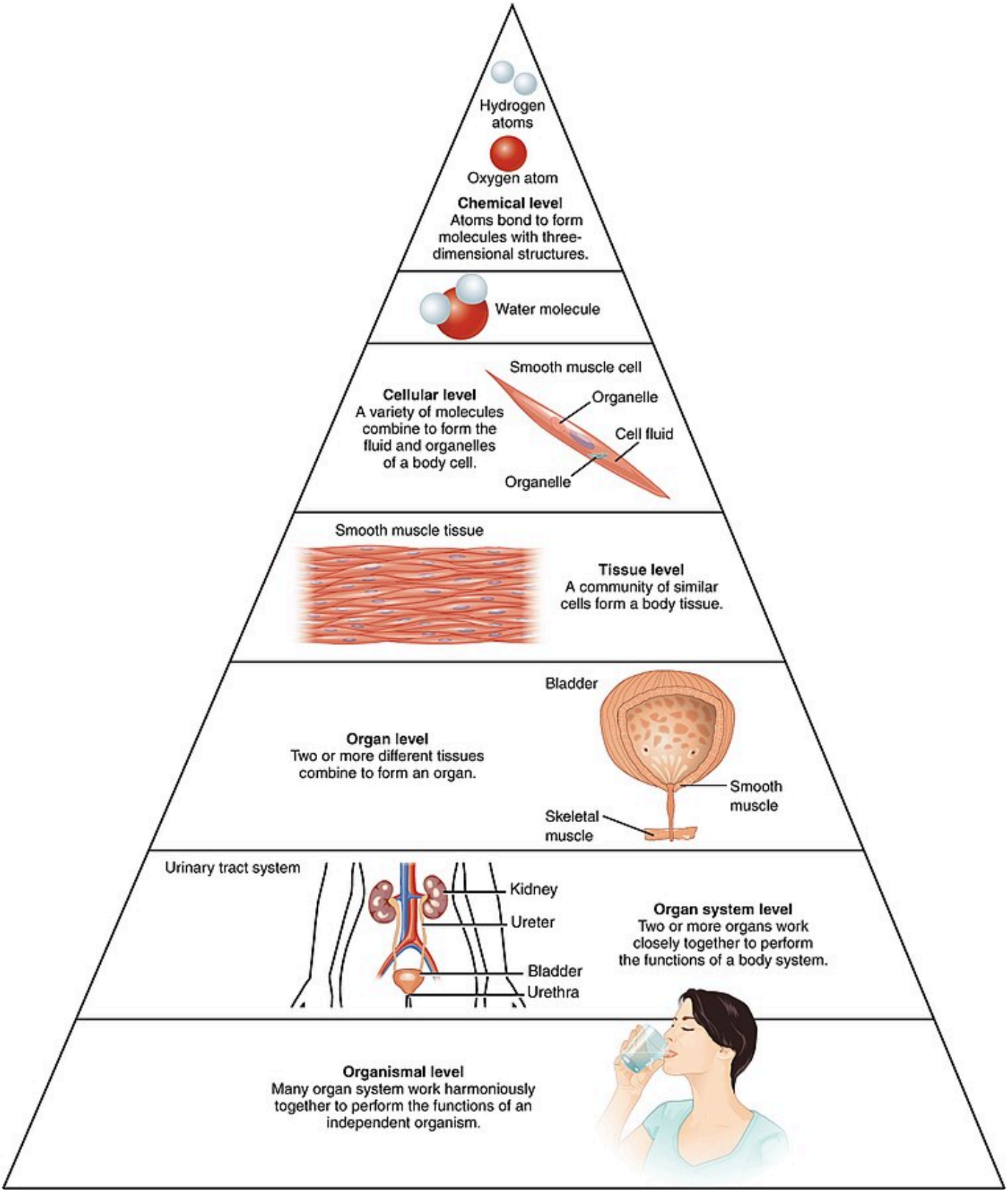


Figure 1.2 Levels of Organization

An **atom** is the smallest unit of matter that has the properties of an element. Atoms are made up of protons, neutrons, and electrons. Two or more atoms combine to form a **molecule**, such as the water molecules, proteins, and sugars found in living things. Molecules are the chemical building blocks of all body structures. A **cell** is the smallest independently functioning unit of a living organism. The human body is composed of trillions of cells, and almost all functions of human physiology are performed by cells. A **tissue** is a group of many similar cells that work together to perform a specific function. An **organ** is an anatomically distinct structure of the organism composed of two or more tissue types. Each organ performs one or more specific physiological functions. Most organs contribute to more than one organ system. An **organ system** is a group of organs that work together to perform major functions or meet physiological needs of the organism. This book covers the eleven organ systems in the human body.[2] See Figure 1.3[3] for an illustration of organ systems.

2. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

3. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Organ systems of the human body* [Diagram]. OpenStax. CC BY-N-SA 4.0. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

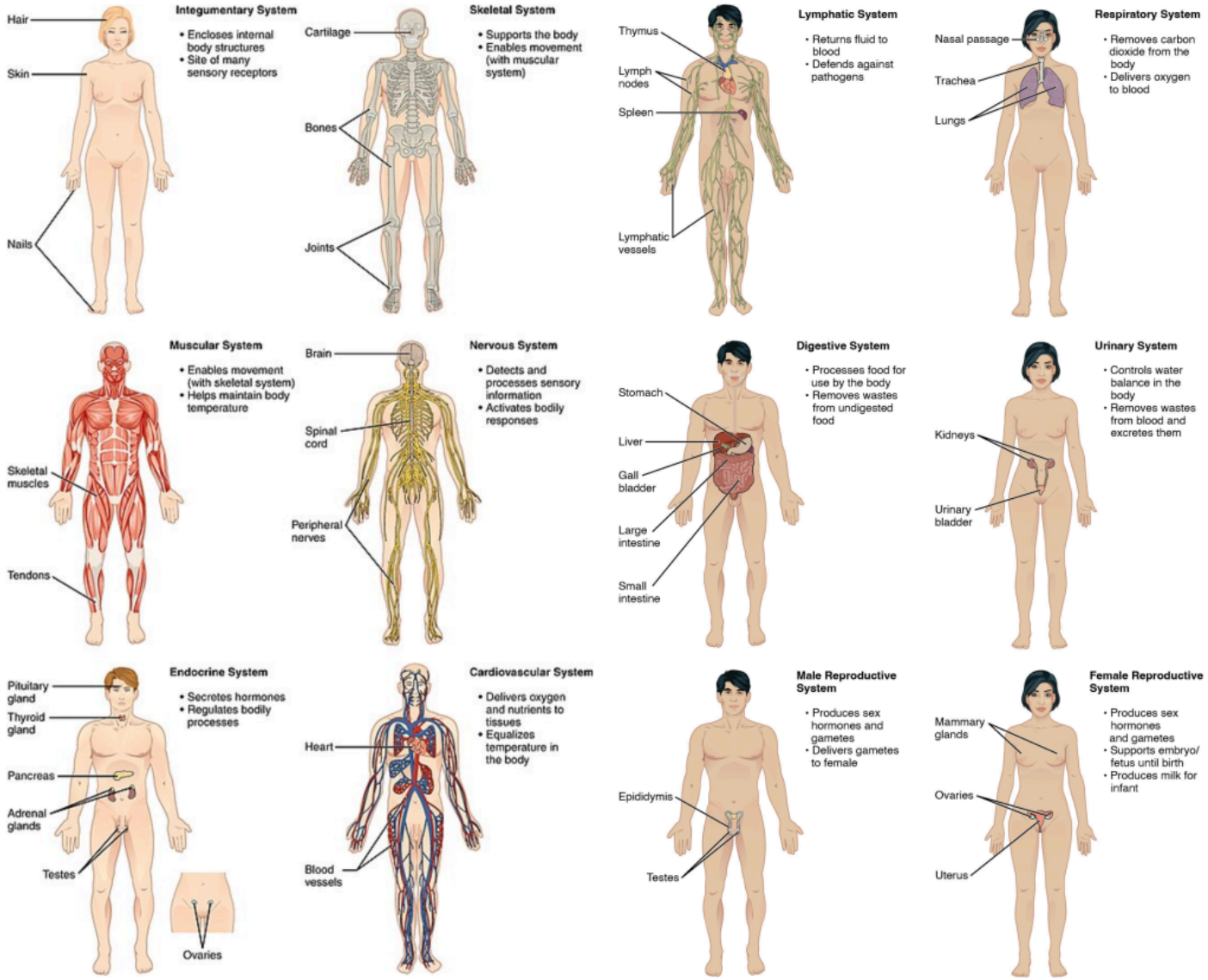


Figure 1.3 Organ Systems

Video

Watch the video “Introduction to Anatomy and Physiology (Levels of Organization Explained)” below to learn more about the levels of organization in the human body.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.



1.4 Anatomical Position

Health care professionals use precise medical terminology when communicating detailed information about the body and its anatomy to reduce medical errors that can result from ambiguity. To further increase precision, a standardized anatomical view of the body is used. Just like paper maps are oriented with north at the top of the page, the **standard anatomical position** is agreed on by the international medical community. In this position, a person is standing upright with the legs together or slightly apart, feet flat on the floor and facing forward, arms at the sides with the palms facing forward and thumbs pointing away from the body, and head and eyes straight ahead. In addition, the arms are usually placed slightly apart from the body so that the hands do not touch the sides.[1,2]

See Figure 1.4[3] for an illustration of the standard anatomical position.

1. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. Lumen Learning. (n.d.). *Anatomy and physiology I.* https://courses.lumenlearning.com/suny-ap1/
3. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Regions of the human body* [Diagram]. OpenStax. CC-BY-NC-SA 4.0. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-6-anatomical-terminology

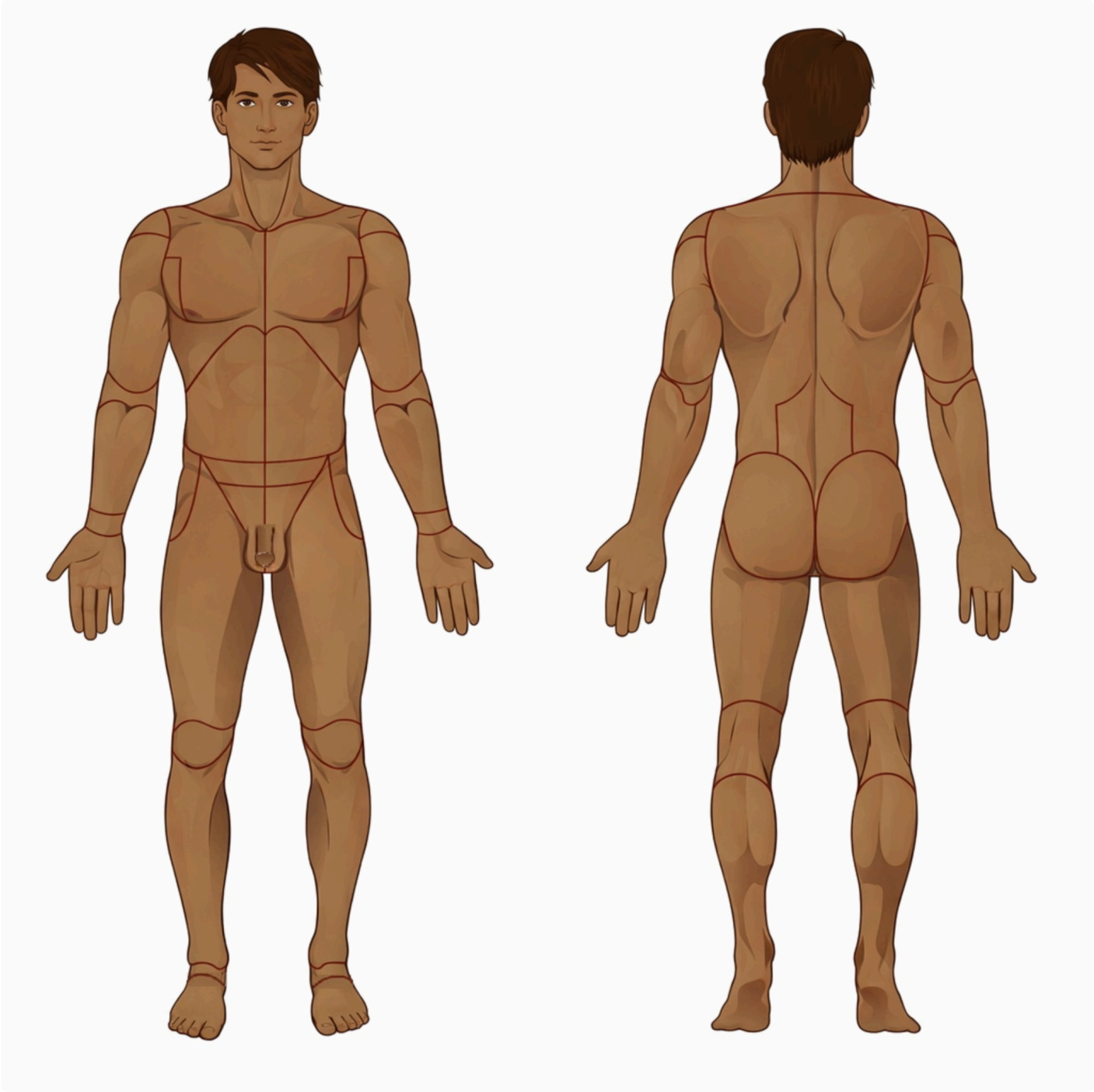


Figure 1.4 Standard Anatomical Position

Regional terms are used to identify specific regions or areas of the body. For example, as illustrated in Figure 1.4, brachial refers to the “upper arm,” and antebrachial refers to the “lower arm” or “forearm.” Similarly, femoral refers to the “upper leg,” and popliteal refers to the area behind the knee.

Prone and Supine

A body that is lying down is described as either prone or supine. These terms are often used to describe the position of the body during examinations or surgical procedures.

- **Prone**: The body lying face down.
- **Supine**: The body lying face up.

See Figure 1.5[4] for an illustration of prone and supine positions.

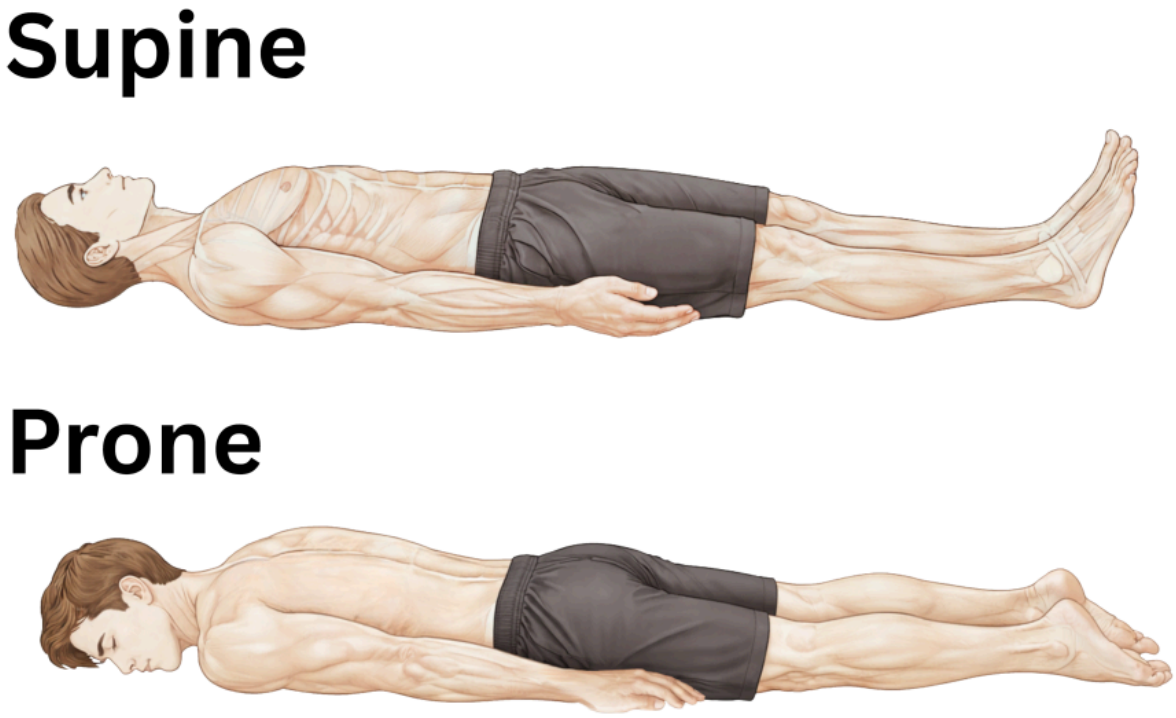


Figure 1.5 Standard Supine and Prone Positions

4. WisTech Open. (2026). *Supine and prone* [Diagram]. CC BY 4.0.

1.5 Directional Terms

Directional terms describe the location of body structures related to each other based on the body in standard anatomical position.[1]

See Figure 1.6 for an illustration of directional terms.[2]

1. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

2. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Directional terms* [Illustration]. OpenStax. CC BY-NC-SA 4.0. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

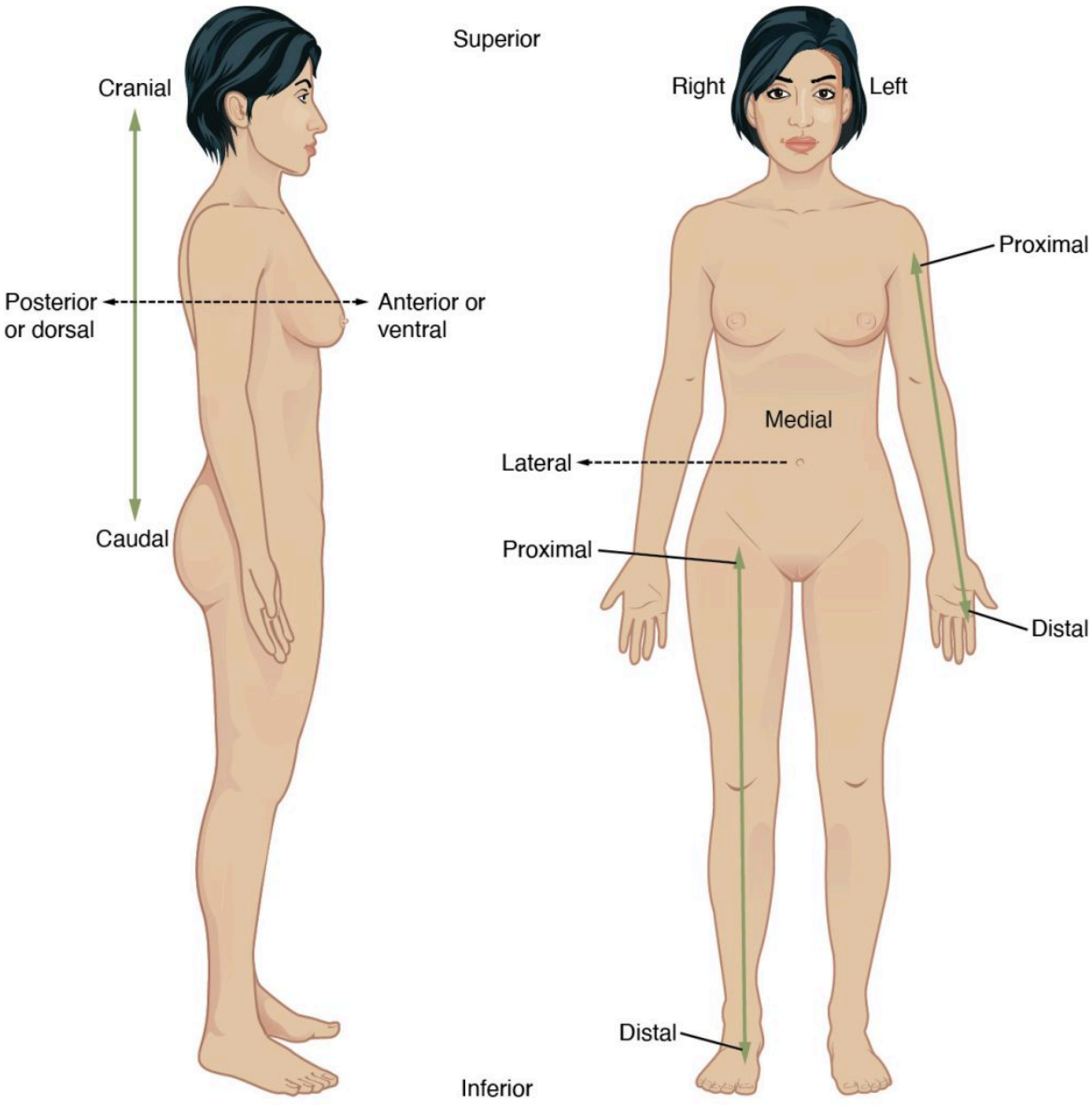


Figure 1.6 Directional Terms Applied to the Human Body

Table 1.5 describes pairs of common directional terms used for the human body.

Table 1.5. Common Directional Terms in the Human Body

Term	Definition	Example
Anterior	Toward the front, or in front of another structure.	The kneecap is on the anterior side of the leg.
Posterior	Toward the back, or behind another structure.	The shoulder blades are posterior to the chest.
Ventral	Toward the belly side of the body.	The stomach is ventral to the spinal cord.
Dorsal	Toward the back side of the body.	The shoulder blades are located on the dorsal side of the body.
Lateral	Toward the side of the body.	The arm is lateral to the torso.
Medial	Toward the midline of the body.	The big toe is medial to the little toe.
Distal	Farther from the point of origin or attachment.	The hand is distal to the elbow.
Proximal	Closer to the point of origin or attachment.	The hip is proximal to the knee.
Inferior	Below or lower than another part.	The mouth is inferior to the nose.
Superior	Above or higher than another part.	The head is superior to the neck.
Caudal	Toward the tailbone or lower end of the spine.	The feet are caudal to the head.
Cranial or cephalic	Toward the head.	The brain is cranial to the spinal cord.
Superficial	Closer to the surface of the body.	The skin is superficial to the bones.

Term	Definition	Example
Deep	Farther from the surface of the body.	The brain is deep within the skull.
Ipsilateral	On the same side as another structure.	The left arm and left leg are ipsilateral to each other.
Contralateral	On the opposite side of another structure.	The left arm and right arm are contralateral to each other.

Video

Watch the video “Anatomical Terms and Body Planes Explained (Directional Terms)” below to learn more about anatomical terminology and body planes used in anatomy and physiology.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Wisc-Online Interactive Activity

*]:pointer-events-auto R6Vx5W_threadScrollVars scroll-mb-[calc(var(--scroll-root-safe-area-inset-bottom,0px)+var(--thread-response-height))] scroll-mt-(--header-height)" dir="auto" data-turn-id="9b2c2e1c-5e8a-4c9f-ad47-f2915aa8f36f" data-testid="conversation-turn-81" data-scroll-anchor="false" data-turn="user">
*]:pointer-events-auto [content-visibility:auto] supports-[content-visibility:auto]:[contain-intrinsic-size:auto_100lvh] R6Vx5W_threadScrollVars

scroll-mb-[calc(var(--scroll-root-safe-area-inset-bottom,0px)+var(--thread-response-height))] scroll-mt-[calc(var(--header-height)+min(200px,max(70px,20svh)))]" dir="auto" data-turn-id="request-69f9e2ee-da1c-8327-b953-91c3888caa2c-16" data-testid="conversation-turn-82" data-scroll-anchor="false" data-turn="assistant">
Complete the Wisc-Online interactive activity **“Anatomical Terminology: Relative Position”** to practice using directional terms to describe the location of body structures.



1.6 Major Planes

Medical imaging devices enable clinicians to see "virtual sections" of living bodies, called **scans**. Scans can be correctly interpreted only if the viewer understands the plane along which the image was made. A **plane** is an imaginary two-dimensional surface that passes through the body. There are four planes commonly referred to in anatomy, including the following:[1]

- The **sagittal plane** is the plane that divides the body or an organ vertically into right and left sides.
  - If this vertical plane runs directly down the middle of the body, it is called a **midsagittal plane** or median plane.
  - If the vertical plane divides the body into unequal right and left sides, it is called a **parasagittal plane**, or less commonly a longitudinal section.
- The **frontal plane** divides the body or an organ into an anterior (front) and a posterior (rear) portion. The frontal plane is often referred to as a **coronal plane**.
- The **transverse plane** divides the body or an organ horizontally into upper and lower portions. Transverse planes produce images referred to as cross sections.
- The **oblique plane** divides the body at an angle between the horizontal and vertical planes.

See Figure 1.7 for an illustration of the sagittal, frontal (coronal), and transverse planes.[2]

1. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Planes of the body* [Diagram]. OpenStax. CC BY-NC-SA 4.0. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

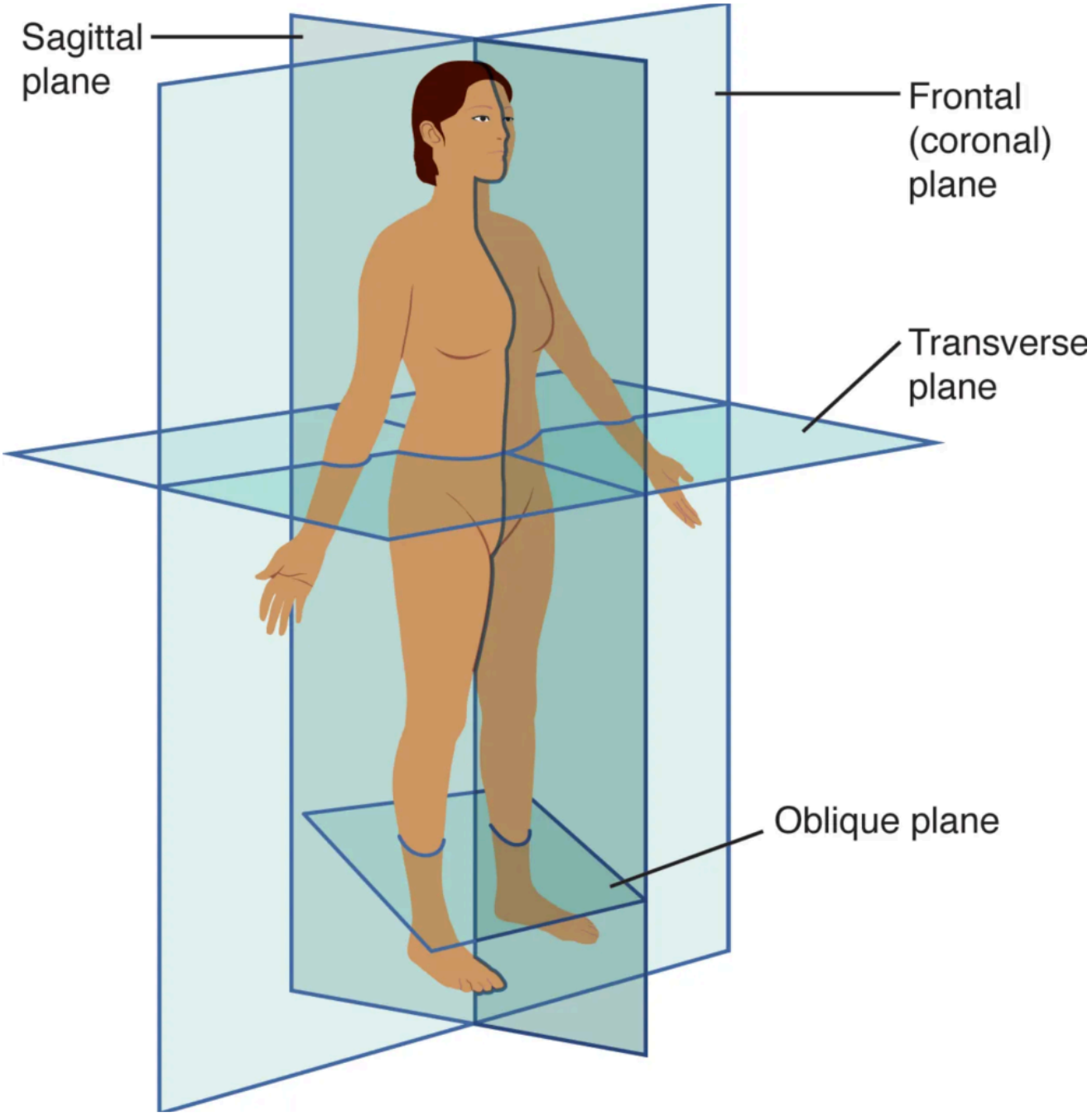


Figure 1.7 Sagittal, Frontal, Transverse, and Oblique Planes

1.7 Major Body Regions and Their Subdivisions

Body Cavities

The body uses membranes, sheaths, and other structures to create cavities or compartments. The ventral (anterior) cavity and dorsal (posterior) cavity are the largest body compartments that contain and protect internal organs,[1]. See Figure 1.8[2] for an illustration of the ventral (anterior) and dorsal (posterior) cavities.

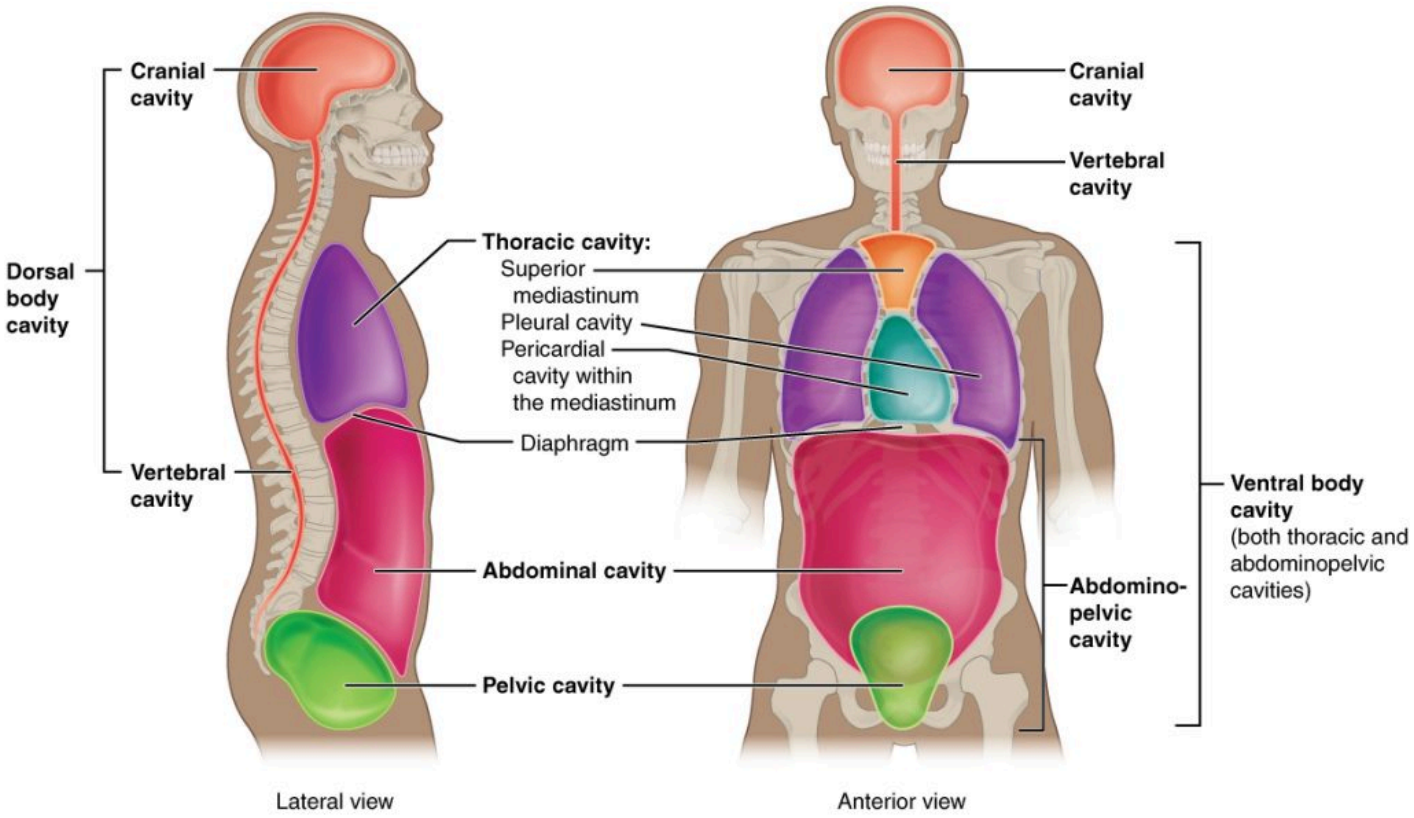


Figure 1.8 Ventral (Anterior) and Dorsal (Posterior) Cavities

1. Lumen Learning. (n.d.). *Anatomy and physiology I*. https://courses.lumenlearning.com/suny-ap1
2. Connexions. (2013). *Dorsal_Ventral_Body_Cavities* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Dorsal_Ventral_Body_Cavities.jpg

The **ventral (anterior) cavity** contains the lungs, heart, stomach, and intestines, and allows for significant changes in the size and shape of these organs as they do their work. The anterior (ventral) cavity has two main subdivisions:

- **Thoracic cavity**: The thoracic cavity is the chest cavity, and it contains the heart and lungs. It's surrounded and protected by the rib cage. The diaphragm forms the floor of the thoracic cavity and separates it from the abdominopelvic cavity. The thoracic cavity is further divided into the **pleural cavity**, which contains the lungs, and the **mediastinum**, which is the central portion of the cavity containing the heart. The **pericardial cavity** surrounds the heart.
- The **abdominopelvic cavity** is the largest cavity in the body. Although no membrane divides the abdominopelvic cavity, it can also be subdivided into the **abdominal cavity**, which contains the digestive organs, and the **pelvic cavity**, which contains the urinary bladder and reproductive organs.

The **posterior (dorsal) cavity** is divided into two smaller cavities:

- The **cranial cavity**, which contains the brain.
- The **spinal cavity** (or vertebral cavity), which contains the spinal cord.

Just as the brain and spinal cord make up a continuous, uninterrupted structure, the cranial and spinal cavities are also continuous. The brain and spinal cord are protected by the bones of the skull and the spine and by cerebrospinal fluid, a colorless fluid that provides a cushion.

Wisc-Online Interactive Activity

Complete the Wisc-Online interactive activity **"Body Sections and Divisions of the Pelvic Cavity"** to review body sections and practice identifying the divisions of the pelvic cavity.

Serous Membranes

A **serous membrane** (also referred to as serosa) is a thin membrane that covers the walls and organs of the thoracic and abdominopelvic cavities. Serous membranes have two layers:

- The **parietal layer** lines the walls of the body cavity.
- The **visceral layer** covers the organs; it is also called the viscera (viscer means "organ").

Between the parietal and visceral layers is a very thin, fluid-filled space, or cavity. Both the parietal and visceral layers secrete slippery, watery fluid into this serous cavity, filling it with fluid. This serous cavity cushions and reduces friction on organs when they move, such as when the lungs inflate or the heart beats. See Figure 1.9[3] for an illustration of a serous membrane surrounding the heart, called the **pericardium**. The pericardium is a double-layered membrane that surrounds the heart, similar to a fluid-filled balloon surrounding a fist.[4]

3. Connexions. (2022). *Serous_Membrane* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Serous_Membrane.jpg

4. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

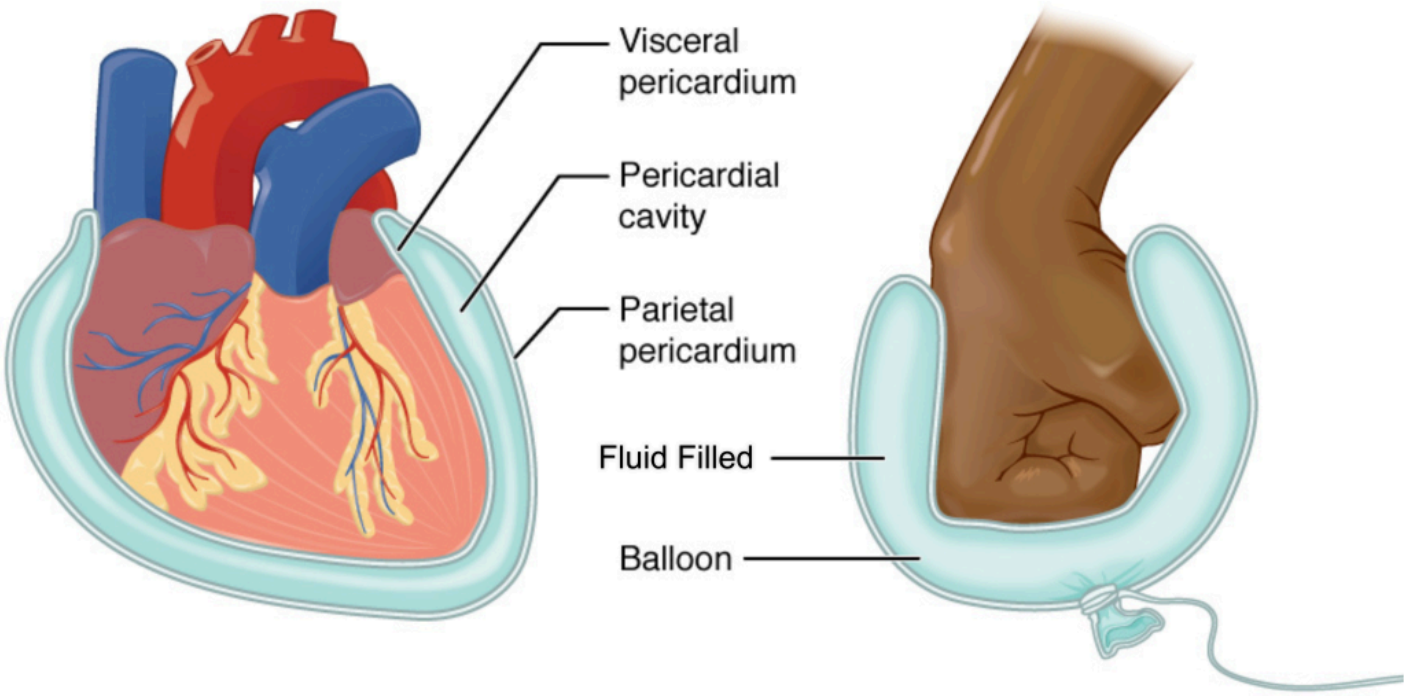


Figure 1.9 Serous Membrane Surrounding the Heart

There are three serous cavities and associated membranes:

- Pleura: The **pleura** is the serous membrane that encloses the pleural cavity, which surrounds the lungs, reducing friction between the lungs and the chest wall. See Figure 1.10[5] for an illustration of the pleura and pleural cavity.
- Pericardium: The **pericardium** is the serous membrane that surrounds the heart, reducing friction caused by the beating of the heart.
- Peritoneum: The **peritoneum** is the serous membrane that surrounds several organs in the abdominopelvic cavity, reducing friction between the organs and the abdominal wall.

5. OpenStax. (2022). *The lung pleura* [Diagram]. Wikimedia Commons. CC-BY 3.0. https://commons.wikimedia.org/wiki/File:2313_The_Lung_Pleurea.jpg

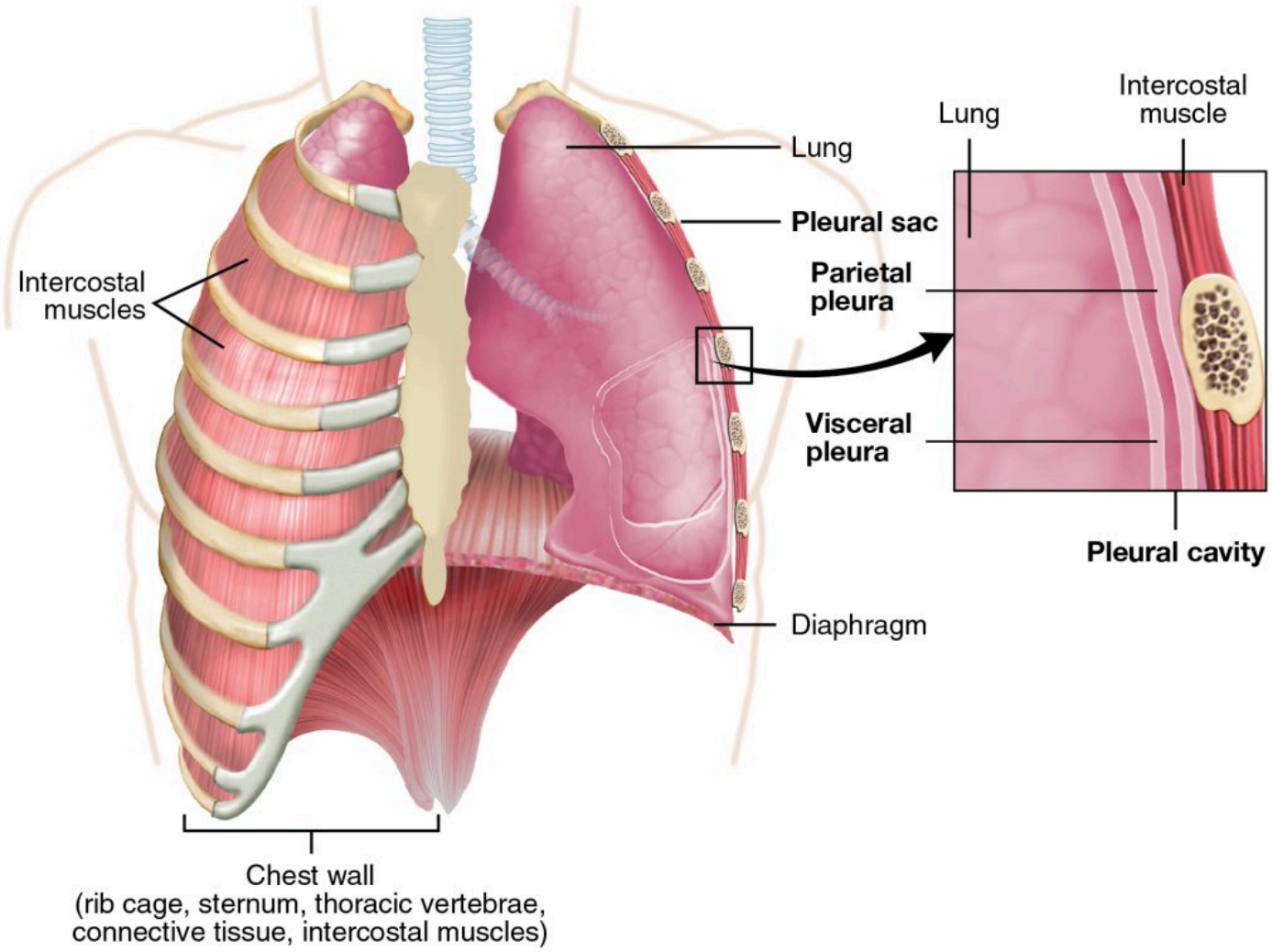


Figure 1.10 The Lung Pleura and Pleural Cavity

Regions and Quadrants of the Abdominopelvic Cavity

To maintain clear communication among health care professionals, the abdominopelvic cavity is divided into either nine regions or four quadrants. See Figure 1.11[6] for an illustration of the abdominopelvic cavity subdivisions.

6. OpenStax. (2013). *Abdominal quadrant regions* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Abdominal_Quadrant_Regions.jpg

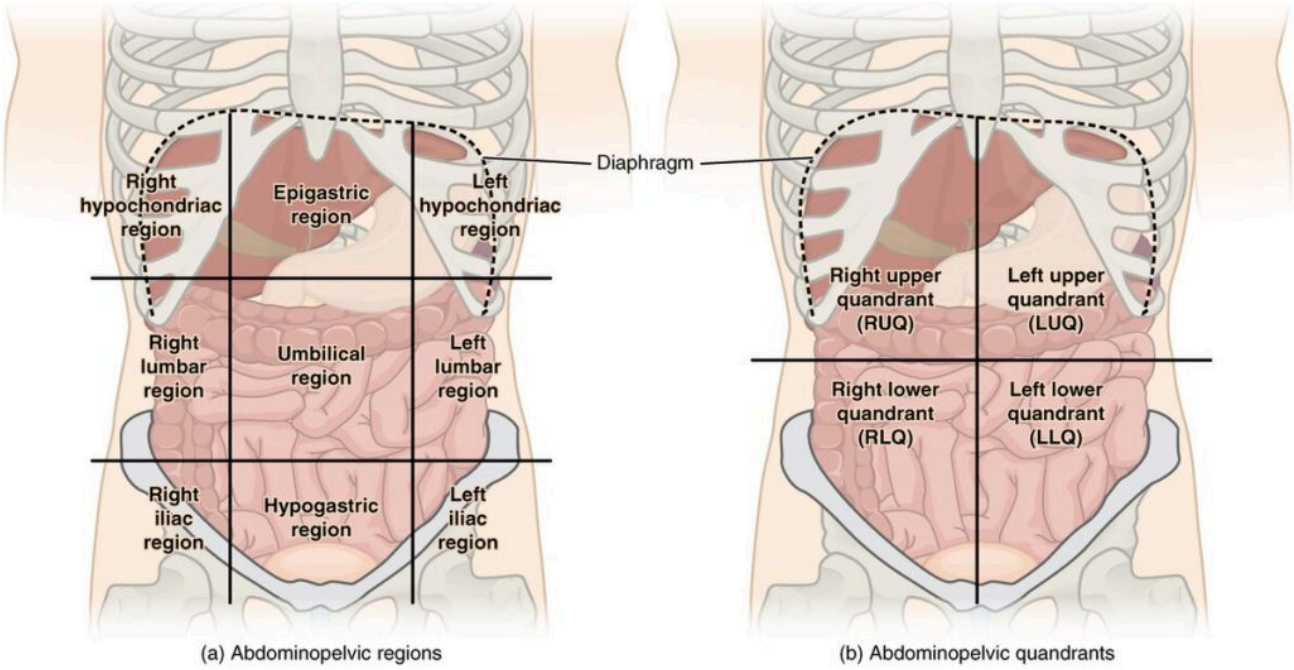


Figure 1.11 Abdominopelvic Cavity Subdivisions: (a) Abdominopelvic Regions and (b) Abdominopelvic Quadrants

The more detailed regional approach divides the cavity into nine regions. One horizontal line lies just below the ribs, one line lies just above the pelvis, and two vertical lines lie as if they were dropped from the middle of each **clavicle** (collarbone).

A simpler quadrants approach is commonly used in health care and divides the cavity into four regions. One horizontal line and one vertical line intersect at the patient's **umbilicus** (also called naval or "belly button").[7,8]

Axial and Appendicular Regions of the Body

Regional terms describe anatomy by dividing the body into regions that contain structures that do similar things. There are two main regions of the body:

- **Axial Region**: The axial region makes up the main axis of the body, including the

7. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

8. Lumen Learning. (n.d.). *Anatomy and physiology I*. https://courses.lumenlearning.com/suny-ap1/

head, neck, chest, and abdomen.

- **Appendicular Region**: The appendicular region includes the arms and legs (called appendages) that connect to the axial region.[9,10]

  See **Figure 6.20** for an illustration of the axial and appendicular skeleton.[11]

9. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

10. Lumen Learning. (n.d.). *Anatomy and physiology I*. https://courses.lumenlearning.com/suny-ap1/

11. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

1.8 Homeostasis and Feedback Systems

Homeostasis is the steady state of internal balance that the body works to maintain. Maintaining homeostasis is vital to life! Various vital signs and levels of chemicals in the body, such as temperature, heart rate, respiratory rate, oxygen level, and hormone levels, need to be kept within a set normal range. Fluctuations outside of normal conditions must be corrected quickly, or they can cause disease or, in extreme cases, even death.

Maintaining homeostasis requires the body to continuously monitor its internal conditions. From body temperature to blood pressure to levels of certain nutrients, each physiological condition has a particular set point. A set point is the physiological value considered normal. For example, the **set point** for normal human body temperature is approximately 37°C (98.6°F). A **normal range** is a set of values that is considered healthy and stable. Many physiological values, such as body temperature and respiratory rate, tend to fluctuate within a normal range. For example, the normal range of respiratory rate in adults is 12 to 20 breaths per minute.

Control centers in the brain and other parts of the body monitor for changes in homeostasis and quickly work to restore those changes by using negative and positive feedback.[1]

Negative Feedback

Negative feedback is a process that corrects a change in homeostasis by reversing it. Reversing the change brings it back to normal. For example, if you run around the block, your heart rate will increase. After you stop running, negative feedback will restore your heart rate to the normal range.

Negative feedback is constantly occurring throughout the human body and has three basic parts:

- Sensor/Receptor: A **sensor**, also known as a **receptor**, monitors a physiological value,

1. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

such as temperature, respiratory rate, blood pressure, etc. This value is reported to the control center.

- Control Center: The **control center** compares the value to the normal range. If the value has changed too much from the set point, then the control center activates an effector.
- Effector: An **effector** reverses the situation and returns the value to the set point or normal range.

See Figure 1.12 for an illustration of a negative feedback loop related to body temperature.[2]

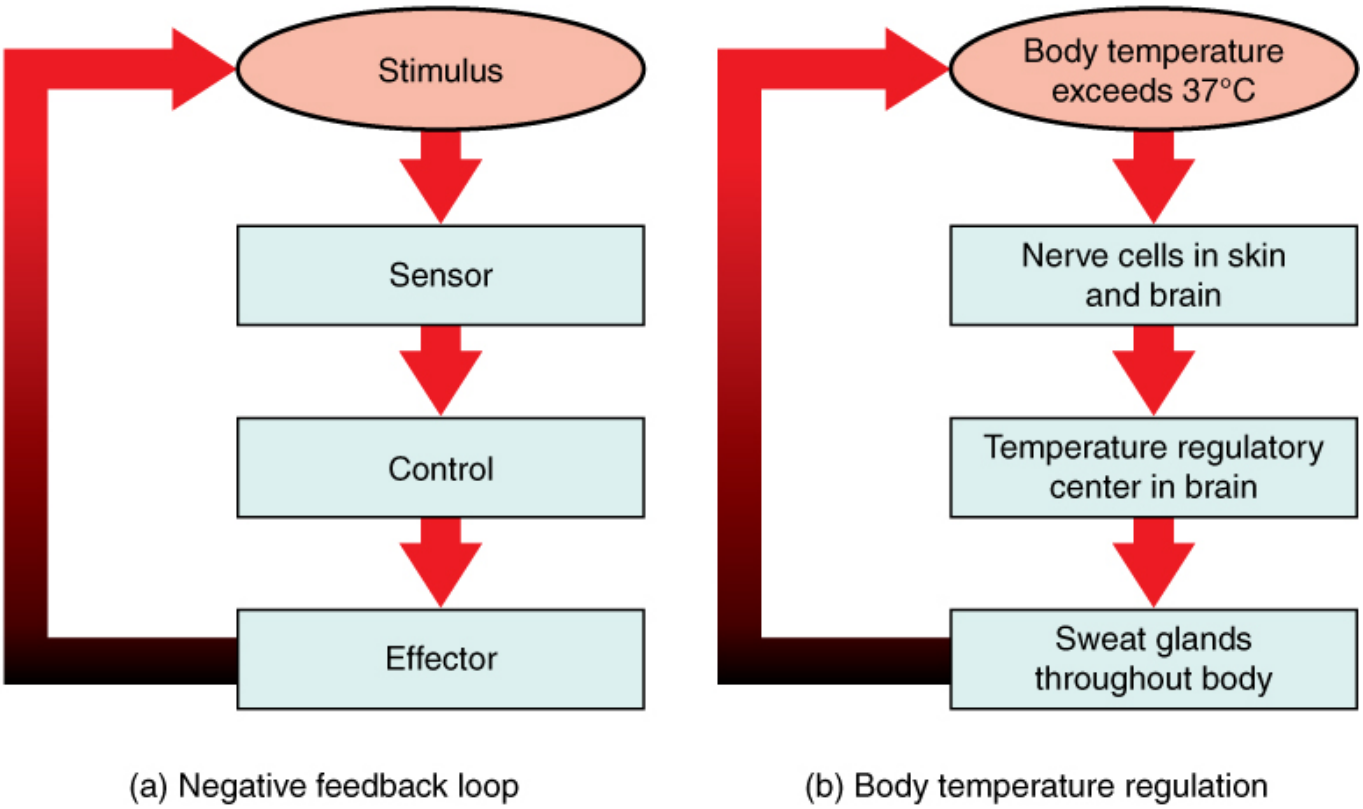


Figure 1.12 Example of a Negative Feedback Loop (a) Related to Body Temperature (b)

A classic example of a negative feedback loop is body temperature regulation. Temperature sensors in nerve cells measure the body's temperature. When the body temperature rises too high, the hypothalamus in the brain (the control center) signals

2. Openstax. (2016). *105 Negative feedback loop* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:105_Negative_Feedback_Loops.jpg

sweat glands (the effectors) to activate and produce sweat, which cools the body down. Once the body temperature returns to normal, the sweating stops.

Positive Feedback

Positive feedback enhances a change in the body's physiological condition instead of reversing it. A change from the set point or normal range results in more change, and the body moves farther away from the normal range or set point. Positive feedback in the body is normal only when there is a definite endpoint.

An example of positive feedback is the labor contractions that occur during childbirth. Once contractions begin, labor requires positive feedback to intensify the uterine contractions and continue the process until the baby is born. The events of childbirth must progress within a short period of time, or the life of the mother and baby are at risk. See Figure 1.13 for an illustration of the example of positive feedback in childbirth.[3]

3. OpenStax. (2016). *106 Pregnancy-positive feedback* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:106_Pregnancy-Positive_Feedback.jpg

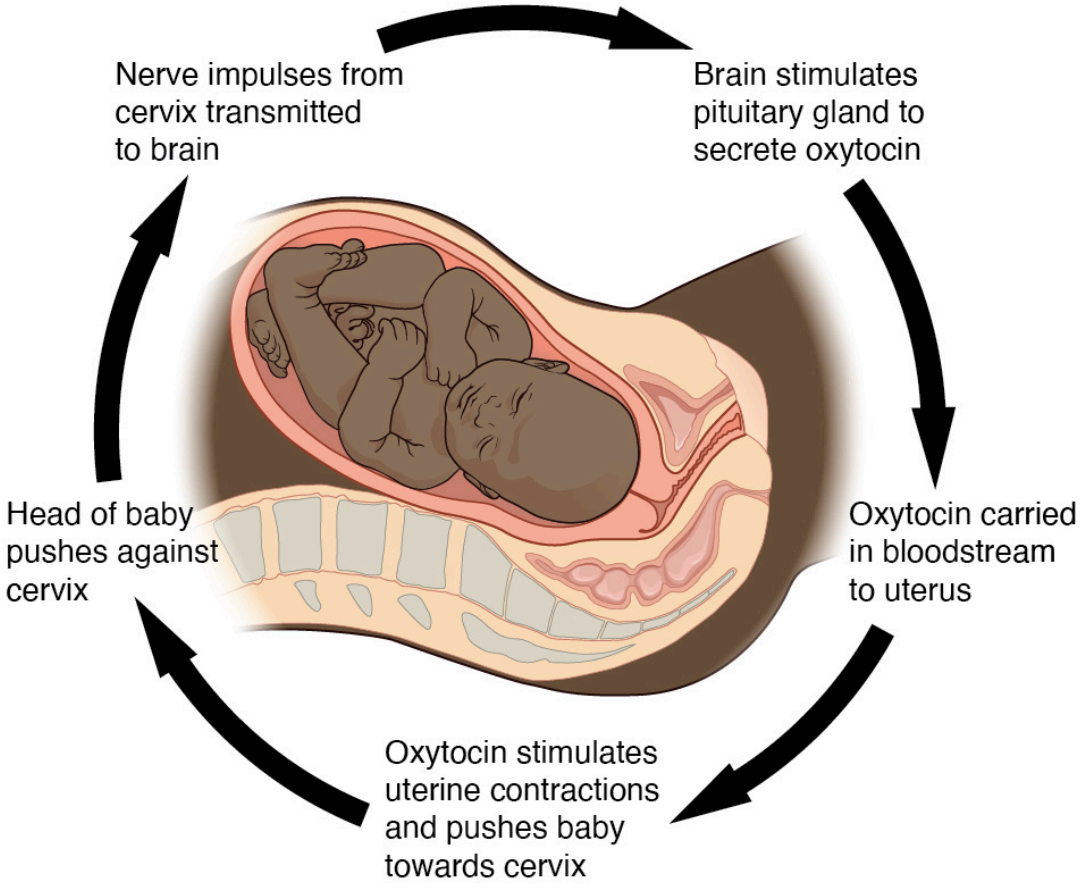


Figure 1.13 Example of a Positive Feedback Loop Related to Childbirth

Video

Watch the video "Homeostasis Explained (Negative and Positive Feedback)" below to learn more about how the body maintains internal balance.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

1.9 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

1.10 Glossary

Abdominal cavity: A cavity that contains the digestive organs. (Chapter 1.7)

Abdominopelvic cavity: The largest cavity in the body, containing the abdominal and pelvic areas. (Chapter 1.7)

Anatomists: Scientists who study the structure of the human body. (Chapter 1.2)

Anatomy: The scientific study of the body's structure. (Chapter 1.2)

Anterior: Toward the front, or in front of another structure. (Chapter 1.5)

Appendicular region: Region that includes the arms and legs (called appendages) that connect to the axial region. (Chapter 1.7)

Atom: The smallest unit of matter that has the properties of an element. (Chapter 1.3)

Axial region: Region that makes up the main axis of the body, including the head, neck, chest, and abdomen. (Chapter 1.7)

Caudal: Near the tailbone or the lowest part of the spinal column. (Chapter 1.5)

Cell: The smallest independently functioning unit of a living organism. (Chapter 1.3)

Clavicle: Collarbone. (Chapter 1.7)

Contralateral: On the opposite side of another structure. (Chapter 1.5)

Control center: Compares the value to the normal range. (Chapter 1.8)

Coronal plane: Plane dividing the body or an organ into an anterior (front) and a posterior (rear) portion; also known as the frontal plane. (Chapter 1.6)

Cranial or cephalic: Towards the head. (Chapter 1.5)

Cranial cavity: A cavity that contains the brain. (Chapter 1.7)

Cytology: The study of cells. (Chapter 1.2)

Deep: Farther from the surface of the body. (Chapter 1.5)

Directional terms: The location of body structures related to each other based on the body in the standard anatomical position. (Chapter 1.5)

Distal: Farther away from the point of origin or attachment to the body. (Chapter 1.5)

Dorsal: Toward the back side of the body. (Chapter 1.5)

Effector: Reverses the situation and returns the value to the set point or normal range. (Chapter 1.8)

Frontal plane: Plane dividing the body or an organ into an anterior (front) and a posterior (rear) portion; also known as the coronal plane. (Chapter 1.6)

Gross anatomy: The study of the large, easily visible parts of the body. (Chapter 1.2)

Histology: The study of tissues. (Chapter 1.2)

Homeostasis: A steady state of internal balance that the body works to maintain. (Chapter 1.2)

Inferior: Below or lower than another part of the body. (Chapter 1.5)

Ipsilateral: On the same side as another structure. (Chapter 1.5)

Lateral: Toward the side of the body. (Chapter 1.5)

Medial: Toward the midline of the body. (Chapter 1.5)

Mediastinum: Central portion of the thoracic cavity. (Chapter 1.7)

Microscopic anatomy: The study of structures seen only with the use of a microscope or other magnification. (Chapter 1.2)

Midsagittal plane: Vertical plane runs directly down the middle of the body. (Chapter 1.6)

Molecule: When two or more atoms combine chemically. (Chapter 1.3)

Negative feedback: A process that corrects a change in homeostasis by reversing it. (Chapter 1.8)

Normal range: A set of values that is considered healthy and stable. (Chapter 1.8)

Oblique plane: Divides the body at an angle between the horizontal and vertical planes. (Chapter 1.6)

Organ: An anatomically distinct structure of the body composed of two or more tissue types. (Chapter 1.3)

Organ system: A group of organs that work together to perform major functions or meet the physiological needs of the body. (Chapter 1.3)

Parasagittal plane: The vertical plane dividing the body into unequal right and left sides. (Chapter 1.6)

Pericardial cavity: The space between the heart and the pericardium, filled with serous fluid to reduce friction during heart contractions. (Chapter 1.7)

Parietal layer: Serous membrane that lines the walls of the body cavity. (Chapter 1.7)

Pelvic cavity: A cavity that contains the urinary bladder and reproductive organs. (Chapter 1.7)

Pericardium: The serous membrane that surrounds the heart, reducing friction caused by the beating of the heart. (Chapter 1.7)

Peritoneum: The serous membrane that surrounds several organs in the abdominopelvic cavity, reducing friction between the organs and the abdominal wall. (Chapter 1.7)

Physiology: The study of how body structures work to support life. (Chapter 1.2)

Plane: An imaginary two-dimensional surface that passes through the body. (Chapter 1.6)

Pleura: The serous membrane surrounding the lungs, reducing friction between the lungs and the chest wall. (Chapter 1.7)

Pleural cavity: The space between the visceral and parietal layers that contains pleural fluid. (Chapter 1.7)

Positive feedback: Enhances a change in the body's physiological condition instead of reversing it. (Chapter 1.8)

Posterior: Toward the back, or behind another structure. (Chapter 1.5)

Posterior (dorsal) cavity: A body cavity located on the back (dorsal) side of the body. (Chapter 1.7)

Prone: The body lying face down. (Chapter 1.4)

Proximal: Closer to the point of origin or attachment to the body. (Chapter 1.5)

Receptor: Also known as a sensor; monitors a physiological value, such as temperature, respiratory rate, blood pressure, etc. (Chapter 1.8)

Regional anatomy: The study of the structures in a specific body region, such as the abdomen. (Chapter 1.2)

Sagittal plane: The plane that divides the body or an organ vertically into right and left sides. (Chapter 1.6)

Scans: "Virtual sections" of living bodies. (Chapter 1.6)

Sensor: Also known as a receptor; monitors a physiological value, such as temperature, respiratory rate, blood pressure, etc. (**Chapter 1.8**)

Serous membrane: A thin membrane that covers the walls and organs of the thoracic and abdominopelvic cavities; also known as serosa. (**Chapter 1.7**)

Set point: The physiological value considered normal. (**Chapter 1.8**)

Spinal cavity: Cavity that contains the spinal cord; also known as the vertebral cavity. (**Chapter 1.7**)

Standard anatomical position: Positioning agreed upon by the international medical community in which a person is standing upright with the legs together or slightly apart, feet flat on the floor and facing forward, arms at the sides with the palms facing forward and thumbs pointing away from the body, and head and eyes straight ahead. (**Chapter 1.4**)

Superficial: Closer to the surface of the body. (**Chapter 1.5**)

Superior: Above or higher than another part of the body. (**Chapter 1.5**)

Supine: The body lying face up. (**Chapter 1.4**)

Systemic anatomy: The study of the structures that make up a specific body system, a group of structures that work together to perform a specific function. (**Chapter 1.2**)

Thoracic cavity: The chest cavity containing the heart and lungs. (**Chapter 1.7**)

Tissue: A group of many similar cells that work together to perform a specific function. (**Chapter 1.3)**

Transverse plane: Divides the body or an organ horizontally into upper and lower portions. (**Chapter 1.6**)

Ventral: Toward the belly side of the body. (**Chapter 1.5**)

Ventral (anterior) cavity: Contains the lungs, heart, stomach, and intestines, and allows for significant changes in the size and shape of these organs as they do their work. (**Chapter 1.7**)

Visceral layer: Serous membrane that covers the organs; it is also called the viscera. (**Chapter 1.7**)

PART II

CHAPTER 2 CHEMICAL COMPONENTS OF LIVING THINGS

2.1 Introduction to Chemical Components of Living Things

Chapter Competency

Classify the major chemical components of living things according to their structure and function.

Learning Objectives

- Describe the major chemical components.
- Correlate components according to structure, function, and the role major chemical components play in body composition.
- Use appropriate terminology.
- Compare the structure of DNA, RNA, and proteins.

Understanding the basics of chemistry is the first step in understanding the human body. Elements form the carbohydrates, nucleotides, proteins, and lipids (all of which will be defined later in this chapter) that are the basic building blocks of all organisms. This chapter will discuss these important building blocks and how the unique properties of the atoms of different elements work with other atoms to form the molecules of life.

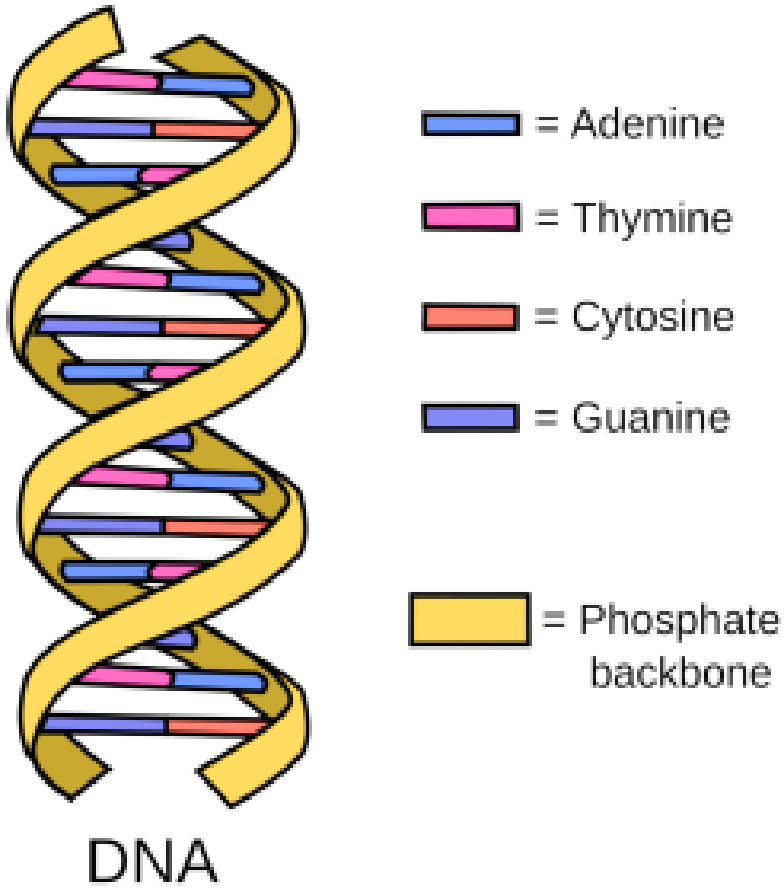


Figure 2.1 DNA Structure

[1]

1. Forluvoft. (2008). *DNA Simple2* [Diagram]. Wikimedia Commons. CC0, Public Domain. https://commons.wikimedia.org/wiki/File:DNA_simple2.svg

2.2 Elements and Compounds

All **matter** (anything that takes up space and has mass) is made up of one or more substances called elements. An **element** is a pure substance that cannot be created or broken down by ordinary chemical means or transformed chemically into other substances. Each element has its own unique set of chemical and physical properties that differentiates it from other elements.

Each element is made of **atoms**, the smallest piece of an element that has the characteristics of the element. A total of 118 elements have been defined; however, only 92 occur naturally, and fewer than 30 are found in living cells. The remaining 26 elements are unstable and, therefore, do not exist for very long or are theoretical and have yet to be detected.

The periodic table is a chart of all of the known elements. Each element has a one to two-letter chemical symbol (such as H, N, O, C, and Cl) and possesses unique properties. For example, sodium's symbol is Na. These unique properties allow elements to combine and to bond with each other in specific ways.

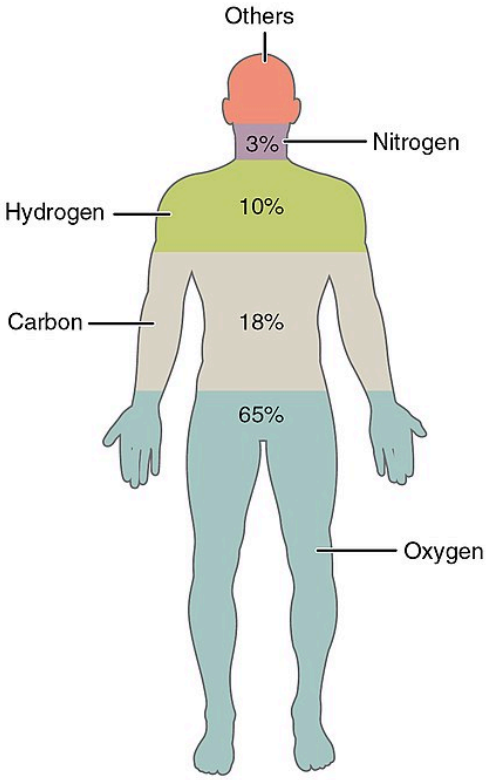
While your body can make many of the chemicals needed for life from elements, it cannot make elements. All the elements in your body are derived from the foods you eat and the air you breathe.

An example of an element that you must take in is calcium (Ca). Calcium is used by the body for many things, including strengthening bones. The calcium in cheese is the same as the calcium that forms your bones. Some other examples of important elements are oxygen, sodium, and iron.

There are many elements found in the human body. See Figure 2.2[1] for a complete list of elements in the human body. The four most abundant elements in the human body are as follows:

- Oxygen (O)
- Carbon (C)
- Hydrogen (H)
- Nitrogen (N)

1. OpenStax. (2013). *Elements of the human body* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:201_Elements_of_the_Human_Body-01.jpg



Element	Symbol	Percentage in Body
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5
Nitrogen	N	3.2
Calcium	Ca	1.5
Phosphorus	P	1.0
Potassium	K	0.4
Sulfur	S	0.3
Sodium	Na	0.2
Chlorine	Cl	0.2
Magnesium	Mg	0.1
Trace elements include boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).		less than 1.0

Figure 2.2 Elements in the Human Body

In nature, elements rarely occur alone. They usually combine to form compounds. A **compound** is a substance composed of two or more elements joined by chemical bonds. For example, glucose (blood sugar) is an important body fuel. It is made up of the same three elements: carbon, hydrogen, and oxygen.

Building Blocks of Molecules

Atoms and Subatomic Particles

An **atom** is the smallest piece of an element that has the characteristics of the element. For example, one atom of hydrogen is the smallest amount of hydrogen that can exist. Atoms are extremely small. In fact, the period at the end of this sentence is millions of atoms wide. At the most basic level, all organisms contain atoms that combine together to form molecules. In multicellular organisms, such as humans, molecules can interact to form cells that combine to form tissues, which make up organs and organ systems. These combinations continue until entire organisms are formed.

Atomic Structure

An atom is made up of even smaller particles called **subatomic particles**. These include protons, neutrons, and electrons.

- **Protons** (p^+): Protons are positively charged particles found in the nucleus or center of the atom.
  - The number of protons determines the atomic number.
    - For example, oxygen has 8 protons, so oxygen's atomic number on the periodic table is 8.
- **Neutrons** (n): Neutrons do not have a charge, so they are neutral. They have a mass of 1. They are also found in the center or nucleus of the atom.
- **Electrons** (e^-): Electrons are very small, negatively charged particles found outside of the atom's nucleus. They "spin" around the nucleus close to the speed of light in electron shells or clouds. It has almost no mass and has a charge of –1.
  - The number of electrons is the same as the number of protons. This keeps the overall atom's charge neutral.
    - For example, oxygen has 8 positively charged protons, so it also has 8 negatively charged electrons.
  - Positively charged protons attract negatively charged electrons, giving the atom structural stability and keeping the electrons close.

See Figure 2.3[2] for an illustration of an atom with its subatomic particles.

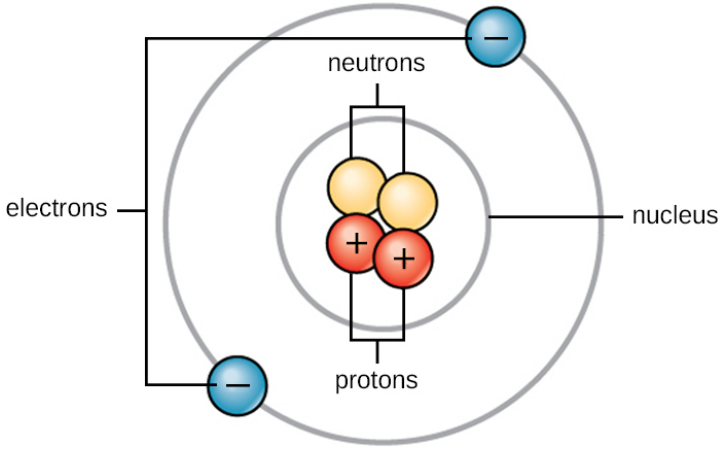
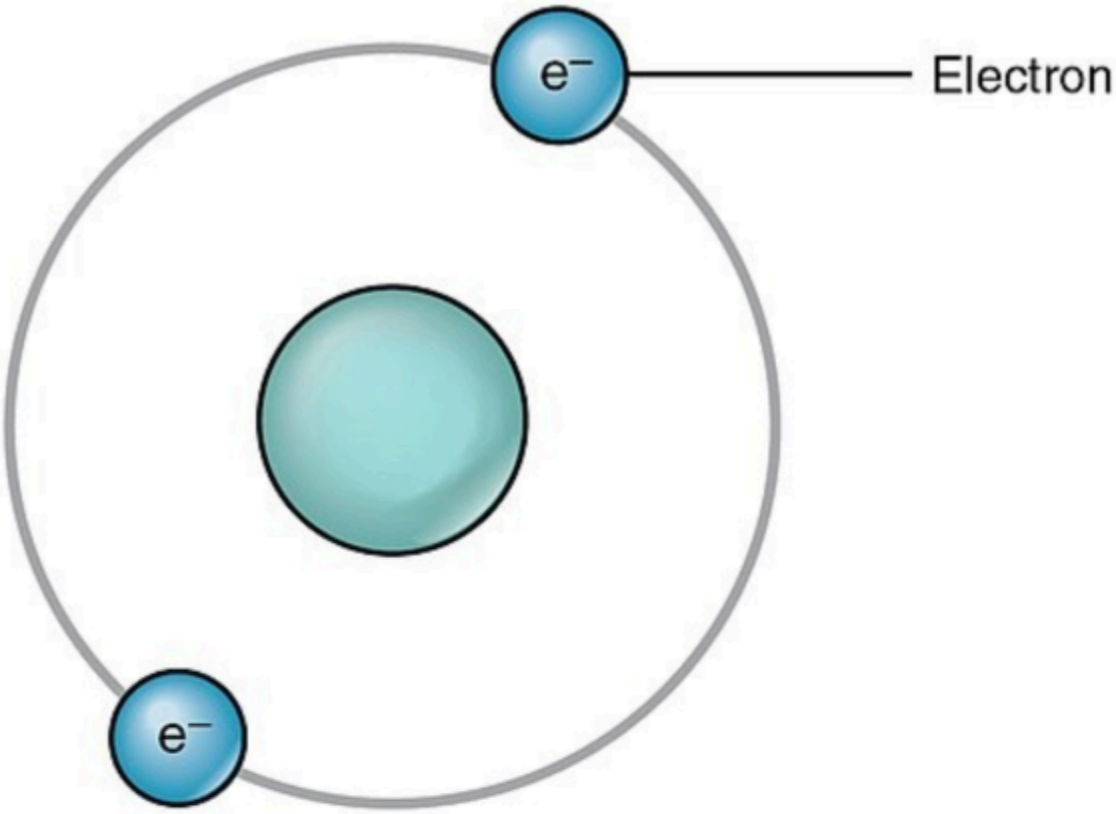


Figure 2.3 Atom (Atom Shown Is a Helium Atom)

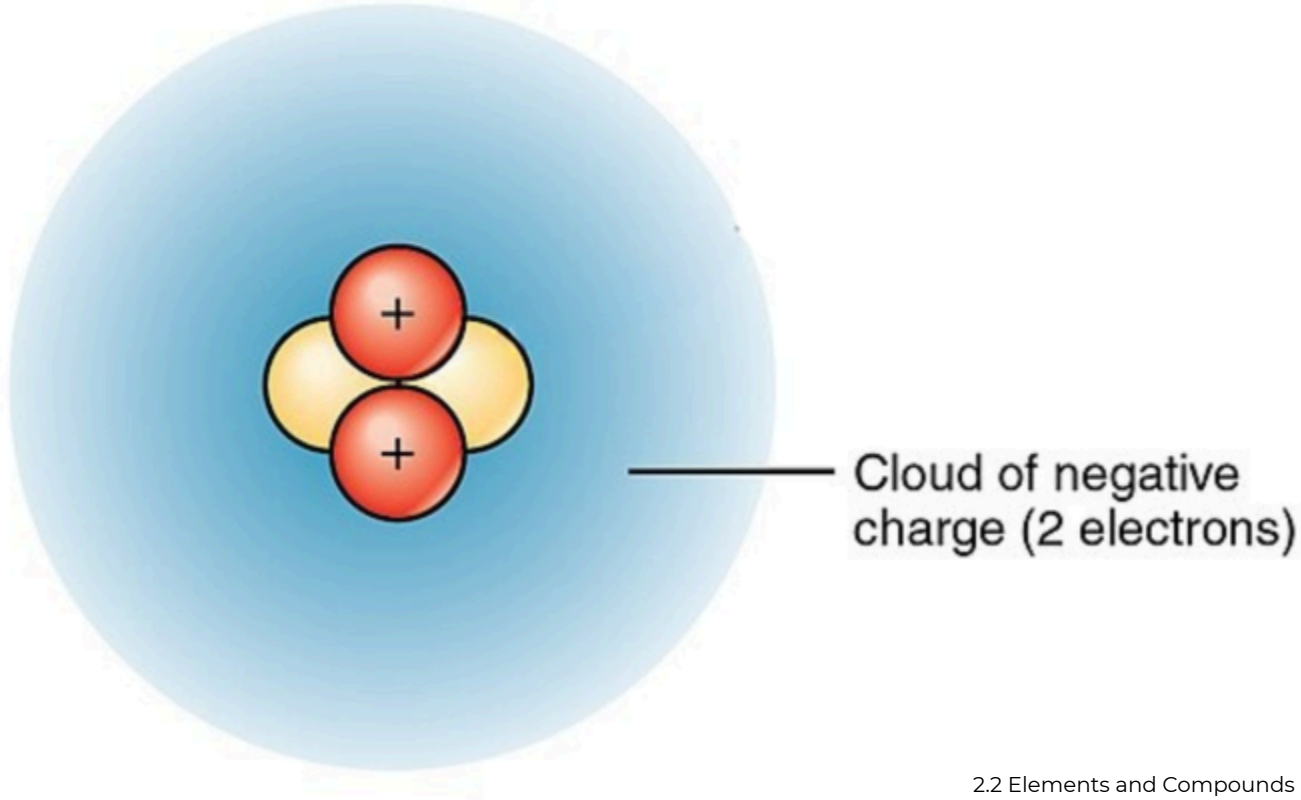
2. CNX OpenStax. (2022). *Bohr atomic structure* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Bohr_Atom_Structure.jpg

Atomic structure can be modeled in different ways. Figure 2.4[3] shows two different models of the structure of a helium (He) atom. In the first model, helium's two electrons are shown circling the nucleus in a ring. This model helps visualize atomic structure. However, in reality, electrons do not travel in fixed rings. They spin around the nucleus in what is sometimes referred to as an electron cloud.

3. OpenStax. (2013). *2*02 *Two models of atomic structure* [Diagram]. Wikimedia Commons. CC BY 4.0. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction



(a) Planetary model



(b) Electron cloud model

Figure 2.4 Two Models of Atomic Structure. (a) In the Planetary Model, the Electrons of Helium Are Depicted as Rings, Similar to Planets Orbiting the Sun. (b) In the Electron Cloud Model, the Electrons of Helium Are Shown in the Entire Area Where They Could Be Found Over Time

Atomic Number and Mass Number

Protons, neutrons, and electrons are the same whether they are found in an atom of carbon (C), sodium (Na), iron (Fe), or any other element. It is the number of protons each element contains that makes it different from other elements. Therefore, the **atomic number**, which is the number of protons in the nucleus of the atom, identifies the element. An atom usually has the same number of electrons as protons, so the atomic number is also the number of electrons.

- Example: Carbon has the atomic number 6, telling us carbon atoms contain six protons. No other element has exactly six protons in its atoms. All atoms of carbon, whether found in your liver or in a lump of coal, contain six protons.

An element's **mass number** is the total number of protons and neutrons in its nucleus. Electrons have so little mass that they do not really contribute to the mass of an atom. Many elements contain the same number of neutrons as protons, but not all. Because protons and neutrons each have a mass of 1, the mass of an atom is equal to the number of protons and neutrons of that atom. The number of electrons does not factor into the overall mass because their mass is so small.

- Examples:
  - The most common form of carbon has six neutrons and six protons, for a mass of 12. Carbon is a relatively light element.
  - Uranium (U) has a mass number of 238 and is referred to as a heavy metal. Its atomic number is 92 (it has 92 protons), but it contains 146 neutrons. Uranium has the most mass of all the naturally occurring elements.

The **periodic table**, as shown in Figure 2.5[4], is a chart organizing the 92 elements found in nature, as well as several elements discovered experimentally. The elements are arranged in order of their atomic number. For each element, the periodic table identifies the chemical symbol, the atomic number, and the mass number, while organizing elements according to their reactivity with other elements. The periodic table also

4. Fowler, S., Roush, R., & Wise, J. (2013). *Concepts of biology* [Image]. OpenStax. CC BY 4.0. https://openstax.org/books/concepts-biology/pages/1-introduction

provides key information about the properties of elements, often indicated by color-coding.[5]

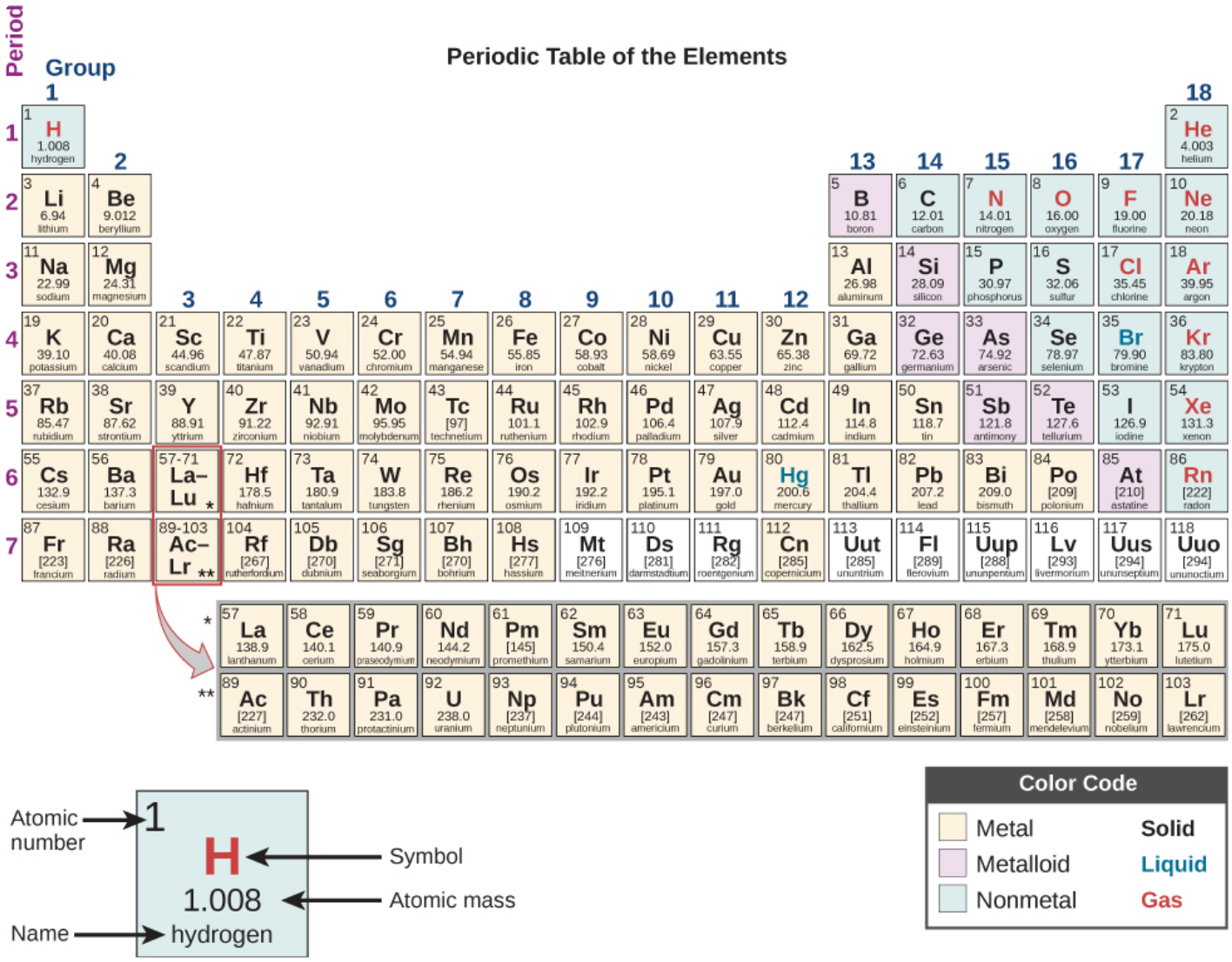


Figure 2.5 Periodic Table

Isotopes

Although each element has a unique number of protons, it can exist as different isotopes. An **isotope** is one of the different forms of an element, distinguished from one

5. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

another by different numbers of neutrons. Some elements, such as carbon, potassium, and uranium, have naturally occurring isotopes.

The most common isotope of carbon is ^{12}C, commonly called carbon-12. ^{12}C has six protons and six neutrons, for a mass number of twelve. All the isotopes of carbon have the same number of protons (six), but the number of neutrons changes. Therefore, ^{13}C has seven neutrons, and ^{14}C has eight neutrons. The different isotopes of an element can also be indicated with the mass number hyphenated (for example, C-12 instead of ^{12}C). Hydrogen has three common isotopes, shown in Figure 2.6.[6] Protium, designated ^{1}H, has one proton and no neutrons. It is by far the most common isotope of hydrogen in nature. Deuterium, designated ^{2}H, has one proton and one neutron. Tritium, designated ^{3}H, has one proton and two neutrons.

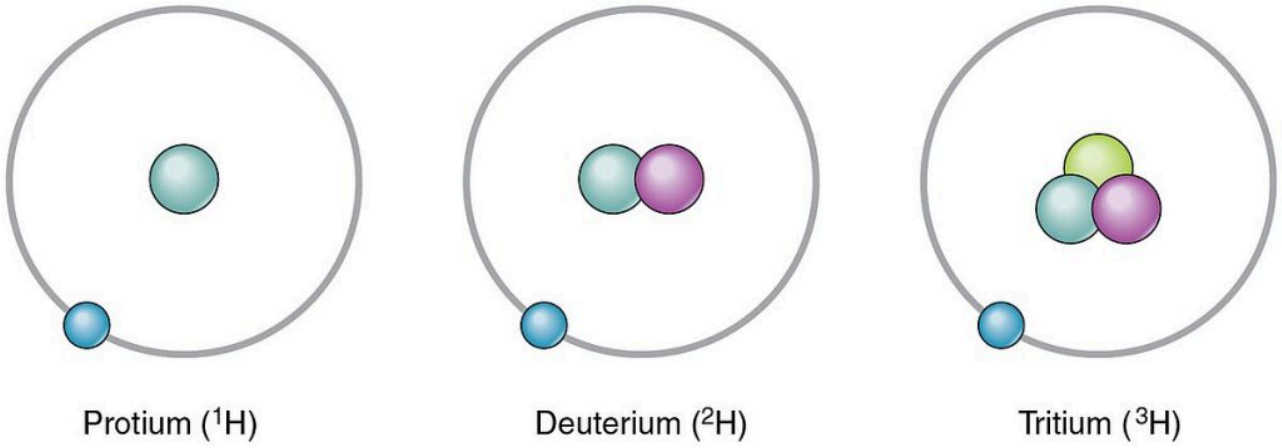


Figure 2.6 Isotopes of Hydrogen

An isotope that contains more than the usual number of neutrons is referred to as a heavy isotope. An example is ^{14}C. Heavy isotopes tend to be unstable, and unstable isotopes are radioactive.

A **radioactive isotope** (also called radioisotopes) has a nucleus that readily decays, giving off subatomic particles and electromagnetic energy. Radioactive isotopes are medically useful. They can be given to patients before medical imaging tests, such as positron emission tomography or PET scans, used to destroy an overactive thyroid gland, can be used to sterilize medical equipment, and given to cancer patients as radiation

6. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Isotopes of hydrogen* [Diagram]. OpenStax. CC BY 4.0. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

therapy treatments. However, excessive exposure to radioactive isotopes can damage human cells and even cause cancer and birth defects in healthy individuals.[7]

Electron Shell

In the human body, atoms do not exist alone. They are constantly reacting with other atoms to make or break down more complex substances. As mentioned earlier, electrons tend to stay within a certain region of space called electron clouds, sometimes referred to as an electron shell. An **electron shell** is a layer of electrons that circles the nucleus at a distinct energy level.

The element atoms found in the human body have from one to five electron shells. The first electron shell holds two electrons. This is always filled with electrons first before any other shell can be filled. Every shell after that holds eight electrons, and the number of shells depends on the number of electrons in the atom.

- Examples:
  - Lithium (Li), atomic number 3, has 3 electrons. Two electrons fill the first shell, and the third electron is in the second shell.
  - Carbon (C), atomic number 6, has 6 electrons. Two electrons fill the first shell, and four electrons are in the second shell.
  - Neon (Ne), atomic number 10, has 10 electrons. Two electrons fill the first shell, and the remaining eight electrons fill the second shell.

See Figure 2.7[8] for an illustration of electron shells.

7. Fowler, S., Roush, R., & Wise, J. (2013). *Concepts of biology*. OpenStax. https://openstax.org/books/concepts-biology/pages/1-introduction

8. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Electron shells* [Diagram]. OpenStax. CC BY-NC-SA. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

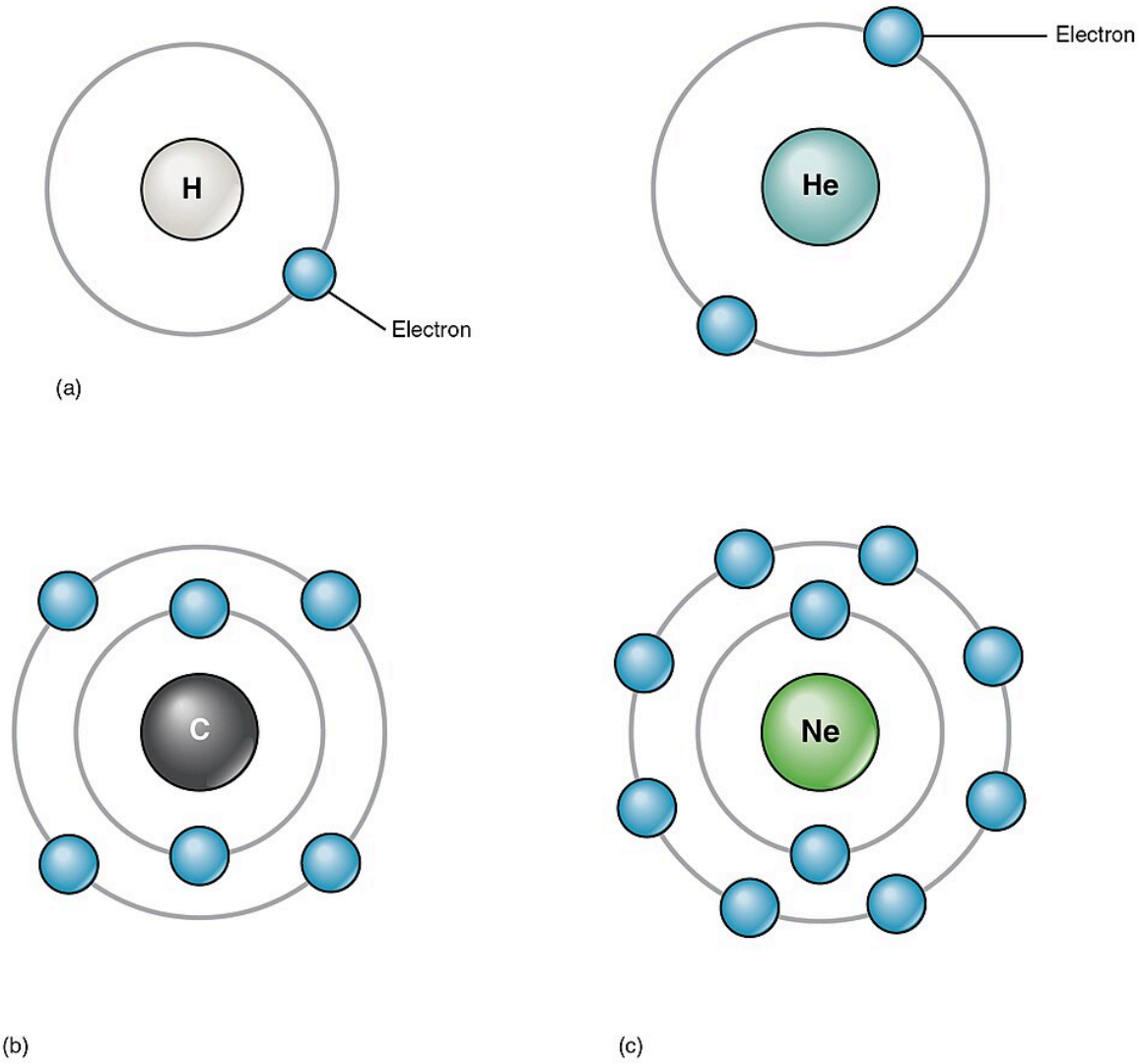


Figure 2.7 Electron Shells. (a) With One Electron, Hydrogen Only Half-Fills Its Electron Shell. Helium Also Has a Single Shell, But Its Two Electrons Fill It; (b) the Electrons of Carbon Fill Its First Electron Shell, But Only Half-Fill Its Second; (c) Neon, an Element That Does Not Occur in the Body, Has 10 electrons, Filling Both of Its Electron Shells.

How elements interact with one another depends on how their electrons are arranged and how many electrons exist in their outermost electron shell. A **valence shell** is an atom's outermost electron shell. If the valence shell is full, the atom is stable, and its electrons are unlikely to be pulled away from the nucleus by the electrical charge of other atoms. If the valence shell is not full, the atom is reactive. It will try to react with other atoms to make the valence shell full.

- For example, hydrogen (atomic number 1) has one electron, which only half-fills its valence shell. This single electron is likely to join with atoms of other elements, so that hydrogen's single valence shell can be full and thus stabilized.

All atoms (except hydrogen and helium with their single electron shells) are most stable when there are exactly eight electrons in their valence shell. This principle is referred to as the octet rule. The **octet rule** states that an atom will give up, gain, or share electrons with another atom so that it ends up with eight electrons in its own valence shell.

- For example, oxygen, with two electrons in the first shell and six electrons in its valence shell, is likely to react with other atoms to add two electrons to oxygen's valence shell, bringing the number to eight.

In nature, atoms of one element tend to join with atoms of other elements in certain ways.

- Examples:
  - Carbon commonly fills its valence shell by linking up with four atoms of hydrogen, forming the simplest of organic molecules, methane, which is also one of the most abundant and stable carbon-containing compounds on Earth.
  - Water is formed because oxygen needs two electrons to fill its valence shell. It commonly interacts with two atoms of hydrogen, forming H_2O.

Atoms must come close enough for the electrons in their valence shells to interact. However, most physicists would say that they never touch each other because the negatively charged electrons in their valence shells repel one another. Instead, atoms link by forming a chemical bond.[9]

Video

Watch the video "Basic Chemistry for Anatomy and Physiology (Elements and Compounds)" below to learn more about basic chemistry concepts used in anatomy and physiology.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of

9. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

the textbook at www.wistechopen.org or scanning the QR code below.



2.3 Chemical Bonds

As discussed previously, most elements don't have enough electrons to fill their outermost shells, but an atom is most stable when all the electron positions in the outermost shell are filled. The way that atoms fill their outermost electron shells is by the formation of chemical bonds. A **bond** is a weak or strong electrical attraction that holds atoms in the same area. The new grouping is more stable or less likely to react again. A stable grouping of two or more atoms held together by chemical bonds is called a **molecule**. The bonded atoms may be of the same element, as in H_2, which is called molecular hydrogen or hydrogen gas. When a molecule is made up of two or more atoms of different elements, it is called a chemical **compound**. A unit of water, or H_2O, is a compound, as is a single molecule of the gas methane, or CH_4.

Three types of chemical bonds are important in human physiology because they hold together substances that are used by the body to maintain homeostasis. These are ionic bonds, covalent bonds, and hydrogen bonds.

Ions and Ionic Bonds

Ions are atoms or molecules with an electrical charge. When an atom does not contain equal numbers of protons and electrons, it is called an **ion**. A **cation** (a positive ion) forms when a neutral atom loses one or more electrons from its valence shell, and an **anion** (a negative ion) forms when a neutral atom gains one or more electrons in its valence shell.

For example, potassium (K) is an important element in all body cells. Its atomic number is 19, so there are 19 protons and 19 electrons: 2 in the first shell, 8 in the second shell, 8 in the third shell, and just one electron in its valence shell. Because its valence shell is not full, potassium is highly likely to participate in chemical reactions to donate that one electron. (It is easier for potassium to donate one electron than to gain seven electrons.) The loss will result in potassium having one more proton than electron, so it will no longer be neutral, but instead have a slightly positive charge. A potassium ion with a positive charge is a cation, written K^+, indicating that it has lost a single electron.

In another example, sodium only has one electron in its outermost shell. It takes less energy for sodium to donate that one electron than it does to accept seven more electrons to fill the outer shell. If sodium loses an electron, it now has 11 protons and only

10 electrons, leaving it with an overall charge of +1. It is now a cation and written as Na^+. See Figure 2.8[1] for an illustration of a sodium atom compared to a sodium ion.

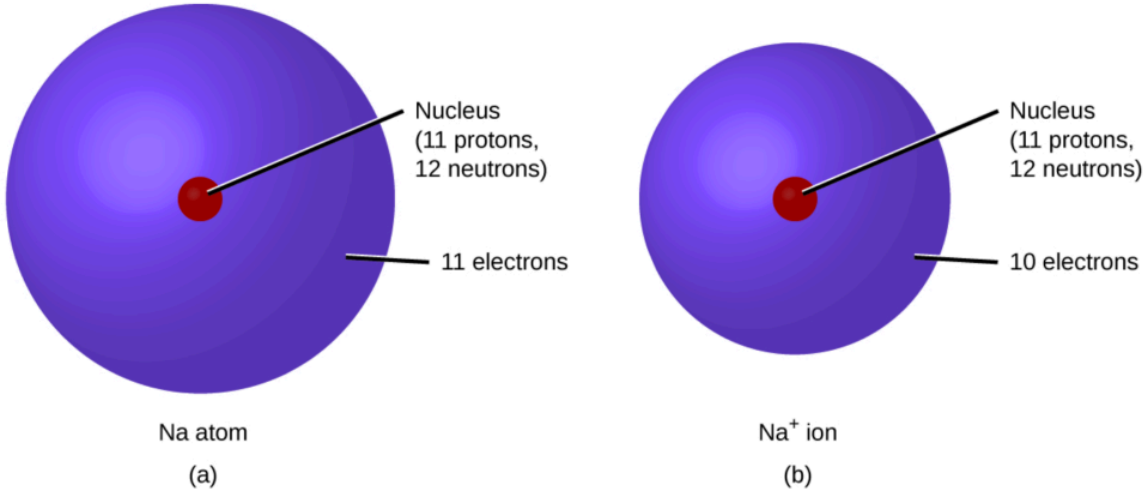


Figure 2.8 (a) Sodium Atom and (b) Sodium Ion

As previously mentioned, atoms can also gain an electron or electrons and become an anion (negatively charged). An example of this is fluorine (F), an important element in bones and teeth. Its atomic number is 9, so it has 9 protons and 9 electrons: 2 electrons in the first shell and seven electrons in its valence shell. Therefore, fluorine is likely to bond with other atoms where it gains one electron to fill its valence shell (it is easier for fluorine to gain one electron than to donate seven electrons). When it does, its electrons will outnumber its protons by one, and it will have an overall negative charge. The ionized form of fluorine is called fluoride and is written as F^-.

Another example of gaining an electron is the chlorine atom. It has seven electrons in its outer shell. Again, it is more energy efficient for chlorine to gain one electron than to lose seven. Therefore, it tends to gain an electron to create an ion with 17 protons and 18 electrons, giving it a net negative (–1) charge. It is now called a chloride ion and written as Cl^-. This movement of electrons from one element to another is referred to as **electron transfer**.

Atoms that have more than one electron to donate or accept will end up with stronger positive or negative charges. A cation that has donated two electrons has a net charge of +2. Using magnesium (Mg) as an example, this can be written Mg^{++} or Mg^{2+}. An

1. OpenStax. (n.d.) *Untitled* [Diagram]. Chemistry. CC BY-NC 4.0. https://chem.libretexts.org/Courses/Lumen_Learning/Book%3A_General_College_Chemistry_I_(Lumen)/06%3A_4-_Chemical_Compounds/6.03%3A_Molecular_and_Ionic_Compounds

anion that has accepted two electrons has a net charge of –2. The ionic form of selenium (Se), for example, is typically written Se^{2-}.

Figure 2.9[2] illustrates the transfer of electrons. A sodium atom (Na) only has one electron in its outermost shell. A chlorine atom (Cl) has seven electrons in its outermost shell. A sodium atom will donate its one electron to empty its shell, and a chlorine atom will accept that electron to fill its shell, becoming a chloride. Both ions now satisfy the octet rule and have complete outermost shells. Because the number of electrons is no longer equal to the number of protons, each is now an ion and has a +1 (sodium) or –1 (chloride) charge. These two ions are then strongly attracted to each other to form the ionic compound, NaCl, better known as table salt. The attraction of many sodium and chloride ions results in the formation of a large grouping of ions called crystals.

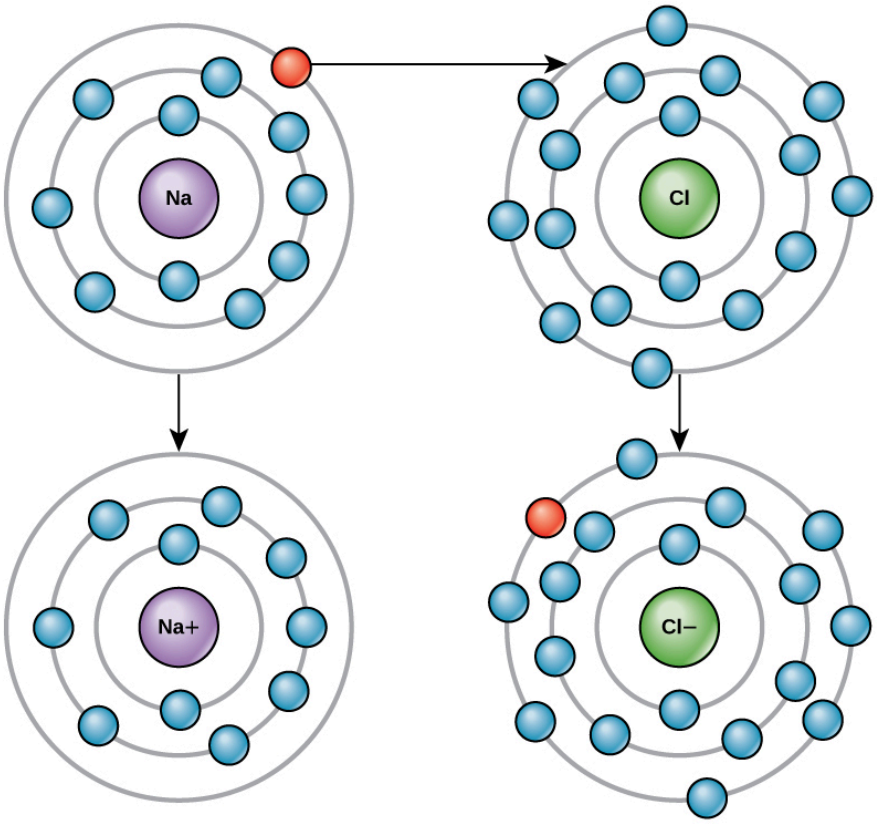


Figure 2.9 Electron Transfer. Sodium Donates an Electron to Empty Its Outer Shell; Chloride Accepts an Electron to Fill Its Outer Shell

Compounds composed of ions are called **ionic compounds** (or salts), and their ions

2. Openstax. (2020). *207 Ionic bonding-01 (Adapted)* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:207_Ionic_Bonding-01.jpg

are held together by ionic bonds. An **ionic bond** is a chemical bond formed between a cation and an anion. The opposite electrical charges create a moderately strong attraction and keep the atoms close to each other. The table salt you sprinkle on your food owes its existence to ionic bonding. As shown in Figure 2.10,[3] sodium commonly donates an electron to chlorine, becoming the cation Na^+. When chlorine accepts the electron, it becomes the chloride anion, Cl^-. With their opposing charges, these two ions strongly attract each other.

3. OpenStax. (2020). *207 Ionic bonding-01* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:207_Ionic_Bonding-01.jpg

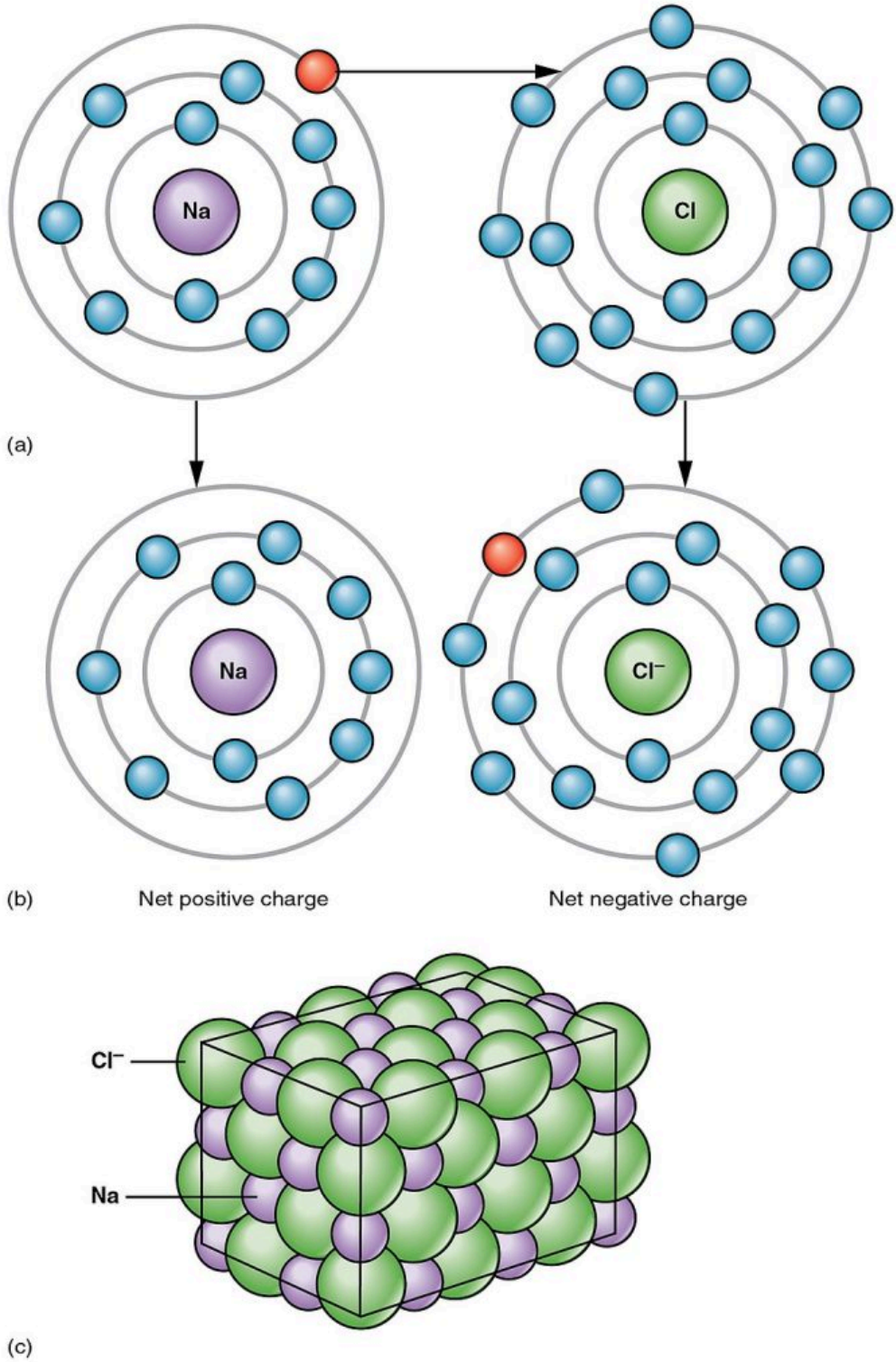


Figure 2.10 Ionic Bonding. (a) Sodium Donates the One Electron in Its Valence Shell to Chlorine, Which Needs Only One Electron to Have a Full Valence Shell; (b) The Opposite Electrical Charges of the Resulting Sodium Cation and Chloride Anion Result in the Formation of an Ionic Bond; (c) The Attraction of Many Sodium and Chloride Ions Results in the Formation of Large Groupings Called Crystals

Most ionic compounds dissolve easily in water. Water is an essential component of life because it is able to break the ionic bonds in salts to free the ions. In fact, in body fluids, most individual atoms exist as ions. These dissolved ions produce electrical charges in the heart and brain, which are observed as waves on an electrocardiogram (EKG or ECG) or an electroencephalogram (EEG).

The electrical activity that comes from the interactions of the charged ions is why they are also called electrolytes. Electrolytes, such as sodium (Na^+) and potassium (K^+), are important as they are used to send nerve signals and are also used in muscle contraction, including the beating of the heart. When electrolyte levels are out of homeostatic balance in the body, it can be life-threatening.

Covalent Bonds

Another type of strong chemical bond between two or more atoms is a covalent bond. **Covalent bonds** form when electrons are shared between two elements. Just like neighbors whose kids hang out at one home and then at the other, the atoms do not lose or gain electrons permanently. Instead, the electrons move back and forth between the elements. They are the strongest and most common form of chemical bond in living organisms. Covalent bonds form between the elements that make up the biological molecules in our cells. Unlike ionic bonds, covalent bonds do not dissociate or break apart in water.

The hydrogen and oxygen atoms that combine to form water molecules are held together with covalent bonds. The electron from the hydrogen atom divides its time between the incomplete outer shell of the hydrogen atom and the incomplete outer shell of the oxygen atom. To fill the outer shell of an oxygen atom, two electrons from two hydrogen atoms are needed, hence the subscript “2” in H_2O. The electrons are shared between the atoms, dividing their time between them to “fill” the outer shells of each.

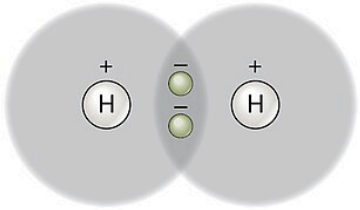
Polar and Nonpolar Covalent Bonds

There are two types of covalent bonds: nonpolar and polar. **Nonpolar covalent bonds** form between two atoms of the same element or between different elements that share the electrons equally. For example, an oxygen atom can bond with another oxygen atom to fill both of their outer electron shells. This association is nonpolar because the electrons will be equally distributed or shared between each oxygen atom. If two atoms share one pair (or two individual) of electrons, then they form a **single bond**. In the case

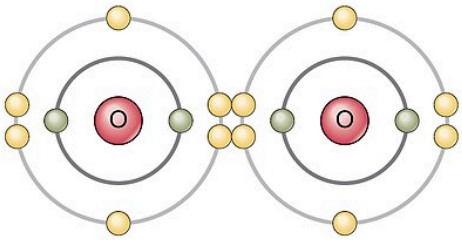
of O_2, two pairs of electrons are shared between them, which forms a **double bond**. A **triple bond** forms when three pairs of electrons are shared between atoms. A triple bond is found in N_2 gas. Another example of a nonpolar covalent bond is found in the methane (CH_4) molecule. These elements all share the electrons equally, creating four nonpolar covalent bonds.

See Figure 2.11[4] for illustrations of several common types of covalent bonds. Two covalently bonded atoms usually share just one or two electron pairs. In covalent bonds, electrons in the two atoms' overlapping orbits are shared to fill the valence shells of both atoms, stabilizing both.[5]

(a) A single covalent bond: hydrogen gas (H—H). Two atoms of hydrogen each share their solitary electron in a single covalent bond.



(b) A double covalent bond: oxygen gas (O═O). An atom of oxygen has six electrons in its valence shell; thus, two more would make it stable. Two atoms of oxygen achieve stability by sharing two pairs of electrons in a double covalent bond.



Molecule of oxygen gas (O_2)

(c) Two double covalent bonds: carbon dioxide (O═C═O). An atom of carbon has four electrons in its valence shell; thus, four more would make it stable. An atom of carbon and two atoms of oxygen achieve stability by sharing two electron pairs each, in two double covalent bonds.

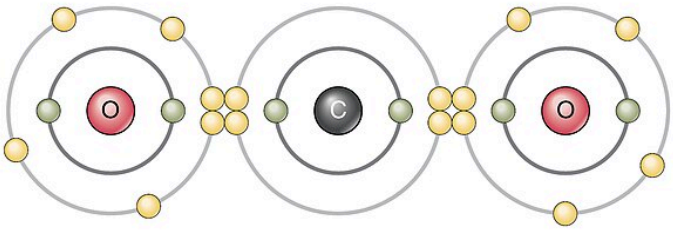


Figure 2.11 Covalent Bonding

4. OpenStax. (2013). *208 Covalent bonding* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:208_Covalent_Bonding-01.jpg

5. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

The covalent bonds shown in Figure 2.10 are balanced. The sharing of the negative electrons is relatively equal, as is the electrical pull of the positive protons in the nucleus of the atoms involved. This is why covalently bonded molecules that are electrically balanced in this way are described as nonpolar; that is, no part is either more positive or more negative than any other.

See Figure 2.12[6] for another illustration of single and double bonds.

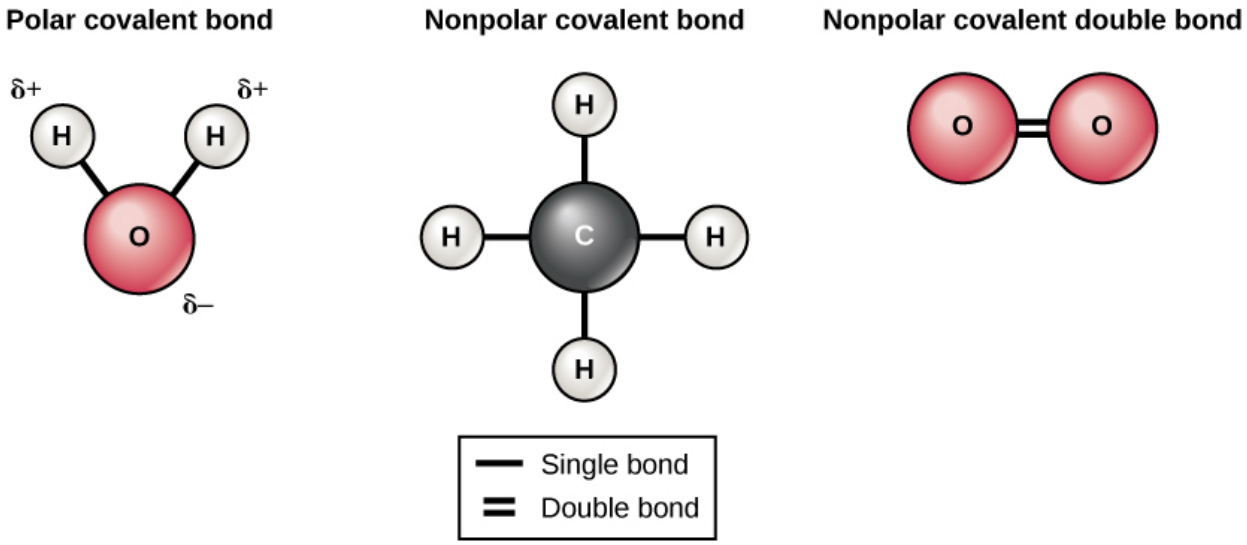


Figure 2.12 Polar and Nonpolar Covalent Bonds; Single Bonds Are Designated With One Solid Line, and Double Bonds Are Designated by Two Solid Lines

Unlike nonpolar bonds, **polar covalent bonds** are formed between two or more different elements that do not share electrons equally. This unequal sharing occurs when one atom "hogs" the electrons in the molecule. This happens when an element is more electronegative than another one and gives it a stronger attractive force, pulling the shared electron closer to itself. The water molecule is an example of a molecule with a polar bond with a slight positive charge on the hydrogen atoms and a slight negative charge on the oxygen. This happens because oxygen is more electronegative than hydrogen and will pull the shared electrons closer to itself (and away from hydrogen).

In a polar covalent bond, the electrons shared by the atoms spend more time closer to one nucleus than to the other nucleus. Because of the unequal distribution of electrons between the different nuclei, a slightly positive (δ^+) or slightly negative (δ^-)

6. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Covalent bonds* [Diagram]. OpenStax. CC BY-NC-SA 4.0. https://openstax.org/books/concepts-biology/pages/2-1-the-building-blocks-of-molecules

charge develops. The covalent bonds between hydrogen and oxygen atoms in water are polar covalent bonds. The shared electrons spend more time near the oxygen nucleus, giving it a small negative charge, than they spend near the hydrogen nuclei, giving these molecules a small positive charge.[7] See Figure 2.13[8] for an illustration of polar covalent bonds in a water molecule.

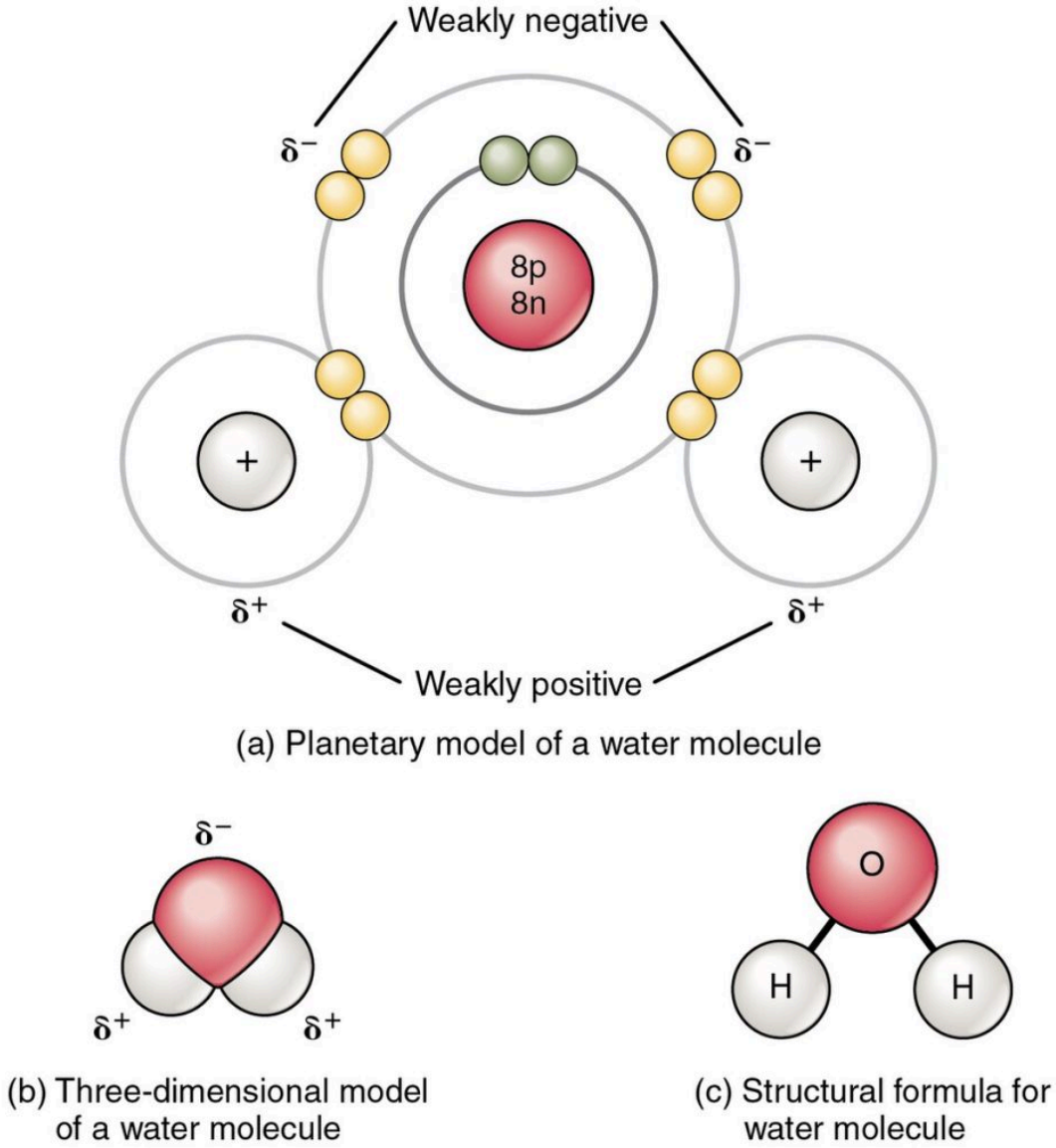


Figure 2.13 Polar Covalent Bonds in a Water Molecule

7. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

8. OpenStax. (2013). *Polar covalent bonds in a water molecule* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:209_Polar_Covalent_Bonds_in_a_Water_Molecule.jpg

Hydrogen Bonds

Ionic and covalent bonds are strong bonds that require considerable energy to break. However, not all bonds between elements are ionic or covalent bonds. Weaker bonds can also form. These are attractions that occur between positive and negative charges in polar covalent molecules that do not require much energy to break. One common example is a **hydrogen bond**. These bonds give rise to the unique properties of water and the unique structures of DNA and proteins.

The most common example of hydrogen bonding occurs between molecules of water. Hydrogen bonding in water molecules occurs because the weakly positive hydrogen atoms are attracted to the weakly negative oxygen atoms in different water molecules. Hydrogen bonding between water molecules is what causes water molecules to be cohesive or "stick" together. Hydrogen bonds give water the unique properties that sustain life. If it were not for hydrogen bonding, water would be a gas rather than a liquid at room temperature. See Figure 2.14[9] for an illustration of hydrogen bonds between water molecules. Notice that the bonds occur between the weakly positive charge on the hydrogen atoms and the weakly negative charge on the oxygen atoms. Hydrogen bonds are weak bonds and are indicated with a dotted (rather than a solid) line.[10]

9. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Hydrogen bonds* [Diagram]. OpenStax. CC BY-NC-SA 4.0. https://openstax.org/books/concepts-biology/pages/2-1-the-building-blocks-of-molecules

10. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

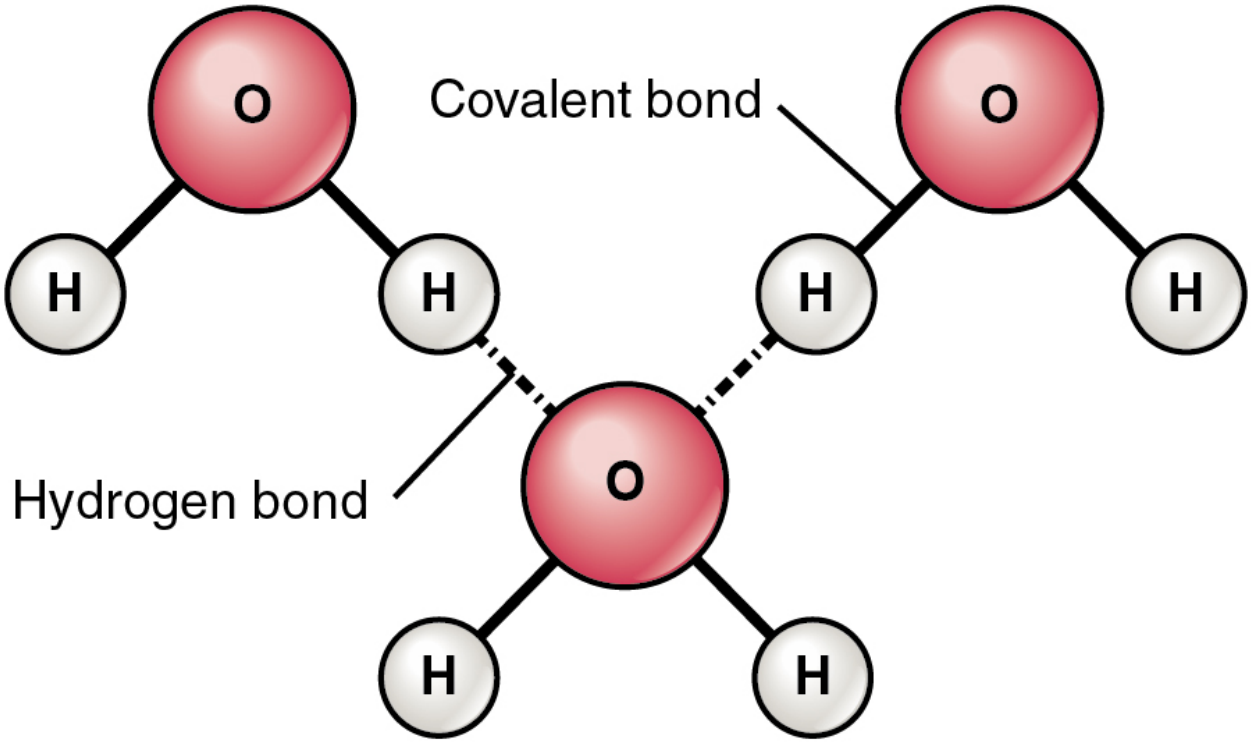


Figure 2.14 Hydrogen Bonds Between Water Molecules

Hydrogen bonds can form between different molecules, and they do not always have to include a water molecule. Hydrogen atoms in polar bonds within any molecule can form bonds with other nearby molecules. For example, hydrogen bonds hold together two long strands of DNA to give the DNA molecule its characteristic double-stranded helix structure. Hydrogen bonds are also responsible for some of the three-dimensional structure of proteins.[11]

Video

Watch the video "Ions Explained (Cations and Anions)" below to learn more about ions and their role in body functions.

11. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Watch the video “Chemical Bonds Explained (Covalent, Ionic, and Hydrogen Bonds)” below to learn more about chemical bonds and how atoms interact.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

2.4 Organic and Inorganic Compounds

This section focuses on the chemistry of human life, meaning compounds that are important for the body's structure and function. Recall that compounds are molecules made up of two or more atoms of different elements. Compounds are classified as either organic or inorganic:

- **Organic compounds** are molecules that contain both carbon and hydrogen. Organic compounds are made by covalent bonds. Carbon and hydrogen are the second and third-most-abundant elements in your body. Most organic compounds in the cells of the body belong to one of four classes: carbohydrates, lipids, proteins, and nucleotides.[1]
- **Inorganic compounds** do not contain carbon-hydrogen bonds and rarely contain carbon. They are compounds that contain ionic bonds. A lot of inorganic compounds contain hydrogen atoms, such as water (H_2O) and hydrochloric acid (HCl), produced by your stomach. Only a few inorganic compounds contain carbon atoms. Carbon dioxide (CO_2) is one of the few examples. The three groups of inorganic compounds essential to life are water, some acids, and bases.[2]

Organic and inorganic compounds are further discussed in the following subsections.

Organic Compounds in the Human Body

There are four major organic compounds (also called **biomolecules**) found in the human body: carbohydrates, lipids (fats), proteins, and nucleotides. Each of these compounds is discussed in the following subsections.

1. Fowler, S., Roush, R., & Wise, J. (2013). *Concepts of biology*. OpenStax. https://openstax.org/books/concepts-biology/pages/1-introduction
2. Fowler, S., Roush, R., & Wise, J. (2013). *Concepts of biology*. OpenStax. https://openstax.org/books/concepts-biology/pages/1-introduction

Carbohydrates

Carbohydrates are macromolecules with which most people are somewhat familiar. To lose weight, some individuals adhere to "low-carb" diets. Athletes, in contrast, often "carb-load" before important competitions to ensure that they have sufficient energy to compete at a high level. Carbohydrates are, in fact, an essential part of our diet; grains, fruits, and vegetables are all natural sources of carbohydrates. **Carbohydrates** provide energy to the body, particularly through **glucose**, a simple sugar. Carbohydrates also have other important functions in humans, animals, and plants. Carbohydrates contain carbon, hydrogen, and oxygen. Carbohydrates are classified into three subtypes: monosaccharides, disaccharides, and polysaccharides.

Monosaccharides

Monosaccharides (*mono-* = "one"; *sacchar-* = "sweet") are simple sugars, the most common of which is glucose. Most sugar names end with the suffix -ose. The chemical formula for glucose is $C_6H_{12}O_6$. Glucose is an important source of energy. During cellular respiration, energy is released from glucose, and that energy is used to make adenosine triphosphate (ATP), a form of energy for the cell. Ribose, deoxyribose, galactose (part of lactose, or milk sugar), and fructose (found in fruit) are other common monosaccharides.



Figure 2.15 Grapes are packed with monosaccharides. Here, an athlete recharges with a fast source of energy for muscles and the brain.

Disaccharides

Disaccharides (*di-* = "two") form when two monosaccharides join together with a covalent bond. Common disaccharides include lactose, maltose, and sucrose. Lactose is a disaccharide consisting of the monomers glucose and galactose. It is found naturally in milk. Maltose, or malt sugar, is a disaccharide formed between two glucose molecules. The most common disaccharide is sucrose, or table sugar, which is composed of glucose and fructose.



Figure 2.16 Person drinking milk, a good source of lactose, which is a disaccharide.

Polysaccharides

A long chain of monosaccharides linked by covalent bonds is known as a **polysaccharide** (*poly-* = "many"). Polysaccharides may be very large molecules. Starch, glycogen, and cellulose are examples of polysaccharides:

- **Starch** is the storage form of glucose in plants and is relatively easy for humans to digest.
- **Glycogen** is the storage form of glucose in humans and other animals and is made up of monomers (building blocks) of glucose bonded together into long chains. Glycogen is usually stored in the liver and muscle cells. Whenever blood glucose levels decrease, glycogen is broken down to release glucose.
- **Cellulose** is a component of plant cell walls. It is commonly known as "fiber" in the diet. Humans can't digest cellulose, but it has many health benefits. Fiber helps you feel full, promotes a healthy digestive tract, and can reduce the risk of heart disease and some forms of cancer.



Figure 2.17 Oranges are rich in polysaccharides

Lipids

Lipids or fats are a second type of organic compound that shares a common feature. Lipids are hydrophobic ("water-fearing"), or insoluble in water, because they are nonpolar molecules. Lipids are large molecules that serve as a second source of fuel for the human body. All lipids contain carbon, hydrogen, and oxygen. Lipids perform many different functions in a cell. Cells use lipids to store energy for long-term use, provide insulation, make up cell membranes, and make some hormones. Lipids important to the human body include triglycerides, phospholipids, steroids, and prostaglandins.

Triglycerides

Triglycerides (fats) are the most common lipid in body tissues and the most common lipid in the human diet. Triglycerides are composed of a glycerol molecule with three fatty acid groups attached. The three fatty acids in the fat may be the same or different. Fatty acids may be saturated or unsaturated. In a fatty acid chain, if there are only single bonds between neighboring carbons, the fatty acid is saturated. When the carbon chain contains one or more double bonds, the fatty acid is unsaturated.

When a person is resting or asleep, most of the energy used is derived from triglycerides (fat) stored in **adipose tissue**. Triglycerides also fuel long, slow physical activities, such as gardening or hiking, and also contribute a percentage of energy to vigorous physical activity. Dietary fat assists in the absorption of fat-soluble vitamins A, D, E, and K. Stored body fat protects and cushions the body's bones and internal organs

and acts as insulation to retain body heat. There are different types of triglycerides called saturated fats, unsaturated fats, cis fats, and trans fats.

Some fatty acids have common names that specify their origin. For example, palmitic acid is derived from the palm tree. Arachidic acid is derived from Arachis hypogaea, the scientific name for peanuts.

Saturated fats are solid or semi-solid at room temperature. For example, butter is a dietary saturated fat. Fat in steak is also saturated fat. Saturated fats contain only single bonds in their chemical structure. Saturated fats are considered unhealthy, and diets high in saturated fats have been linked to heart disease. See Figure 2.18[3] for an illustration of saturated fats and their connection to coronary artery disease.

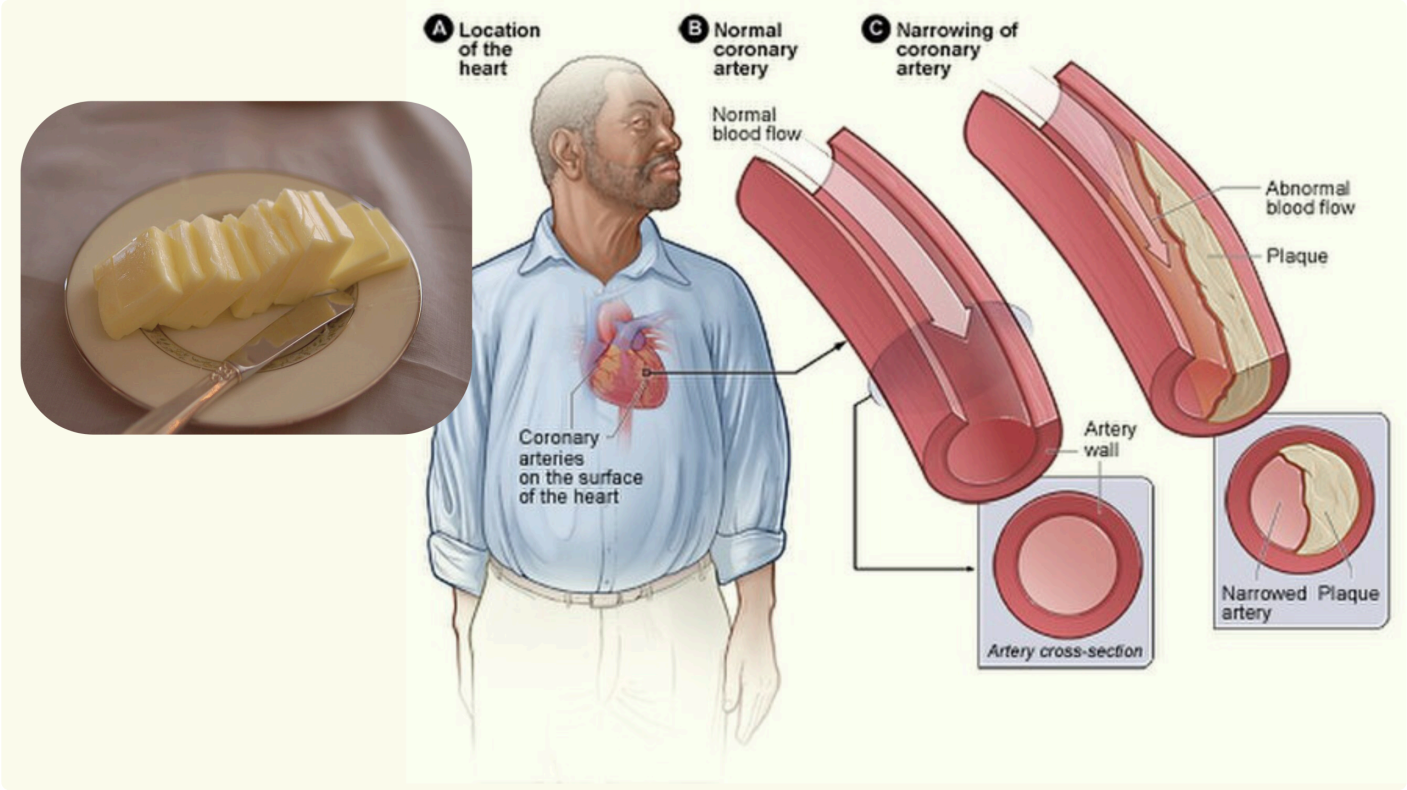


Figure 2.18 Butter Is an Example of Saturated Fat; a Diet High in Saturated Fat Can Lead to Coronary Artery Disease, or a Build-up of Plaque in the Coronary Arteries

3. (a) National Heart, Lung, and Blood Institute. (2011). *Atherosclerosis 2011* [Image]. National Institutes of Health. Public domain. https://simple.wikipedia.org/wiki/Atherosclerosis#/media/File:Atherosclerosis_2011-es.png, and (b) Carey Tilden. (2006). *Butter with a butter knife* [Photograph]. Wikimedia Commons. CC BY 2.0. https://commons.wikimedia.org/wiki/File:Butter_with_a_butter_knife.jpg

Unsaturated fats are liquid at room temperature. They contain one or more double bonds in their chemical structure. If there is one double bond in the molecule, then it is called a monounsaturated fat, and if there is more than one double bond, then it is known as a polyunsaturated fat. Plant oils, such as olive oil and avocado oil, as well as the fat in salmon, are examples of unsaturated fats. These types of fats are considered healthier than saturated fats, and diets high in unsaturated fats help reduce the risk of heart disease.

Trans fats are created from unsaturated fatty acids (such as corn oil) when they are chemically treated to produce partially hydrogenated fats. Trans fats are commonly found in processed foods, such as margarine, fried foods, and commercially baked products. They are even more harmful to the heart and blood vessels than saturated fats. Many fast-food restaurants have recently eliminated the use of trans fats, and U.S. food labels are now required to list their trans fat content.

Essential fatty acids are fatty acids that are required but not made by the human body, so they must be supplemented through the diet. Omega-3 fatty acids fall into this category and are one of only two known essential fatty acids for humans (the other being omega-6 fatty acids). They are a type of polyunsaturated fat and are called omega-3 fatty acids because the third carbon from the end of the fatty acid participates in a double bond.

Salmon, trout, and tuna are good sources of omega-3 fatty acids. Omega-3 fatty acids are important in brain function and normal growth and development. They may also prevent heart disease and reduce the risk of cancer.

Like carbohydrates, fats have received a lot of bad publicity. It is true that eating an excess of fried foods and other “fatty” foods leads to weight gain. However, fats do have important functions. Fats serve as long-term energy storage and provide insulation for the body. Therefore, “healthy” unsaturated fats in moderate amounts should be consumed on a regular basis.

Phospholipids

Phospholipids are the main component of cell membranes, which protect cells from environmental damage and allow for cellular processes. Phospholipids are found in dairy milk and chicken eggs. Like triglycerides, they are composed of fatty acid chains attached to a glycerol backbone. Instead of three fatty acids attached, there are two fatty acids, and the third carbon of the glycerol backbone is bound to a phosphate group.

A phospholipid has both hydrophobic (repelled by water) and hydrophilic (attracted

to water) regions. The fatty acid chains or tails are hydrophobic and are arranged in a bilayer (two rows) in the cell membrane so that the tails point inwards to protect them from the watery environments inside and outside of the cell. The phosphate is hydrophilic and interacts with water. See Figure 2.19[4] for an illustration of a phospholipid, and Figure 2.20[5] for an illustration of the phospholipid bilayer.

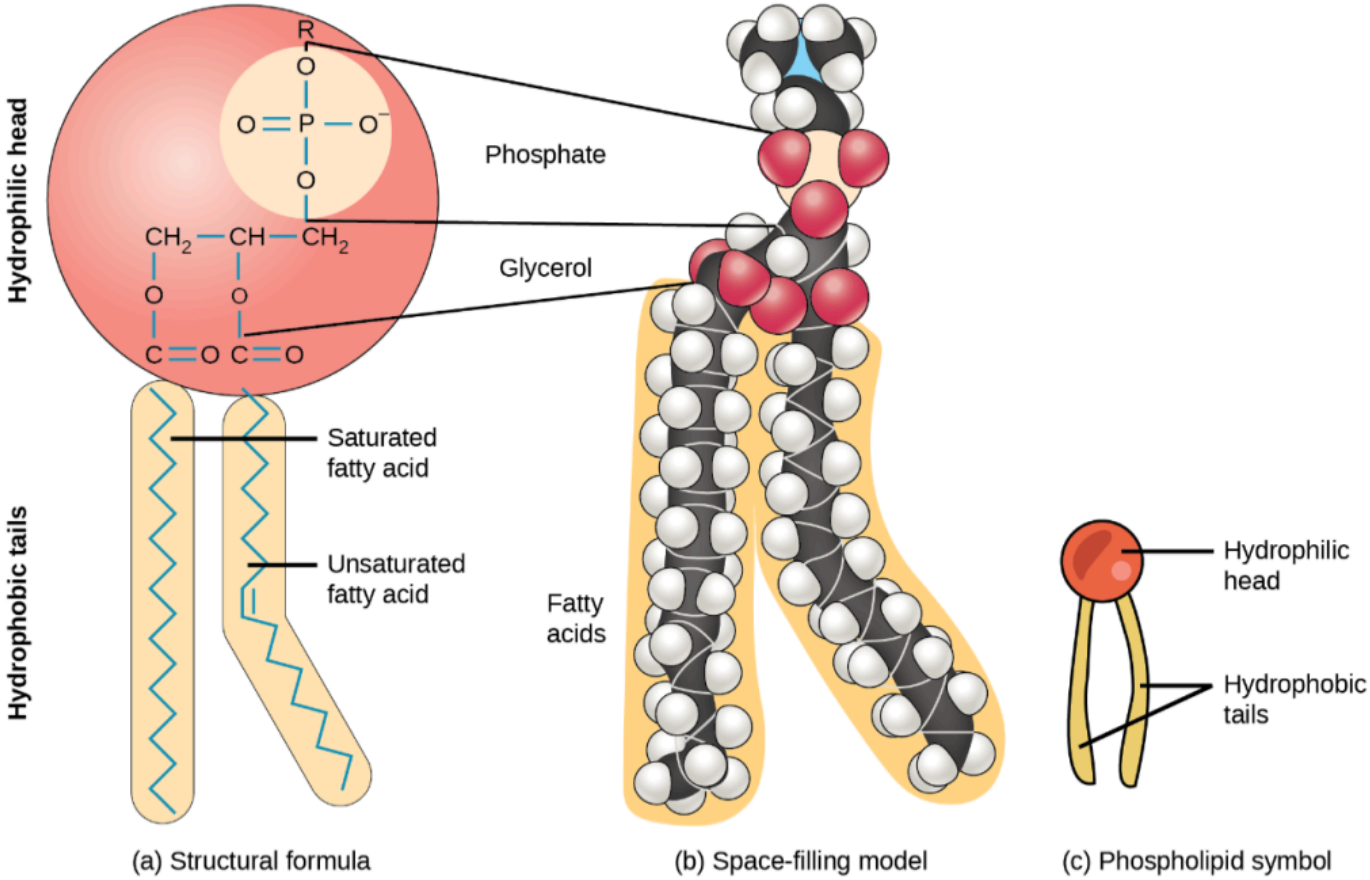


Figure 2.19 Phospholipid Molecule

4. Unknown author. (2019). *Struttura_dei_fosfolipidi* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Struttura_dei_fosfolipidi.png

5. OpenStax. (2013). *0302 Phospholipid bilayer* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0302_Phospholipid_Bilayer.jpg

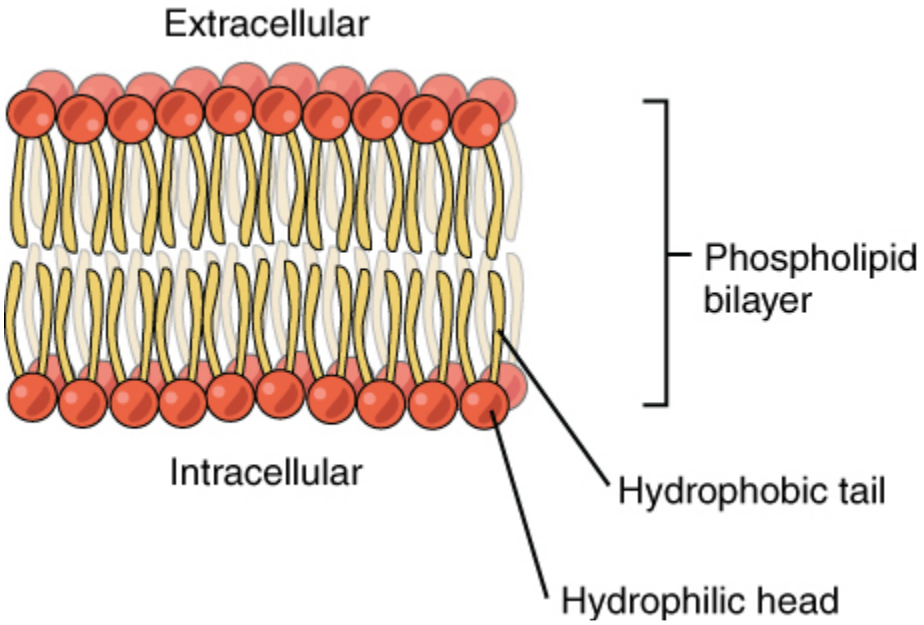


Figure 2.20 Phospholipid Bilayer. Phospholipids Form a Bilayer with the Hydrophilic Heads Facing the Watery Intracellular and Extracellular Environments and the Hydrophobic Tails on the Inside, Away from the Watery Intracellular and Extracellular Environments

Steroids

Steroids are classified as lipids because they are hydrophobic and insoluble in water. All steroids have four rings of carbon atoms linked together in their chemical structure. Cholesterol is the most common steroid in the human body and is the building block of many hormones. It is also used in digestion, vitamin D synthesis, and the formation of cell membranes. Cholesterol is made by the liver and is also present in most animal products, such as meats, eggs, and dairy products. Although cholesterol is often spoken of in negative terms, it is necessary for the proper functioning of the body.

LDL and HDL

Because cholesterol does not dissolve in blood, it is transported through the bloodstream by proteins called lipoproteins. Two of the most important are low-density lipoproteins (LDL) and high-density lipoproteins (HDL). LDL delivers cholesterol from the liver to body cells, but excess LDL can deposit cholesterol in artery walls, contributing to atherosclerosis and increasing the risk of cardiovascular disease. In contrast, HDL helps remove excess cholesterol from tissues and blood vessels, transporting it back

to the liver for processing and excretion. For this reason, LDL is often referred to as "bad" cholesterol, while HDL is known as "good" cholesterol, reflecting their opposing roles in cardiovascular health. See Figure 2.21[6] from the National Institutes of Health on "Cholesterol and Your Heart."

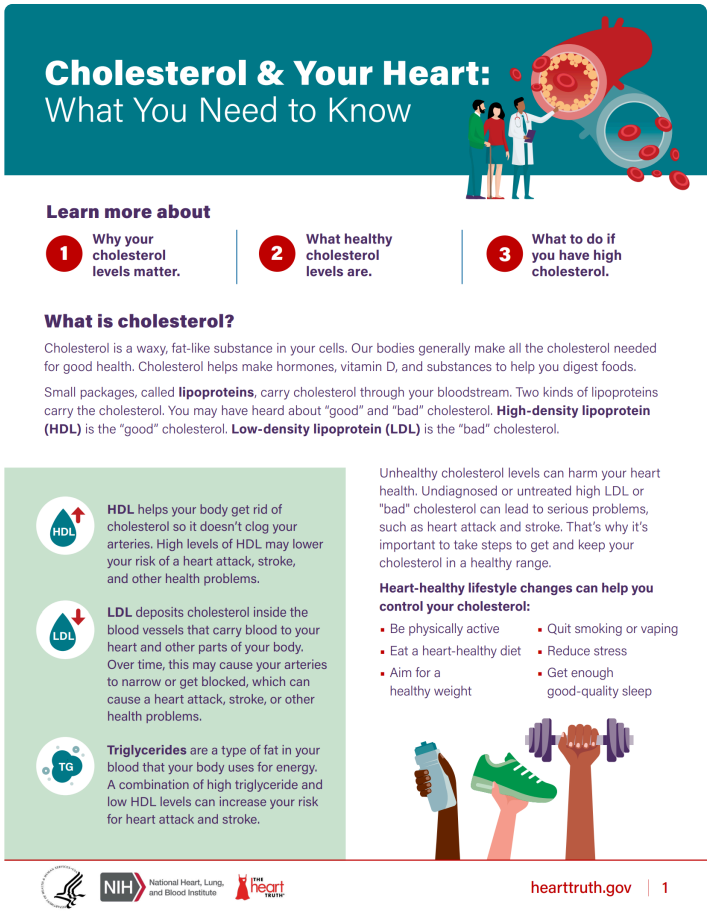


Figure 2.21: Cholesterol factbook from the National Institutes of Health on cholesterol and your heart. Explore the resource "Resident Assessment and Care Screening Form" on the Centers for Medicare & Medicaid Services (CMS) website.

Prostaglandins

Like a hormone, a **prostaglandin** is one of a group of signaling molecules derived from unsaturated fatty acids. One reason that the omega-3 fatty acids found in fish are beneficial is that they stimulate the production of certain prostaglandins that help regulate aspects of blood pressure and inflammation and, thereby, reduce the risk for heart disease. Prostaglandins also sensitize nerves to pain. One class of pain-relieving medications called nonsteroidal anti-inflammatory drugs (NSAIDs), like ibuprofen and naproxen, works by reducing the effects of prostaglandins.

Proteins

Proteins are a third type of organic compound that are critical components of all tissues and organs. Proteins include the collagen found in skin, the hemoglobin that carries oxygen in the blood, and the actin and myosin responsible for muscle movement. Proteins also make up digestive **enzymes** (catalysts that help speed up chemical reactions), antibodies, the neurotransmitters that nerve cells use to communicate with other cells, and some hormones. Hormones are chemical signaling molecules that control specific physiological processes, including growth, development, metabolism, and reproduction.

6. National Institutes of Health. (n.d.) *NIH Publication No. 22-HL-8191* [Infographic]. Public domain. https://www.nhlbi.nih.gov/resources/cholesterol-your-heart-what-you-need-know-fact-sheet

For example, insulin is a protein hormone that maintains blood glucose levels. The body can also use proteins for energy when dietary intake of carbohydrates and fat is inadequate, and stores of glycogen and adipose tissue become depleted.

A **protein** is an organic molecule made up of building blocks called **amino acids** that are linked by peptide bonds. A **peptide bond** is a covalent bond between two amino acids that forms by **dehydration synthesis** (the elimination of water to combine molecules). Just 20 different amino acids make up thousands of different proteins in the human body by joining together to form protein polymers. Each type of protein contains a unique combination of these 20 amino acids, ranging from a few dozen to several hundred. A **peptide** is a very short chain of amino acids, and strands containing fewer than 100 amino acids are generally referred to as **polypeptides** rather than proteins. See Figure 2.22[7] for an illustration of basic protein structure.

The human body can produce eleven of the 20 amino acids, but nine cannot be made and must be consumed in the diet. These are known as the **essential amino acids**.

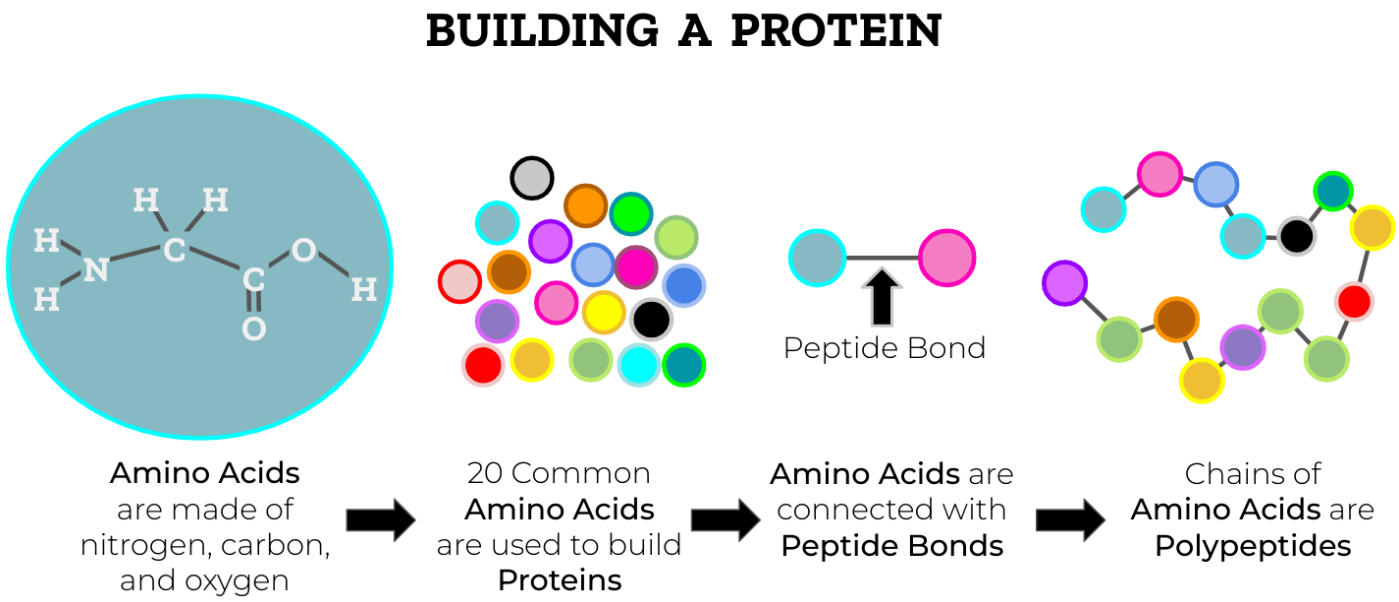


Figure 2.22 Basic Protein Structure

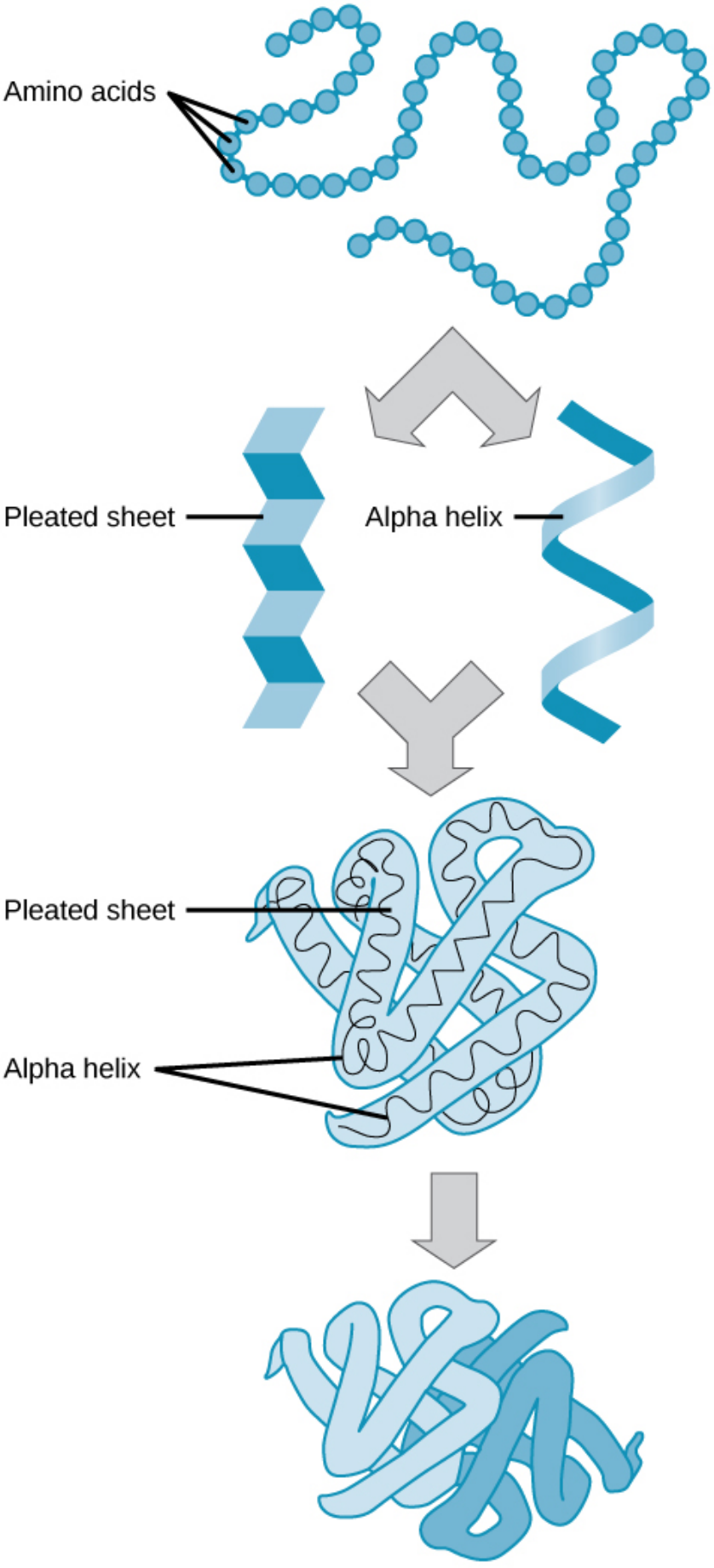
Proteins have different shapes; some proteins are globular in shape, whereas others are fibrous in nature. For example, hemoglobin is a globular protein, but collagen, found in our skin, is a fibrous protein. Protein shape is critical to its function. Changes in

7. SadiesBurrow. (2023). *Basic protein structure* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Basic_Protein_Structure.png

temperature, pH, and exposure to chemicals may lead to permanent changes in the shape of the protein, leading to a loss of function or denaturation (which will be discussed in more detail later). All proteins are made up of different arrangements of the same 20 amino acids.

The sequence and number of amino acids ultimately determine a protein's shape, size, and function. Each amino acid is attached to another amino acid by a covalent bond, known as a peptide bond. As discussed earlier, the shape of a protein is critical to its function. To understand how the protein gets its final shape or conformation, we need to understand the four levels of protein structure: primary, secondary, tertiary, and quaternary. See Figure 2.23[8] for an illustration of four levels of protein structure.

8. CNX OpenStax. (2016). *Figure 03-04-09* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Figure_03_04_09.jpg



Primary Protein structure
sequence of a chain of animo acids

Secondary Protein structure
hydrogen bonding of the peptide backbone causes the amino acids to fold into a repeating pattern

Tertiary protein structure
three-dimensional folding pattern of a protein due to side chain interactions

Quaternary protein structure
protein consisting of more than one amino acid chain

Figure 2.23 Four Levels of Protein Structure

The unique sequence and number of amino acids in a polypeptide chain are its primary structure.

The unique sequence for every protein is ultimately determined by the gene or section of deoxyribonucleic acid (DNA) that encodes the protein. Any change in the gene sequence may lead to a different amino acid being added to the polypeptide chain, causing a change in protein structure and function. For example, sickle cell anemia is caused by a change in protein structure as a result of gene encoding, meaning that it is an inherited disorder. In sickle cell anemia, the hemoglobin β chain has a single amino acid substitution, causing a change in both the structure and function of the protein. What is most remarkable to consider is that a hemoglobin molecule is made up of two alpha chains and two beta chains that each consist of about 150 amino acids. The molecule, therefore, has about 600 amino acids. The structural difference between a normal hemoglobin molecule and a sickle cell molecule—that dramatically decreases life expectancy in the affected individuals—is a single amino acid in the 600. Because of this change of one amino acid in the chain, the normally biconcave, or disc-shaped, red blood cells assume a crescent or "sickle" shape, which clogs arteries. This can lead to a myriad of serious health problems, such as breathlessness, dizziness, headaches, and abdominal pain, for those who have this disease.

Each protein has its own unique sequence and shape held together by chemical interactions. If the protein is subject to changes in temperature, pH, or exposure to chemicals, the protein structure may change, losing its shape in what is known as denaturation, as discussed earlier. Denaturation is often reversible because the primary structure is preserved if the denaturing agent is removed, allowing the protein to resume its function. Sometimes denaturation is irreversible, leading to a loss of function. One example of protein denaturation can be seen when an egg is fried or boiled. The albumin protein in the liquid egg white is denatured when placed in a hot pan, changing from a clear substance to an opaque white substance. Not all proteins are denatured at high temperatures; for instance, bacteria that survive in hot springs have proteins that are adapted to function at those temperatures.

Enzymes

For atoms to react and form bonds, they must come into contact with each other, which often occurs due to random collisions. Higher temperatures (caused by the

transfer of energy) cause chemical reactions to occur at a faster rate due to the faster movement of atoms, ions, and molecules. The faster the movement, the more likely they are to come in contact with each other and react. However, in the human body, higher temperatures, such as a high fever, can damage body cells and become life-threatening. On the other hand, a normal body temperature is not high enough to promote the chemical reactions that sustain life. For this reason, catalysts known as enzymes are critical to facilitate chemical reactions and molecular bonding that occur in the human body.

A **catalyst** is a substance that increases the rate and force at which atoms, ions, and molecules collide, thereby increasing the chances that the electrons in their valence shells will interact. An **enzyme** is a catalyst usually composed of protein, although there are a few enzymes that are made from ribonucleic acid (RNA) instead. Like all catalysts, enzymes work by lowering the amount of energy (e.g., heat) that is required to start a chemical reaction. Without an enzyme acting as a catalyst, a much larger amount of energy is needed to start a chemical reaction. See Figure 2.24[9] for an illustration of the energy required to start a reaction without an enzyme compared to that required for a reaction with an enzyme. Enzymes decrease the amount of energy required for a chemical reaction to occur.

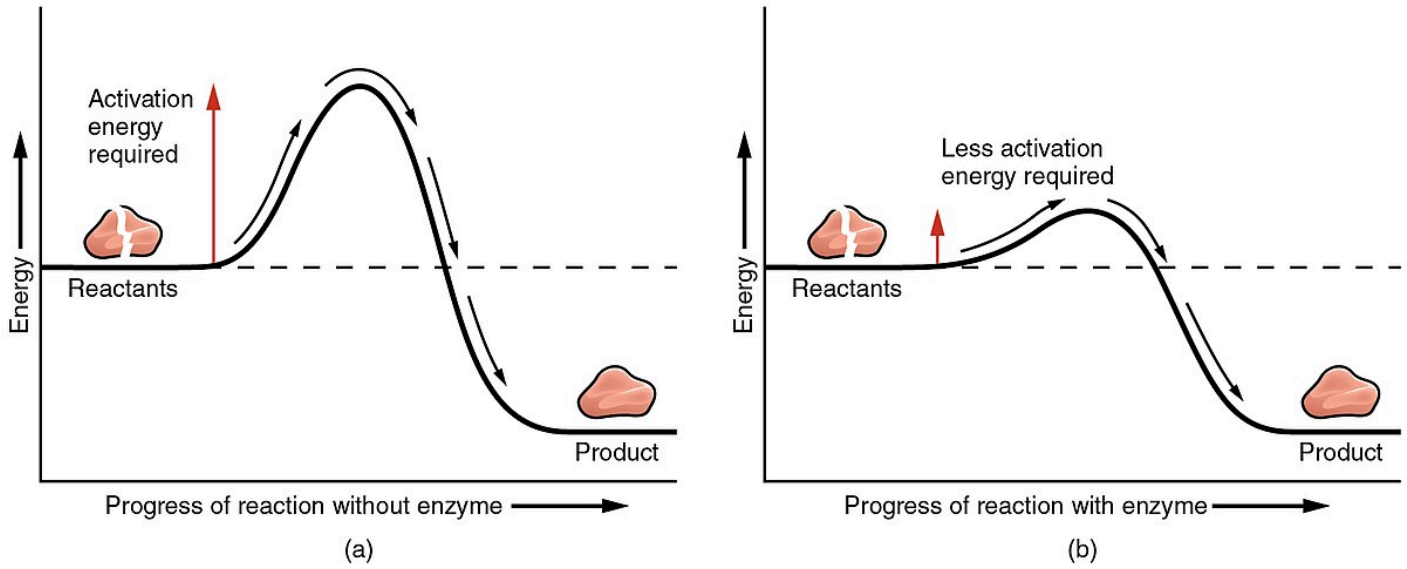


Figure 2.24 (a) Energy Required Without an Enzyme and (b) Less Energy Required to Begin a Reaction

9. OpenStax. (2013). *212_Enzymes-01* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:212_Enzymes-01.jpg

Nucleotides

Nucleotides are the fourth type of organic compound in the human body and are used to build nucleic acids (DNA or RNA) and adenosine triphosphate (ATP). Nucleic acids are key macromolecules in the continuity of life. They carry the genetic blueprint of a cell and carry instructions for the functioning of the cell. ATP is an important energy molecule for cells in the body.

The two main types of nucleic acids are deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). DNA is the genetic material found in all living organisms, ranging from single-celled bacteria to multicellular humans. The other type of nucleic acid, RNA, is mostly involved in protein synthesis. The DNA molecules never leave the nucleus but instead use different types of RNA to manufacture proteins using instructions from the DNA's genetic code.

Molecules called nucleotides are the building blocks of both DNA and RNA that hold the instructions on how to build and maintain the human body. A nucleotide consists of the following:

- A sugar molecule (i.e., deoxyribose in DNA or ribose in RNA)
- A phosphate group
- A nitrogen-containing base
  - In DNA, the bases are adenine (A), cytosine (C), guanine (G), and thymine (T).
  - In RNA, the base uracil (U) takes the place of thymine.

DNA and RNA molecules are polymers made up of long chains of nucleotides. See Figure 2.25[10] for an illustration showing the nucleotides in DNA and RNA. The following subsections will further explain the structure of DNA, RNA, and chromosomes.

10. WisTech Open. (2025). *The four nucleotides of DNA and RNA by Julia Brown* [Diagram]. Chippewa Valley Technical College. CC BY 4.0.

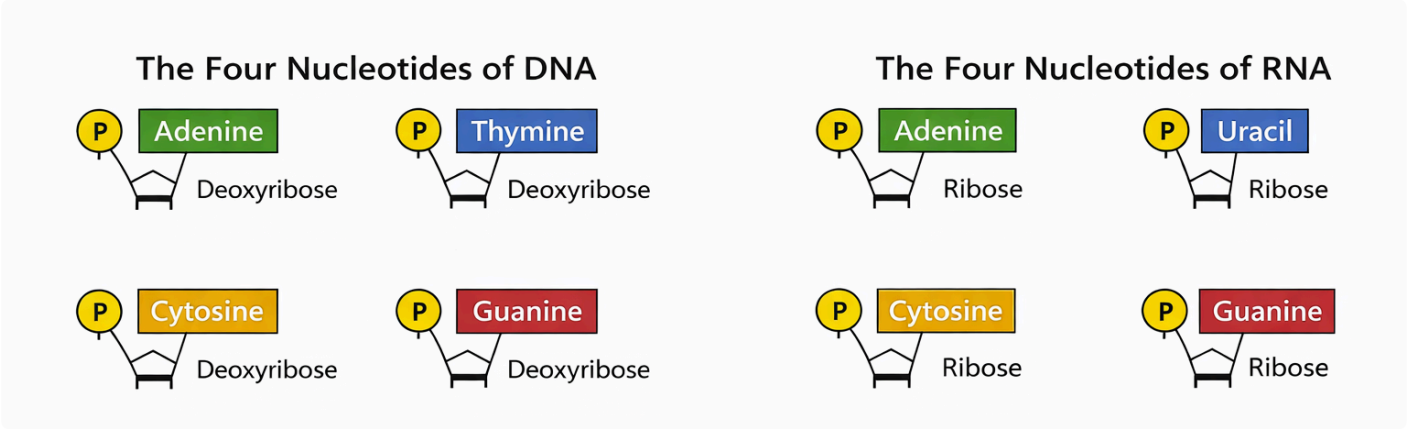


Figure 2.25 The Four Nucleotides of DNA and RNA

DNA

DNA is found in the nucleus of every cell in the human body, except for red blood cells. The primary structure of DNA is a **double helix**, where two strands of nucleotides wind around each other like a spiral staircase. When learning about the structure of DNA, it is helpful to think of it like a ladder. The sides of the ladder are made of alternating sugar (deoxyribose) and phosphate groups. The rungs of the ladder are made up of pairs of the nitrogen-containing bases adenine (A), thymine (T), cytosine (C), or guanine (G). Note that adenine always pairs with thymine (A-T), and guanine always pairs with cytosine (G-C). The bases are held together with hydrogen bonds. See Figure 2.26[11] for an illustration of the double helix structure of DNA.[12]

11. OpenStax. (2013). *229 Nucleotides-01* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:229_Nucleotides-01.jpg

12. Fowler, S., Roush, R., & Wise, J. (2013). *Concepts of biology*. OpenStax. https://openstax.org/books/concepts-biology/pages/1-introduction

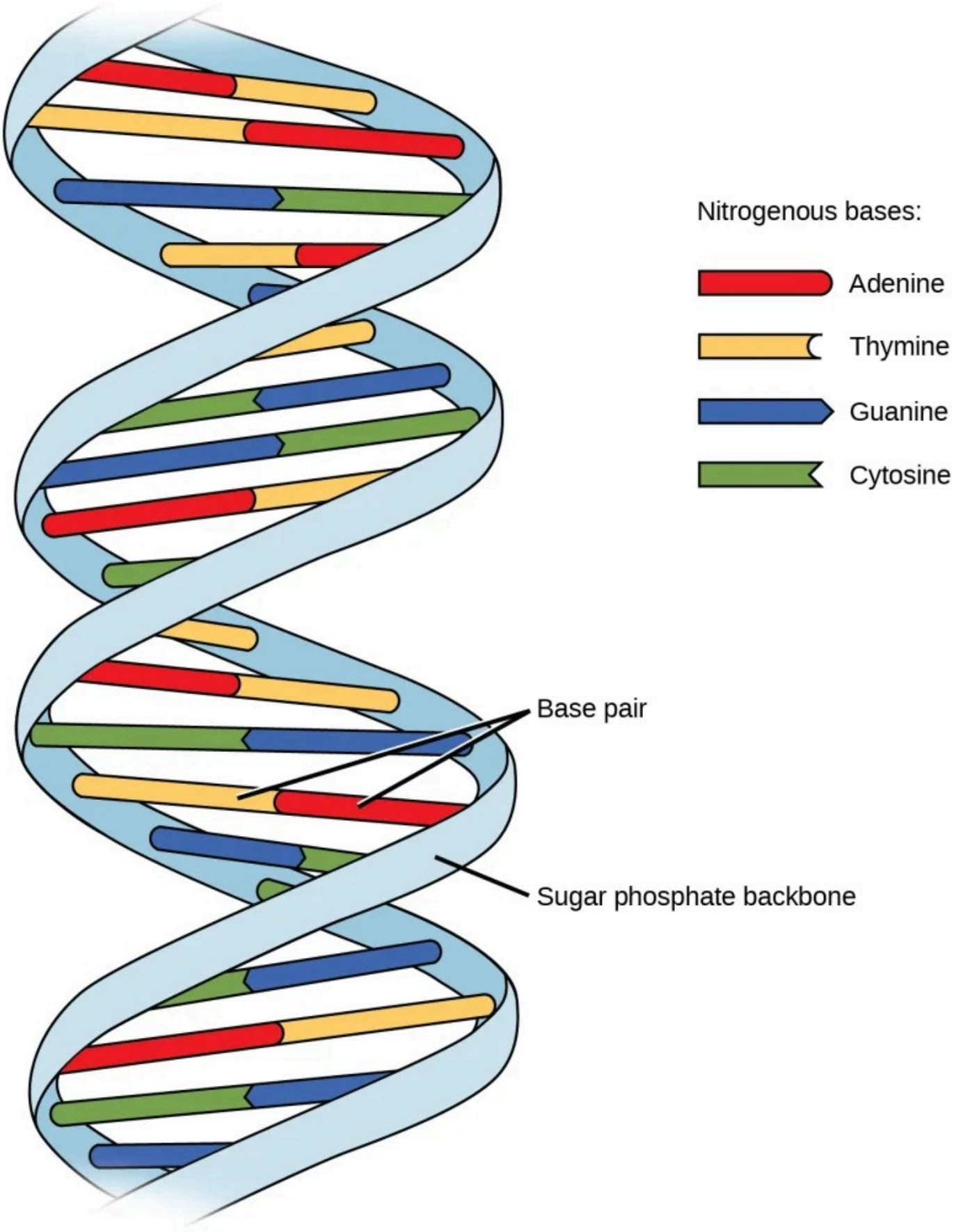


Figure 2.26 DNA Double Helix

DNA stays within the nucleus and is very accurate at copying itself during a process called replication. The sequence of the base pairs (i.e., the As, Ts, Cs, and Gs) forms genes, which provide the genetic information necessary to build a protein. Humans have about three billion base pairs, making almost 22,000 genes in their DNA. DNA is unique for each individual except identical twins. Genes are contained in 46 chromosomes inside the nucleus of each cell and are passed from generation to generation. Chromosomes can be seen through a microscope when the nucleus dissolves during cell division. See Figure 2.27[13] for an illustration of chromosomes.

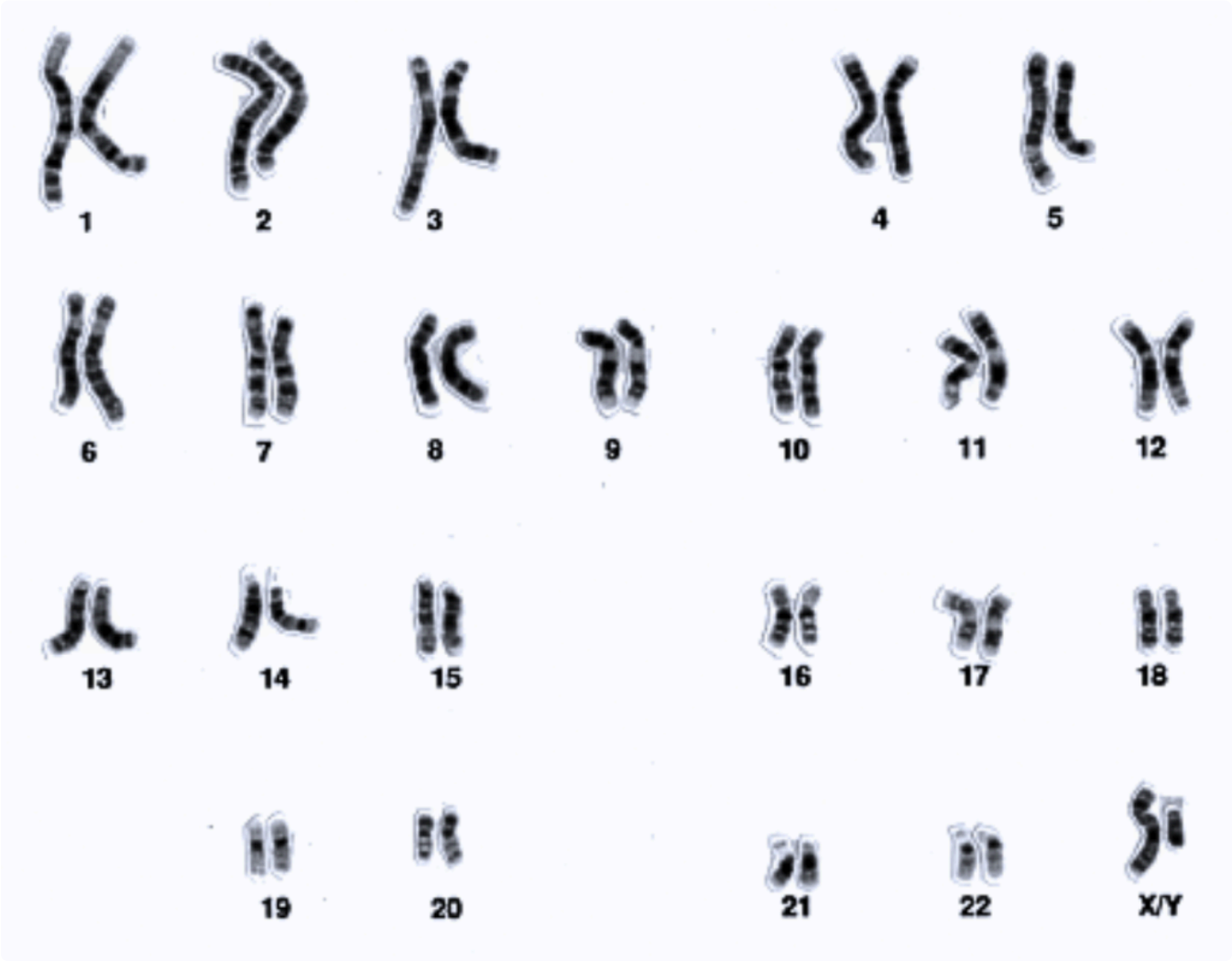


Figure 2.27 Chromosomes

13. National Human Genome Research Institute. (2012). *NHGRI human male karyotype* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:NHGRI_human_male_karyotype.png

RNA

RNA is also made up of building blocks called nucleotides that contain a sugar molecule attached to a phosphate group and nitrogen-containing bases. However, unlike the double-stranded DNA, RNA is single-stranded, and the sugar molecule is ribose. Although RNA is single-stranded, its nucleotides are added during transcription by complementary base pairing with DNA: cytosine pairs with guanine, and adenine pairs with uracil. RNA is located inside and outside the nucleus. RNA synthesis is less accurate than DNA replication, so a strand of RNA may contain more errors or mutations than DNA. RNA plays a vital role in protein synthesis, including carrying the genetic code from DNA to the ribosomes (a cell structure discussed in Chapter 3) and helping to assemble amino acids into proteins. See Figure 2.28[14] for an illustration of RNA. Table 2.1 summarizes the differences between DNA and RNA.



Figure 2.28 RNA

Table 2.1. DNA Compared to RNA

14. DataBase Center for Life Science. (2019). *RNA* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:201904_RNA.svg

Characteristic	DNA	RNA
Number of Strands	Double-stranded	Single-stranded
Sugar	Deoxyribose	Ribose
Nitrogenous Bases	Adenine, cytosine, guanine, and thymine	Adenine, cytosine, guanine, and uracil
Location	Remains in the nucleus	Found inside and outside the nucleus
Types	One type of DNA	Several types of RNA: • mRNA (messenger RNA) • tRNA (transfer RNA) • rRNA (ribosomal RNA)
Copying Accuracy	Highly accurate self-replication	More errors occur during RNA synthesis

Video

Watch the video "DNA and RNA Explained (Structure and Function)" below to learn more about the structure and function of DNA.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Watch the video "DNA vs RNA (Updated)" below to learn the key differences between DNA and RNA and how each molecule functions in storing and expressing genetic information.[15]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Adenosine Triphosphate

The nucleotide **adenosine triphosphate (ATP)** is composed of a ribose sugar, an adenine base, and three phosphate groups. ATP is classified as a high-energy compound because the two covalent bonds linking its three phosphates store a significant amount of potential energy. In the body, the energy released from these high-energy bonds helps fuel all of the body's functions, such as contracting muscles, maintaining the electrical potential of nerve cells, and absorbing food in the gastrointestinal tract. The products of this reaction are a molecule of adenosine diphosphate (ADP) and a lone phosphate group (P_i). ATP, ADP, and P_i are constantly being cycled through reactions that build ATP and store energy and reactions that break down ATP and release energy. The metabolic reactions that produce ATP come from various sources. See Figure 2.29[16] for an illustration of the structure of ATP.

15. Amoeba Sisters. (2019, August 29). *DNA vs RNA (Updated)* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=JQByjprj_mA

16. OpenStax. (2013). *The structure of ATP molecules* [Diagram]. Wikimedia Commons. CC BY 4.0. https://creativecommons.org/licenses/by/4.0/

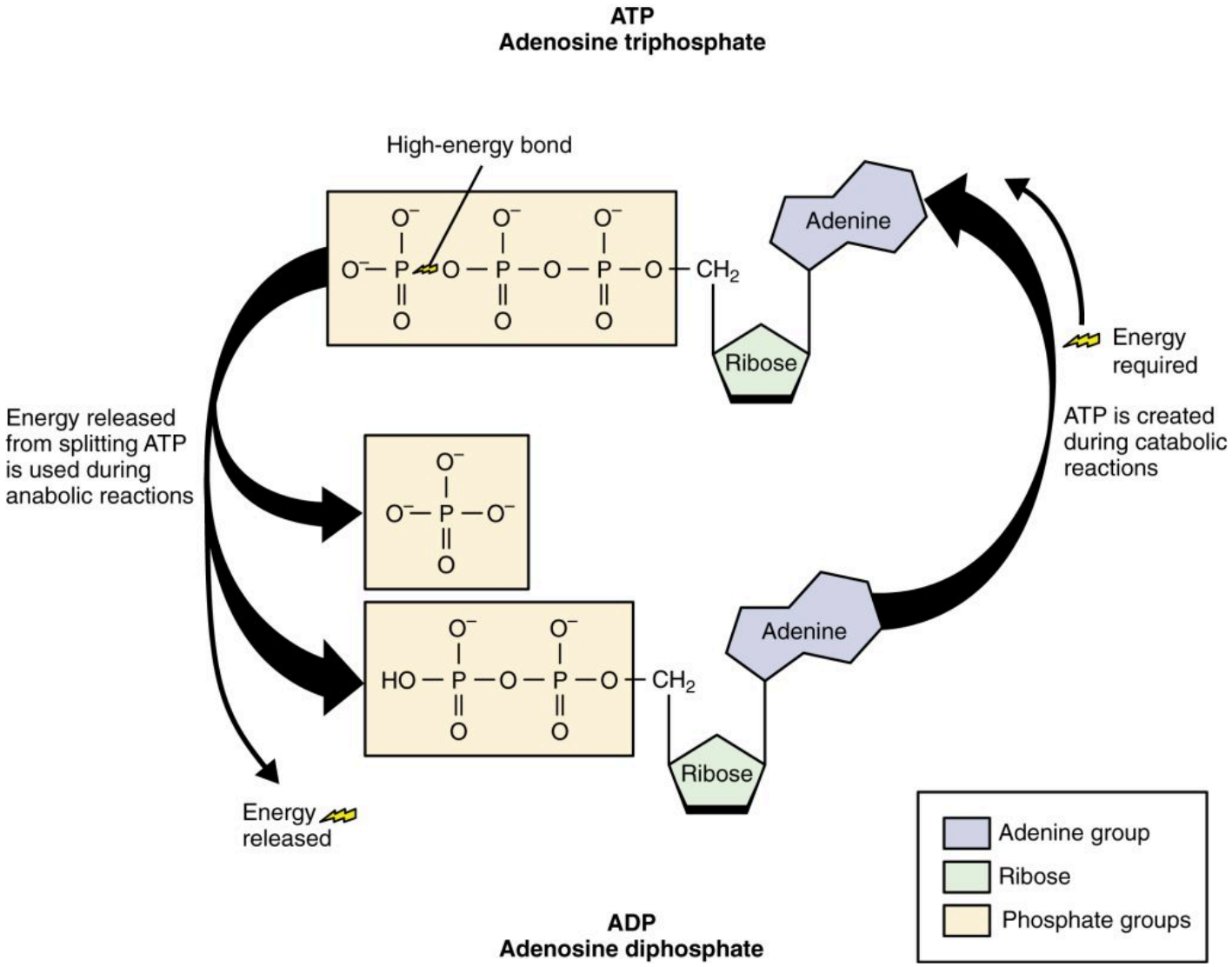


Figure 2.29 Structure of the ATP Molecule

Video

Watch the video "Biomolecules (Updated 2023)" below to learn about the four major types of biomolecules—carbohydrates, lipids, proteins, and nucleic acids—and their roles in living organisms.[17]

17. Amoeba Sisters. (2023, July 30). *Biomolecules (Updated 2023)* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=1Dx7LDwINLU

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Inorganic Compounds

Water

As much as 70% of an adult's body weight is water. This water is contained both inside and outside the cells that make up tissues and organs. Water has several important roles in the body, including the following:

- Lubricant. Water is a major component of many of the body's lubricating fluids. Just as oil lubricates the hinge on a door, water lubricates the body joints, helps the lungs expand and recoil with breathing, keeps food moving through the digestive tract, and allows the abdominal organs to stay friction-free.
- Cushion. Water is also used as a cushion to protect structures throughout the body. It protects cells and organs from physical trauma, cushions the brain within the skull, and even protects a developing fetus in the mother's uterus.
- Heat Regulator: In the body, water acts as a **heat sink** by absorbing the heat generated by chemical reactions without greatly increasing the body's temperature. Water stored in the body helps keep the body temperature cool when the environmental temperature soars. This cooling effect happens as warm blood from the body's core flows to the blood vessels just under the skin and is transferred to the environment. At the same time, sweat glands release warm water as sweat. As the water evaporates into the air, it carries away heat, and cooler blood circulates back to the body's core.
- Component of Liquid Mixtures: A **mixture** is a combination of two or more

substances that maintain their own chemical identity and are not chemically bonded into a larger substance. As an example, if you stir flour and sugar together in a bowl, they form a mixture but do not bond to form a new compound. There are three types of liquid mixtures that contain water as a key component: solutions, colloids, and suspensions.

Water in Solutions

For cells in the body to survive, they must be kept moist in a water-based liquid called a solution. A **liquid solution** consists of a substance called a **solute** dissolved into a **solvent** (liquid). An important characteristic of solutions is that they are **homogeneous**, meaning the solute molecules are distributed evenly throughout the solution. For example, if you stir sugar into a glass of water, the sugar (solute) dissolves into sugar molecules separated by water molecules (the solvent). The ratio of sugar molecules to water molecules on the left side of the glass is the same as the ratio of sugar molecules to water molecules on the right side of the glass. If you were to add more sugar, the ratio of sugar molecules to water molecules would increase, but the distribution of molecules would still be even.

Water is the most abundant solvent in the body. Essentially all of the body's chemical reactions occur among compounds dissolved in water. For this reason, water is considered the **universal solvent**, and it is believed that life cannot exist without water. Because water molecules are polar molecules, with regions of positive and negative electrical charge, water readily dissolves ionic compounds and polar covalent compounds. These types of compounds are referred to as **hydrophilic** ("water-loving"). Nonpolar molecules do not readily dissolve in water and are called **hydrophobic** ("water-fearing"). For example, sugar dissolves in water because sugar molecules contain regions of hydrogen-oxygen polar bonds, making it hydrophilic.

Concentrations of Solutes

The concentration of a solute is the number of particles of that solute in a given space. For example, when measuring blood glucose in the body, the concentration is measured in milligrams (mg) of glucose per deciliter (dL) of blood, which in a healthy adult is about 70-100 mg/dL.

Colloids

A **colloid** is a mixture that is like a heavy solution. The solute particles consist of tiny clumps of molecules that are large enough to make the liquid mixture look opaque because the particles are large enough to scatter light. For example, blood, mucus, tears, and breast milk are all examples of colloids in the human body.

Suspension

A **suspension** is a liquid mixture in which a heavier substance is suspended temporarily in a liquid, but over time, the substance settles out. This separation of particles from a suspension is called **sedimentation**.

An example of sedimentation in the human body is a diagnostic blood test called the sedimentation rate. This test measures how quickly red blood cells in a test tube settle out of the watery portion of blood (known as **plasma**) over a set period of time. Rapid sedimentation of blood cells does not normally happen in a healthy person, but medical conditions producing inflammation cause the red blood cells to clump together and settle to the bottom of the test tube more quickly than normal. Therefore, an elevated sedimentation rate indicates inflammation is occurring in the body.

Acids and Bases

Acids and bases, like salts, dissolve in water into ions in the human body. Acids and bases can change the properties of the solutions in which they are dissolved.

Acids

An **acid** is a hydrogen-containing substance that releases hydrogen ions (H^+) in a solution. Because a hydrogen atom has just one proton and one electron, a positively charged hydrogen ion is simply a proton. This solitary proton is very likely to participate in chemical reactions.

Strong acids are compounds that release all their H^+ in a solution, meaning they ionize completely. For example, hydrochloric acid (HCl) that is released from cells in the

lining of the stomach is a strong acid because it releases all of its H^+ in the stomach's watery environment. This strong acid aids in digestion and kills ingested microbes.

Weak acids do not ionize completely, meaning some of their hydrogen ions remain bonded within a compound in solution. An example of a weak acid is vinegar (acetic acid), which is called acetate after it gives up a proton (H^+).

Bases

A **base** is a molecule in a solution that accepts hydrogen ions (H^+) already present in the solution or releases hydroxyl ions (OH^-). The hydroxyl ions (also known as hydroxide ions) combine with H^+ to form a water molecule, thereby removing H^+ and reducing the solution's acidity.

Strong bases release most or all of their hydroxyl (OH^-) ions. Weak bases release only some hydroxyl ions or absorb only a few H^+. An example of a base in the human body is bicarbonate (HCO_3^-), which is secreted by the pancreas into the small intestine to neutralize stomach acid. Bicarbonate accepts some of the H^+ protons, thereby reducing the acidity of the solution. If bicarbonate were not released, food mixed with hydrochloric acid would burn the small and large intestines.

Often, the word alkaline is used to describe a solution that contains a base or is basic.

See Figure 2.30[18] for an illustration of acids and bases.

18. OpenStax College. (2013). *215 Acids and bases-01* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:215_Acids_and_Bases-01.jpg

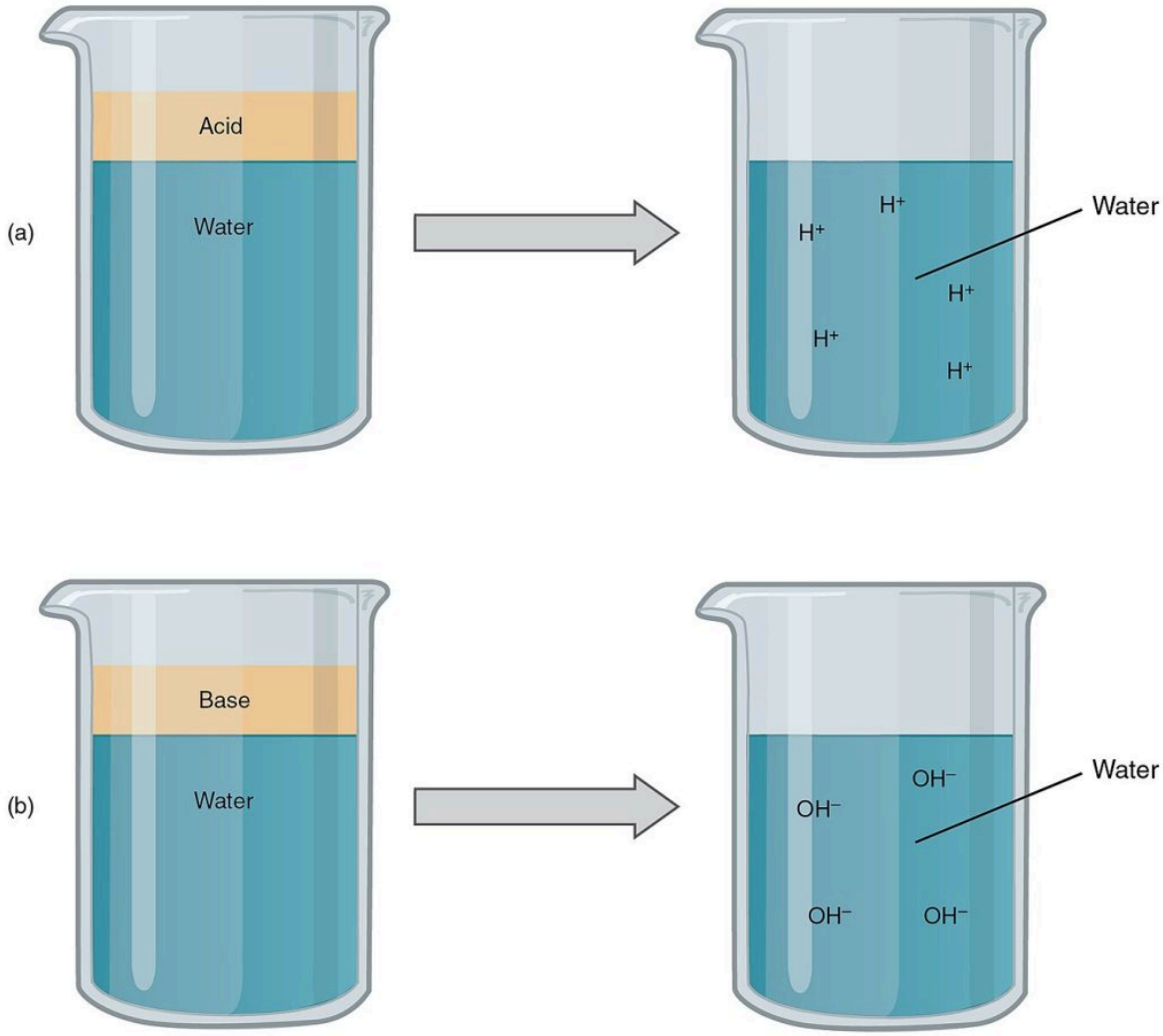


Figure 2.30 Acids and Bases. (a) In a Watery Solution, an Acid Dissociates into Hydrogen Ions (H^+) and Anions—Nearly Every Molecule of a Strong Acid Dissociates, Producing a High Concentration of H^+; (b) In a Watery Solution, a Base Dissociates into Hydroxyl Ions (OH^-) and Cations—Nearly Every Molecule of a Strong Base Dissociates, Producing a High Concentration of OH^-

pH

The acidity or alkalinity of a solution is indicated by its **pH**, a measure of the concentration of hydrogen (H^+) ions. The pH scale usually goes from 0 to 14, with numbers less than 7 being acids, 7 being neutral (neither acidic nor basic), and numbers greater than 7 being bases. Smaller numbers on the pH scale are more acidic or have a greater concentration of H^+. For example, a solution with a pH of 0 is a very strong acid, whereas a solution with a pH of 6 would be a weak acid. Larger numbers on the pH scale are more basic (alkaline) and have a lower concentration of H^+. A solution with a pH of

14 would be a very strong base compared to a solution with a pH of 8, which would be a weak base.

A change of one unit on the pH scale represents a change in the concentration of hydrogen ions by a factor of 10, and a change of two units represents a change in the concentration of hydrogen ions by a factor of 100. Thus, small changes in pH represent large changes in the concentration of hydrogen ions.

Pure water is neutral. It is neither acidic nor basic and has a pH of 7.0. The blood in your veins is slightly alkaline (pH = 7.4). The environment in your stomach is highly acidic (pH = 1 to 2), and saliva is a weak acid (pH = 6.3 to 6.6). The pH of semen is alkaline (pH = 7.2 to 8).

See Figure 2.31[19] for an illustration of the pH scale.

19. OpenStax College. (2013). *216 pH scale-01* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:216_pH_Scale-01.jpg

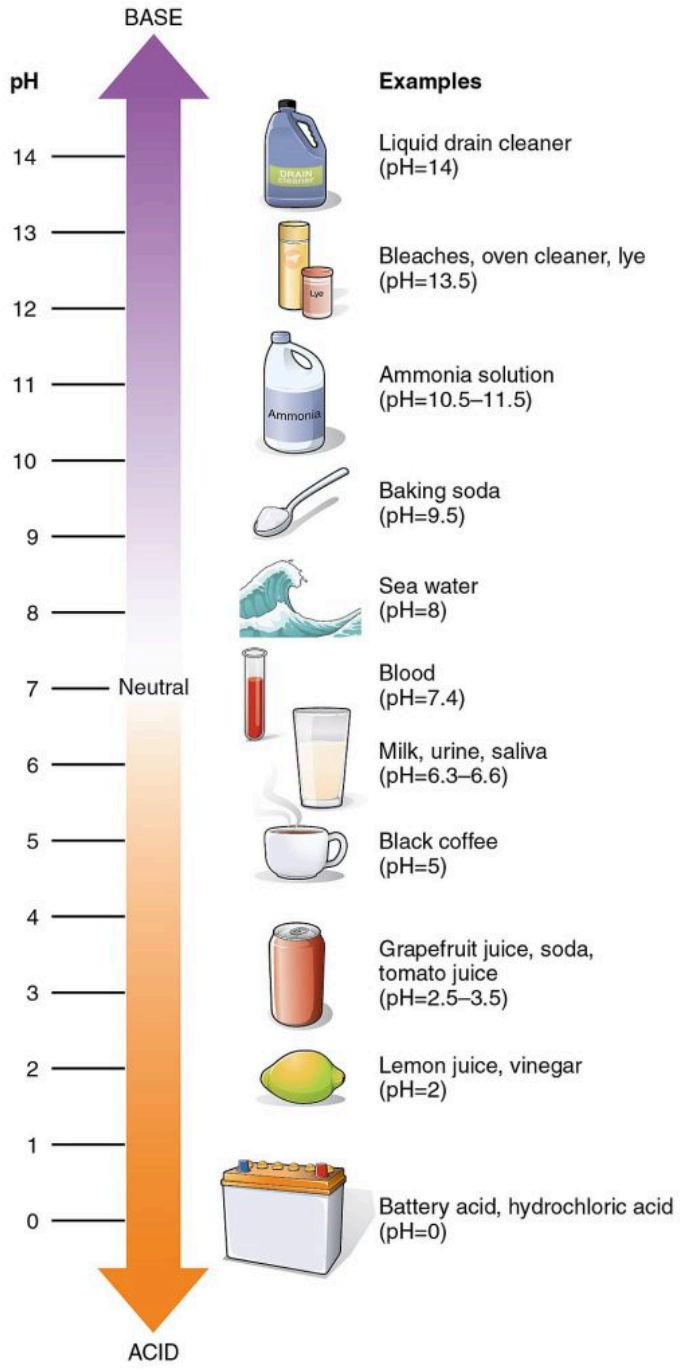


Figure 2.31 The pH Scale

Blood Buffer

The pH of human blood normally ranges from 7.35 to 7.45. All cells of the body depend on homeostatic regulation of this acid–base balance for normal functioning. Maintaining a stable pH range is critical because fluctuations where the blood becomes too acidic or too alkaline disrupt cell and protein function and can lead to seizures, coma, or even

death. At this slightly basic pH, blood can reduce the acidity that results from carbon dioxide (CO_2) being constantly released into the bloodstream by the cells of the body. The body also has several homeostatic mechanisms for regulating acid-base balance, such as exhaling CO_2 while breathing, excreting hydrogen or bicarbonate ions in the urine, and using buffers in body fluids.

A **buffer** refers to a chemical system within the body that is primarily composed of a weak acid and a weak base. Buffers attempt to maintain a stable pH level by neutralizing added acids and bases. For example, if the blood pH drops slightly below 7.35 and becomes more acidic, the blood buffer acts as a weak base, and bicarbonate (HCO_3^-) binds to the excess hydrogen ions. In contrast, if blood pH rises slightly above 7.45, the blood buffer acts as a weak acid, and the carbonic acid (H_2CO_3) contributes hydrogen ions to make the blood more acidic.[20]

Video

Watch the video "Macromolecules Explained (Carbohydrates, Lipids, Proteins, Nucleic Acids)" below to learn more about the major macromolecules found in the body.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

20. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

2.5 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

2.6 Glossary

Acid: A hydrogen-containing substance that releases hydrogen ions (H+) in a solution. (**Chapter 2.4**)

Adenosine triphosphate (ATP): A molecule that acts as the primary energy carrier in cells. It consists of the nitrogenous base adenine, the sugar ribose, and three phosphate groups. (**Chapter 2.4**)

Adipose tissue: A type of connective tissue that stores energy in the form of fat. (**Chapter 2.4**)

Amino acids: The building blocks of proteins, consisting of a central carbon atom bonded to an amino group (-NH_2), a carboxyl group (-COOH), a hydrogen atom, and a variable side chain (R group) that determines their properties. (**Chapter 2.4**)

Anion: A negative ion. (**Chapter 2.3**)

Atomic number: The number of protons in the nucleus of an atom of that element. It uniquely identifies the element. (**Chapter 2.2**)

Atoms: The smallest amount of an element. (**Chapter 2.2**)

Base: A molecule in a solution that accepts hydrogen ions (H+) already present in the solution or releases hydroxyl ions (OH–). (**Chapter 2.4**)

Biomolecules: Organic molecules that are essential for life, including carbohydrates, proteins, lipids, and nucleic acids. (**Chapter 2.4**)

Bond: A weak or strong electrical attraction that holds atoms in the same area. (**Chapter 2.3**)

Buffer: A solution that resists changes in its pH when small amounts of an acid or base are added to it. (**Chapter 2.4**)

Carbohydrates: Provide energy to the body through glucose. (**Chapter 2.4**)

Catalyst: A substance that increases the rate and force at which atoms, ions, and molecules collide, thereby increasing the chances that the electrons in their valence shells will interact. (**Chapter 2.4**)

Cation: A positive ion. (**Chapter 2.3**)

Cellulose: A component of plant cell walls; commonly known as “fiber” in the diet. (**Chapter 2.4**)

Colloid: A mixture that is like a heavy solution. (Chapter 2.4)

Compound: A substance composed of two or more elements joined by chemical bonds. (Chapter 2.2, Chapter 2.3)

Covalent bond: A type of bond that forms when electrons are shared between two elements. (Chapter 2.3)

Dehydration synthesis: The elimination of water to combine molecules. (Chapter 2.4)

Disaccharides: When two monosaccharides join together with a covalent bond. (Chapter 2.4)

Double bond: A type of bond in which two pairs of electrons are shared. (Chapter 2.3)

Double helix: Two strands of nucleotides wind around each other like a spiral staircase. (Chapter 2.4)

Electrons: Very small, negatively charged particles found outside of the atom's nucleus. They have no mass and a charge of -1. (Chapter 2.2)

Electron shell: A layer of electrons that circle the nucleus at a distinct energy level. (Chapter 2.2)

Electron transfer: The movement of electrons from one element to another. (Chapter 2.3)

Element: A pure substance that cannot be created or broken down by ordinary chemical means or transformed chemically into different substances. (Chapter 2.2)

Enzyme: A catalyst that helps speed up chemical reactions. (Chapter 2.4)

Essential amino acids: Amino acids that cannot be made by the body and must be consumed in the diet. (Chapter 2.4)

Genes: A distinct sequence of nucleotides forming part of a chromosome, resulting in a unit of heredity that is transferred to offspring. (Chapter 2.4)

Glucose: A simple sugar. (Chapter 2.4)

Glycogen: The storage form of glucose in humans and other animals, which is made up of monomers (building blocks) of glucose bonded together into long chains. (Chapter 2.4)

Heat sink: A device or material that absorbs and dissipates heat from an object to prevent overheating. (Chapter 2.4)

Homogeneous: Solutes that are distributed evenly throughout a solution. (Chapter 2.4)

Hydrogen bond: A weak to moderate attractive force that occurs between a hydrogen atom, which is covalently bonded to a more electronegative atom (like oxygen, nitrogen, or fluorine), and another electronegative atom with a lone pair of electrons. (Chapter 2.3)

Hydrophilic: A substance or molecule that has an affinity for water. (Chapter 2.4)

Hydrophobic: A term used to describe substances that repel or do not dissolve in water. (Chapter 2.4)

Inorganic compounds: Compounds that do not contain carbon-hydrogen bonds and rarely contain carbon. (Chapter 2.4)

Ion: An atom that does not contain equal numbers of protons and electrons. (Chapter 2.3)

Ionic bond: A chemical bond formed between a cation and an anion. (Chapter 2.3)

Ionic compounds: Compounds composed of ions; also known as salts. (Chapter 2.3)

Isotope: Different forms of an element, distinguished from one another by different numbers of neutrons. (Chapter 2.2)

Lipids: A diverse group of organic molecules that are primarily hydrophobic and insoluble in water. They include fats, oils, phospholipids, steroids, and waxes, and they play essential roles in energy storage, cell membrane structure, hormone production, and insulation. (Chapter 2.4)

Liquid solution: Consists of a substance called a solute dissolved in a solvent. (Chapter 2.4)

Mass number: The total number of protons and neutrons in the element's nucleus. (Chapter 2.2)

Matter: Anything that takes up space and has mass. (Chapter 2.2)

Molecule: A stable grouping of two or more atoms held together by chemical bonds. (Chapter 2.3)

Monosaccharides: Simple sugars, the most common of which is glucose. (Chapter 2.4)

Mixture: A combination of two or more substances that maintain their own chemical identity and are not chemically bonded into a larger substance. (Chapter 2.4)

Neutrons: Found in the center or nucleus of an atom, and do not have a charge, so they are neutral. They have a mass of 1. (Chapter 2.2)

Nonpolar covalent bond: A type of bonds that form between two atoms of the same element or between different elements that share the electrons equally. (Chapter 2.3)

Nucleotides: The basic building block of nucleic acids like DNA and RNA. (Chapter 2.4)

Octet rule: A rule that states that an atom will give up, gain, or share electrons with another atom so that it ends up with eight electrons in its own valence shell. (Chapter 2.2)

Organic compounds: Molecules that contain both carbon and hydrogen. (Chapter 2.4)

Peptide: A very short chain of amino acids. (Chapter 2.4)

Peptide bond: A covalent bond between two amino acids that forms by dehydration synthesis. (Chapter 2.4)

Periodic table: A chart that organizes all known chemical elements based on their atomic number, electron configuration, and recurring chemical properties. (Chapter 2.2)

pH: A measure of the concentration of hydrogen (H+) ions. (Chapter 2.4)

Phospholipids: The main component of cell membranes, which protect cells from environmental damage and allow for cellular processes. (Chapter 2.4)

Plasma: Watery portion of the blood. (Chapter 2.4)

Polar covalent bonds: A type of bond formed between two or more different elements that do not share electrons equally. (Chapter 2.3)

Polypeptides: Strands containing fewer than 100 amino acids. (Chapter 2.4)

Polysaccharide: A long chain of monosaccharides linked by covalent bonds. (Chapter 2.4)

Prostaglandin: A lipid compound derived from fatty acids that acts as a signaling molecule in the body. (Chapter 2.4)

Protein: An organic molecule made up of building blocks called amino acids that are linked by peptide bonds. (Chapter 2.4)

Protons: Positively charged particles found in the nucleus or center of the atom. (Chapter 2.2)

Radioactive isotope: Also known as a radioisotope, an atom with an unstable nucleus that undergoes radioactive decay, emitting radiation in the form of alpha particles, beta particles, or gamma rays. This process occurs as the atom seeks a more stable energy state. (**Chapter 2.2**)

Ribonucleic acid (RNA): A single-stranded nucleic acid that plays a crucial role in the synthesis of proteins. (**Chapter 2.4**)

Saturated fats: A type of fat in which all the carbon atoms in the fatty acid chains are connected by single bonds, meaning they are "saturated" with hydrogen atoms. (**Chapter 2.4**)

Sedimentation: Separation of particles from a suspension. (**Chapter 2.4**)

Single bond: A type of bond in which two atoms share one pair (or two individual) of electrons. (**Chapter 2.3**)

Solute: A substance that is dissolved in a solvent to form a solution. (**Chapter 2.4**)

Solvent: A substance, typically a liquid, that dissolves a solute to form a solution. (**Chapter 2.4**)

Starch: The storage form of glucose in plants, which is relatively easy for humans to digest. (**Chapter 2.4**)

Steroids: A class of lipids characterized by their hydrophobic nature and insolubility in water. They have a distinct chemical structure consisting of four interconnected rings of carbon atoms. (**Chapter 2.4**)

Suspension: A liquid mixture in which a heavier substance is suspended temporarily in a liquid, but over time, the substance settles out. (**Chapter 2.4**)

Trans fats: A type of unsaturated fat that has been artificially modified through a process called hydrogenation, which adds hydrogen to liquid oils to make them more solid and shelf-stable. (**Chapter 2.4**)

Triglyceride: A type of lipid (fat) composed of one glycerol molecule and three fatty acid chains. It is the main form of stored fat in the body and a major source of energy. (**Chapter 2.4**)

Triple bond: A type of bond in which three pairs of electrons are shared between atoms. (**Chapter 2.3**)

Universal solvent: A term commonly used to describe water due to its ability to dissolve a wide variety of substances. (**Chapter 2.4**)

Unsaturated fats: A type of fat in which the fatty acid chains contain one or more

double bonds between carbon atoms, meaning they are not fully saturated with hydrogen atoms. (**Chapter 2.4**)

Valence shell: An atom's outermost electron shell. (**Chapter 2.2**)

PART III

CHAPTER 3 STRUCTURE AND FUNCTION OF CELLS

3.1 Introduction to Cells

Chapter Competency

Characterize the basic structure and functions of the cell and its parts.

Learning Objectives

- Address major components of the cell.
- Identify the major functional components of the cell.
- Identify the major transport mechanisms of the cell membranes.
- Illustrate the relationships among the organelles of a cell.
- Illustrate the cell cycle.

Imagine you are working as a medical laboratory technician analyzing a patient's blood sample. Under the microscope, you observe cells that appear abnormal in size, shape, or number. Additional test results suggest problems with energy production, fluid balance, or uncontrolled cell growth. To understand what these findings may indicate, you must first understand how cells are structured, how they function, and how they maintain homeostasis.

Cells are the smallest independently functioning units of life. Each cell is a dynamic system with specialized components working together to sustain function and survival. The cell membrane controls what enters and exits through various transport mechanisms, helping maintain balance within the cell. Inside the cell, organelles such as the nucleus, mitochondria, ribosomes, and endoplasmic reticulum interact to regulate activity, produce energy, synthesize proteins, and support cellular function.

Cells also follow a precise cycle of growth and division, allowing the body to develop, repair, and maintain itself. In this chapter, you will explore the cell's major components, transport systems, organelles, and cell cycle. By mastering these concepts, you will gain a deeper understanding of the microscopic processes that sustain life and support the function of tissues, organs, and body systems.

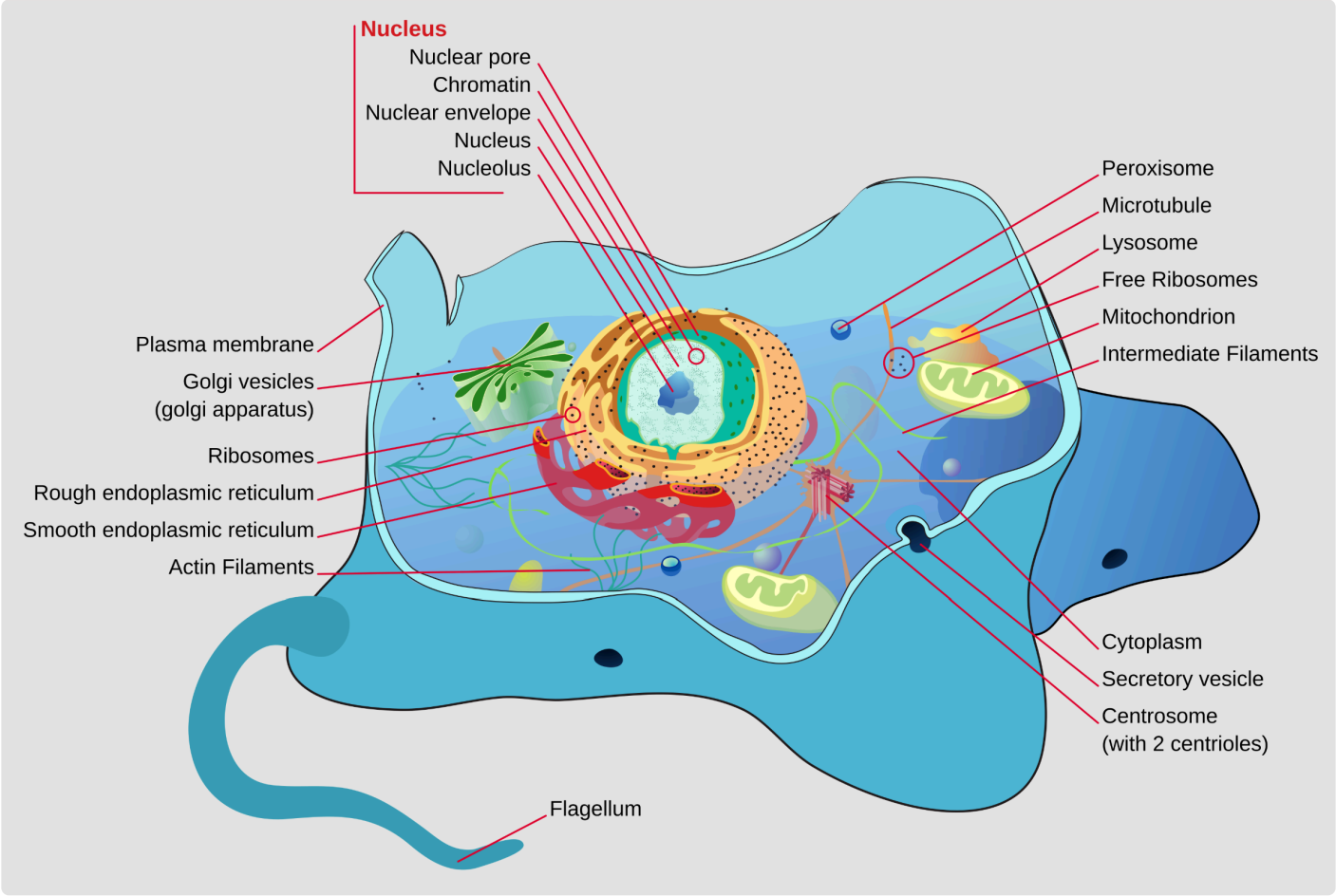


Figure 3.1 Structure of an Animal Cell

1

1. Ruiz, M. (2006). *Animal cell structure en* [Diagram]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Animal_cell_structure_en.svg

3.2 Structure and Composition of the Cell Membrane

Structure and Composition of the Cell Membrane

All living cells in the human body have a cell membrane surrounding them. Just as the outer layer of your skin separates your body from the environment, the **cell membrane** (also known as the **plasma membrane**) separates the inside of the cell from the outside of the cell, providing a protective barrier around the cell and regulating what can go into or out of the cell.

The cell membrane is a very flexible bilayer (meaning it has two layers) made up of molecules called **phospholipids**. A single phospholipid molecule has a phosphate group on one end, called the "head," and two side-by-side chains of fatty acids that make up the "tails." See Figure 3.2[1] for an illustration of a phospholipid molecule.

1. CNX OpenStax. (2016). *Figure 05 01 02* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Figure_05_01_02.jpg

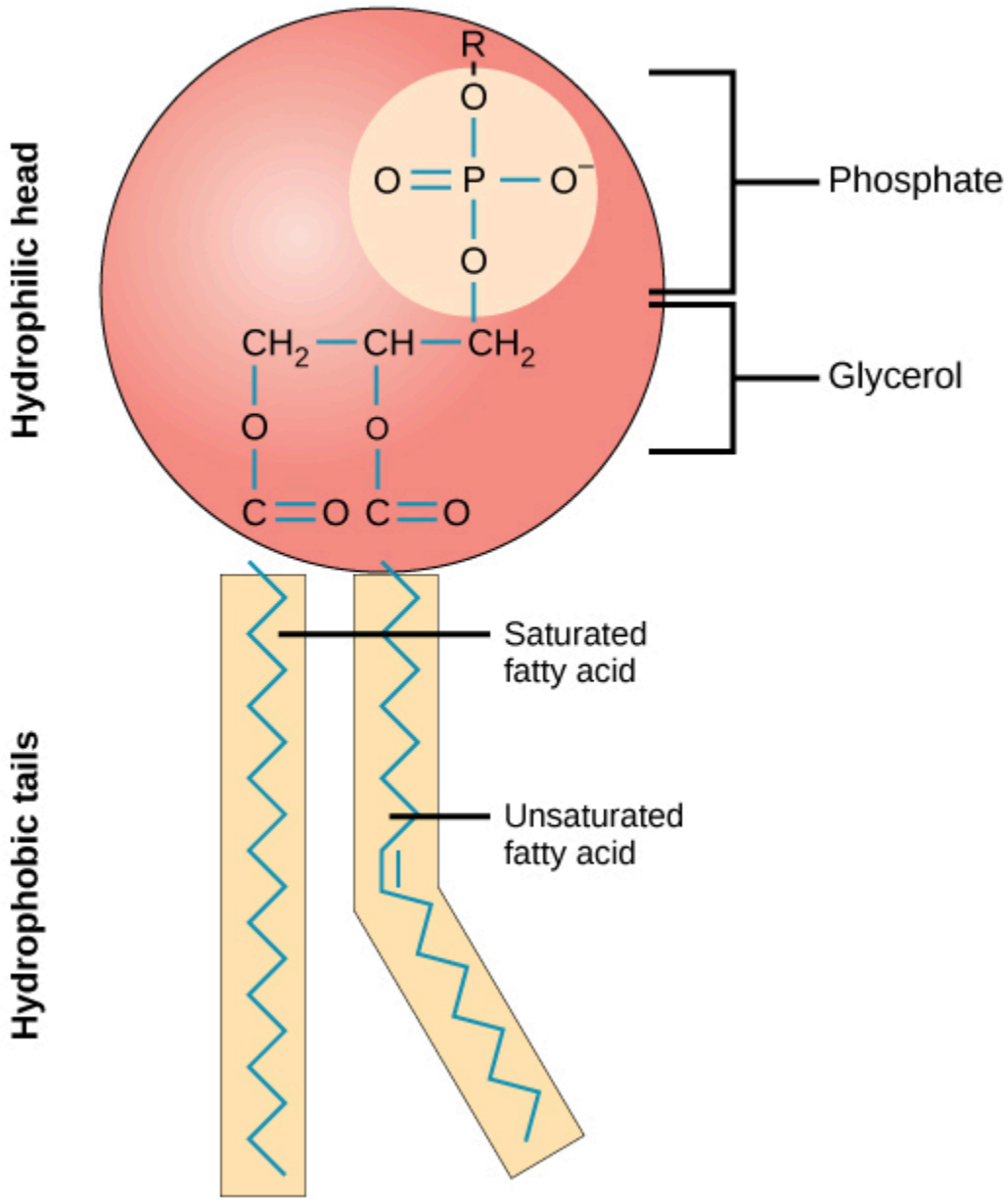


Figure 3.2 Phospholipid Structure

The phosphate "head" is negatively charged, making it polar and **hydrophilic**, meaning "water-loving or attracted to water." The phosphate heads are attracted to the watery environments outside of the cell (**extracellular fluid**) and inside of the cell (**intracellular fluid** or **cytosol**), so they naturally organize themselves to be in contact with these areas.

The lipid tails are uncharged, making them nonpolar and are **hydrophobic**, meaning "water fearing or repelling to water." Because of this, the fatty acid tails naturally organize themselves away from the watery environments of the extracellular and intracellular

fluids and point to the inside of the cell membrane. See Figure 3.3[2] for an illustration of the phospholipid bilayer.

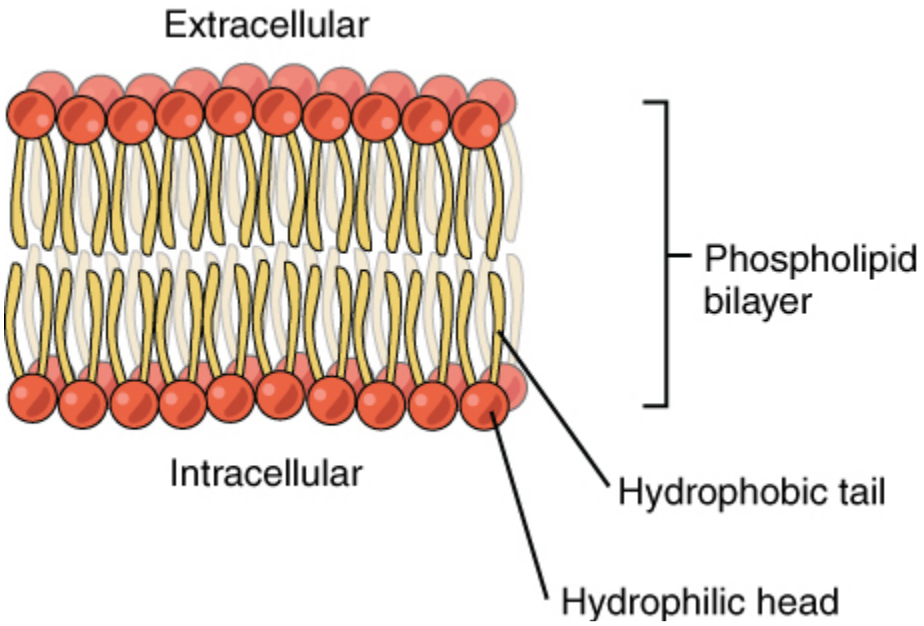


Figure 3.3 Phospholipid Molecule

Phospholipids are considered **amphipathic** molecules because they contain both a hydrophilic and a hydrophobic region. Another great example of an amphipathic substance is soap. Soap works to remove oil and grease stains because of its amphipathic properties. The hydrophilic portion can dissolve in water, while the hydrophobic portion can trap grease that can then be washed away.

Membrane Proteins

The phospholipid bilayer forms the basic structure of the cell membrane, but it also contains many types of proteins on and within the membrane. Two types of proteins that are commonly associated with the cell membrane are integral proteins and peripheral proteins, as shown in Figure 3.4.[3]

2. OpenStax. (2016). *0302 Phospholipid bilayer* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0302_Phospholipid_Bilayer.jpg
3. OpenStax. (2016). *0303 Lipid bilayer with various components* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0303_Lipid_Bilayer_With_Various_Components.jpg

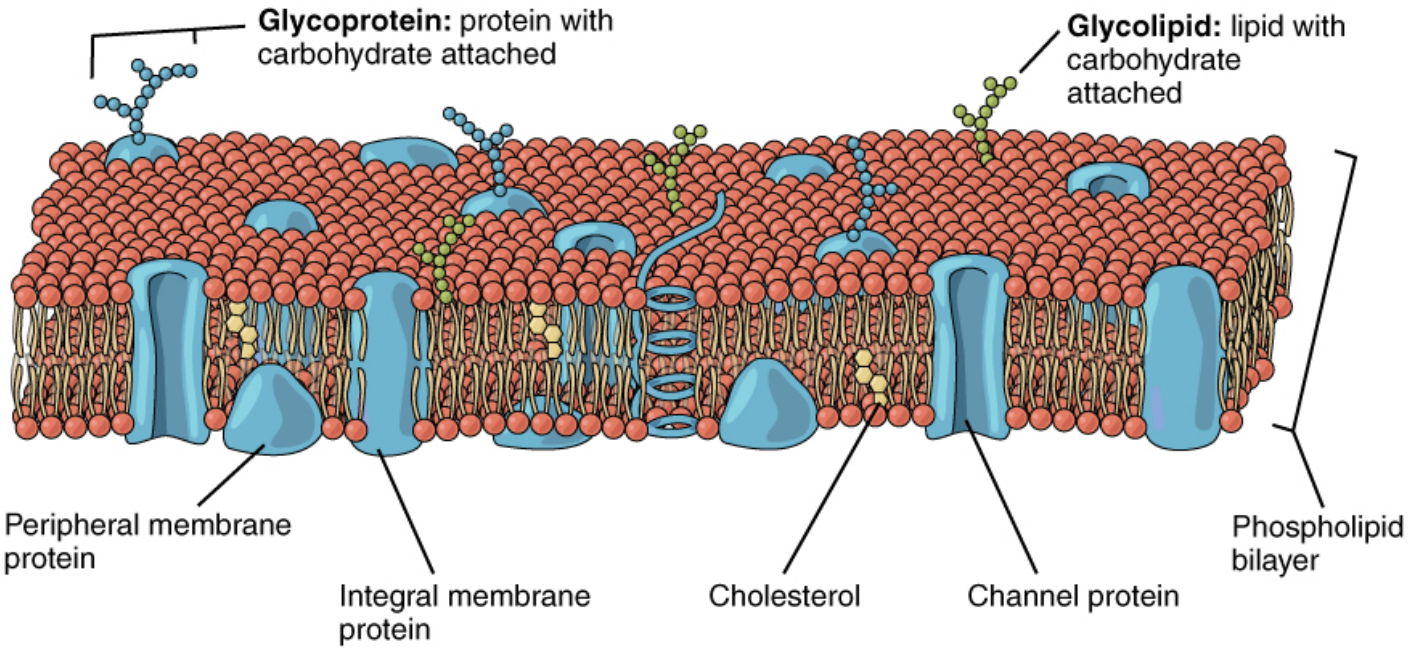


Figure 3.4 Integral and Peripheral Proteins in the Cell Membrane

Integral proteins are proteins that are embedded in the membrane. They include the following proteins:

- **Carrier proteins**: Proteins that change their shape to move substances across the cell membrane.
- **Channel proteins**: Proteins that selectively allow materials, such as certain ions, to pass into or out of the cell.
- **Cell recognition proteins**: Proteins that mark a cell's identity so that it can be recognized by other cells.
  - A **receptor** is a type of recognition protein that can bind a specific molecule outside of the cell, and this binding can cause a chemical reaction inside the cell.
  - A **ligand** is a molecule that binds to and activates a receptor.
- **Dual receptor** and **ion channel proteins**: Some integral proteins are receptors and channel proteins. For example, when a dopamine molecule binds to a dopamine receptor protein, a channel in the cell membrane opens to allow certain ions to flow into the cell.
- **Glycoproteins**: Proteins that have carbohydrate molecules attached that extend **extracellularly** (outside of the cell). The attached carbohydrate molecules on glycoproteins help with cell recognition.

Peripheral proteins are typically only found on the inner or outer surface of the cell

membrane, but can also be attached to the internal or external surface of an integral protein. These proteins usually perform a specific function for the cell. For example, some peripheral proteins on the surface of intestinal cells break down nutrients to sizes that can pass through the cells and into the bloodstream.[4]

Video

Watch the video "Cell Membrane Explained (Structure and Function)" below to learn more about the structure and function of the cell membrane.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

4. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

3.3 Transport Across the Cell Membrane

One of the great wonders of the cell membrane is its ability to regulate the amount of substances inside the cell. These substances include the following:

- **Ions**, such as calcium (Ca^{2+}), sodium (Na^{+}), potassium (K^{+}), and chloride (Cl^{-})
- **Nutrients**, including sugars, fatty acids, and amino acids
- **Wastes** that must leave the cell, such as carbon dioxide (CO_2)

The membrane's phospholipid bilayer provides the first level of control. The phospholipids are tightly packed together, and the membrane has a hydrophobic (nonpolar) interior. This allows the membrane to be **selectively permeable** (or **semipermeable**) and only allows small, nonpolar, fat-soluble materials to move across it. Some examples of these materials are other lipids, oxygen, and carbon dioxide gases, and alcohol.

Water-soluble materials, such as glucose, amino acids, and electrolytes, need assistance to cross the membrane because they are repelled by the hydrophobic tails in the middle of the cell membrane.

All substances that move through the membrane do so by either passive or active transport.

- **Passive transport** is the movement of substances across the membrane without the use of energy. For example, when riding a bike down a hill, no energy is needed to move the bike. You can coast down the hill without pedaling the bike. This is similar to the passive transport of substances across the membrane. No input of energy is required to move the substance across the membrane.
- **Active transport** is the movement of substances across the membrane using an energy molecule called adenosine triphosphate (ATP). For example, riding a bike uphill requires energy. You have to pedal the bike to get up the hill. This is similar to active transport of substances across the membrane. Energy is also required to move the substance across the membrane.

Passive Transport

To understand how substances move passively (without energy provided by the cell) across a cell membrane, it is necessary to understand concentration gradients and diffusion.

A **concentration gradient** is the difference in concentration (amount) of a substance from one area to another. Molecules are always in motion and will move from where they are more concentrated to where they are less concentrated until they are equally distributed. When molecules move from an area of greater concentration to a lower concentration, they are said to move down their concentration gradient.

Diffusion

Diffusion (or **simple diffusion**) is the movement of a substance from an area of higher concentration to an area of lower concentration. For example, imagine being inside a closed bathroom. If a bottle of perfume were sprayed, the scent molecules would naturally diffuse from the spot where they left the bottle to all corners of the bathroom, and this diffusion would continue until all of the perfume molecules were evenly distributed. Another example of diffusion is when a spoonful of sugar is placed in a cup of tea. Eventually, the sugar will diffuse throughout the tea until it is evenly distributed. See Figure 3.5[1] for an illustration of diffusion of small molecules across a cell membrane, from an area of higher concentration to lower concentration, over a period of time.

1. OpenStax College. (2016). *0305 Simple diffusion across plasma membrane* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0305_Simple_Diffusion_Across_Plasma_Membrane.jpg

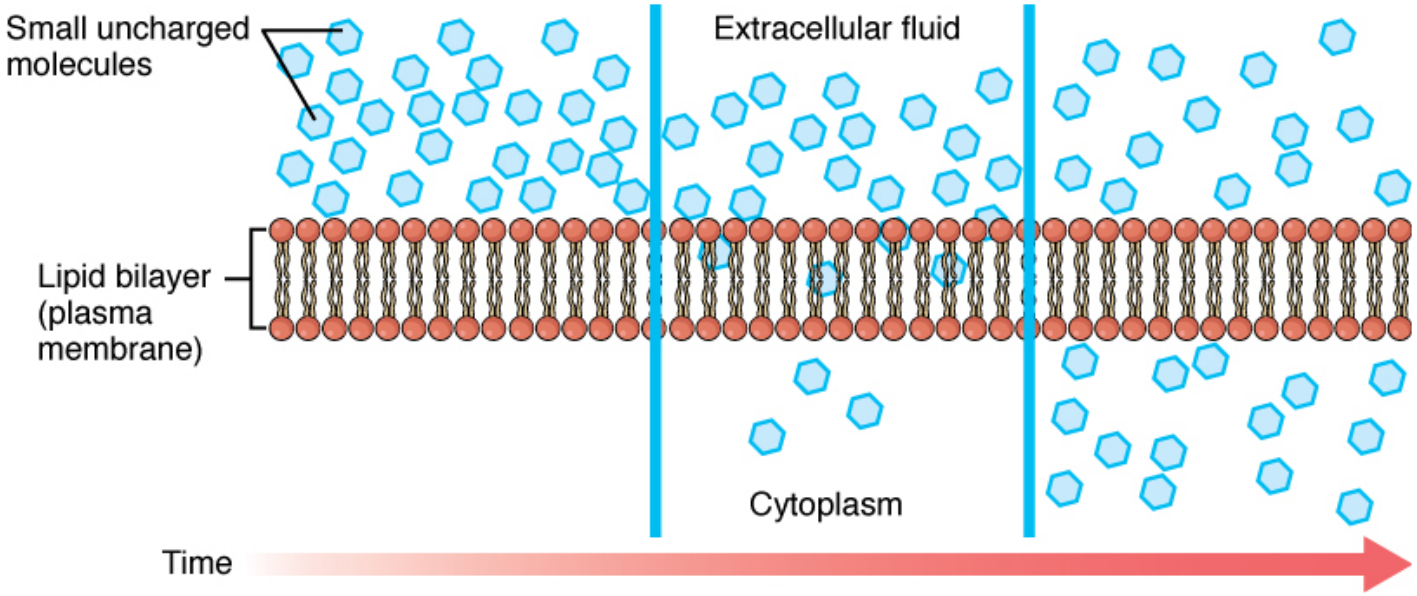


Figure 3.5 Diffusion

Heat increases the speed of diffusion. In both of the previous examples, if the room is warmer or the tea is hotter, diffusion occurs even faster. The human body has a body temperature around 98.6° F, which naturally helps diffusion occur within the body.

Substances that easily move across the selectively permeable cell membrane, such as oxygen (O_2) and carbon dioxide (CO_2), easily diffuse down their concentration gradient until they reach equilibrium or are evenly spread out. Oxygen (O_2) diffuses into cells because it is more concentrated outside of the cell, and carbon dioxide (CO_2) diffuses out of the cell because it is more concentrated inside. These are both examples of passive diffusion because no energy is required.

Very small polar molecules, such as water, can go through the cell membrane by simple diffusion because they are so small. However, large polar or ionic molecules, which are hydrophilic (water-loving), cannot easily cross the cell membrane via simple diffusion as they are repelled by the hydrophobic fatty acid tails inside the phospholipid bilayer. These molecules need assistance to get into the cell.

Facilitated diffusion is used for substances that cannot cross the cell membrane on their own due to their size, charge, and/or polarity. Carrier proteins and channel proteins are used for facilitated diffusion to help move substances across the membrane from a

high concentration to a low concentration. See Figure 3.6[2] for an illustration of facilitated diffusion.

2. OpenStax College. (2016). *0306 Facilitated diffusion* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0306_Facilitated_Diffusion.jpg

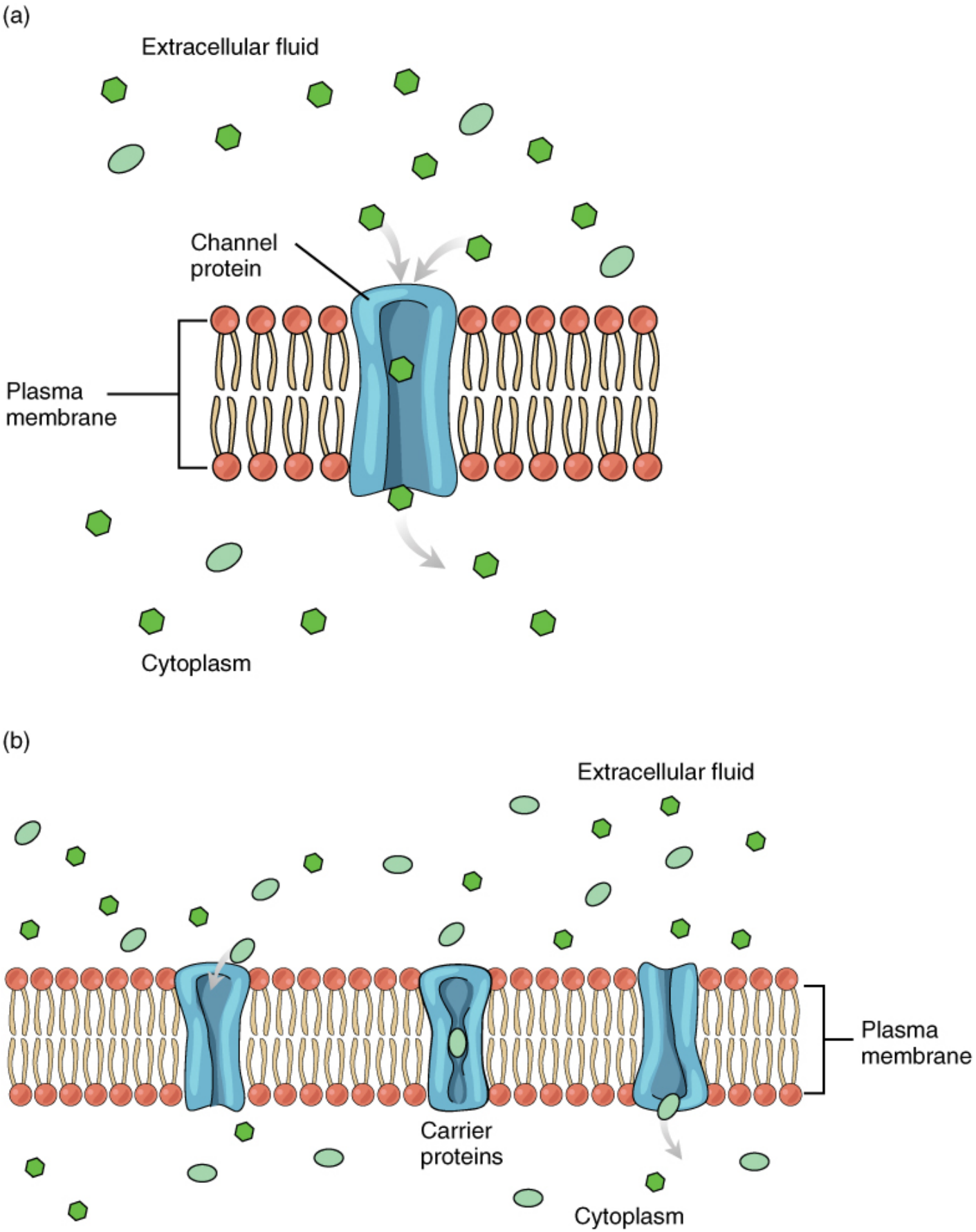


Figure 3.6 Facilitated Diffusion: (a) Channel Proteins and (b) Carrier Proteins

An example of a substance that uses facilitated diffusion to get into a cell via channel proteins is sodium. Even though sodium ions (Na^+) are highly concentrated outside of cells, they are charged, so they cannot pass directly through the cell membrane. Their diffusion is facilitated by proteins that form sodium channels (also called "pores").

An example of facilitated diffusion via a carrier protein is the movement of **glucose** (blood sugar) into the cell, where it is used to make ATP. Although glucose is more concentrated outside of a cell, it cannot cross the phospholipid bilayer by simple diffusion because it is both large and polar. A specialized carrier protein called a **glucose transporter** helps facilitate its diffusion into the cell.

There are many other substances that use facilitated diffusion to move into a cell (such as amino acids) or out of a cell (such as wastes). Because facilitated diffusion is a passive process, it does not require energy.

Video

Watch the video "Cell Transport" below to learn how materials move across the cell membrane through processes such as diffusion, osmosis, and active transport.[3]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Osmosis

Osmosis is the diffusion of water through a selectively permeable membrane from an

3. Amoeba Sisters. (n.d.). Cell transport [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=Ptmlvtei8hw

area of high concentration of water molecules to an area of low concentration of water molecules. In other words, water moves from a dilute or watery environment towards a concentrated ("saltier") environment, commonly referred to as "water follows salt." The less concentrated or dilute environment has more water and less solute present in its solution, whereas the concentrated solution has more solute dissolved in it. Water easily moves across cell membranes through protein channels or by simply slipping between the lipid tails of the membrane itself.

Isotonic Solutions

Because some cells cannot regulate the movement of water on their own, these cells must be in an environment where the concentration of solutes outside of the cells (in the extracellular fluid) is equal to the concentration of solutes inside the cells (in the cytosol or intracellular fluid). Solutions that have the same concentration of solutes as the concentration inside the cell are said to be **isotonic** (i.e., same or equal tension). When the cell is in an isotonic environment, water will enter and leave the cell at the same rate and there will be no overall net gain or loss of water. The cell maintains its normal shape and function.

An important part of homeostasis is to create an environment in which all of the body's cells are in an isotonic solution. Several organs in the body, particularly the kidneys, work to maintain this homeostasis.

Hypertonic and Hypotonic Solutions

When the concentration of solutes outside of the cell is different from the concentration of the solutes inside the cell, water will move from one side of the cell membrane to the other to try to equalize the two concentrations during **osmosis**.

A solution that has a higher concentration of solutes than another solution is said to be **hypertonic**, and water molecules tend to diffuse into a hypertonic solution. Cells in a hypertonic solution will shrivel (crenate) if too much water leaves the cell via osmosis. In contrast, a solution that has a lower concentration of solutes than another solution is said to be **hypotonic**, and water molecules tend to diffuse out of a hypotonic solution. Cells in a hypotonic solution will take on too much water and swell, with the risk of

eventually bursting (**lysing**). See Figure 3.7[4] for an illustration of the movement of water into and out of cells in isotonic, hypertonic, and hypotonic solutions.

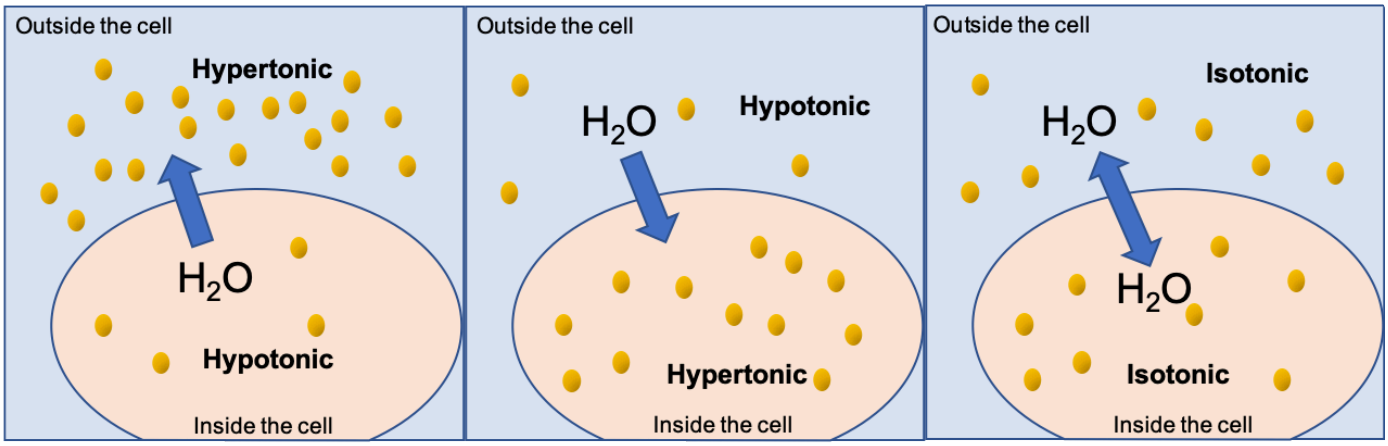


Figure 3.7 Movement of Water into and out of Cells in Hypertonic, Isotonic, and Hypotonic Environments

Clinical Connection

Intravenous fluids are commonly administered to hospitalized patients. It is important for nurses and health care providers to understand the effects of osmosis on the patient's cells as a result of the concentration of the administered fluids. For example, if a hypertonic intravenous solution is administered into a patient's bloodstream, water will move by osmosis out of their cells and into the bloodstream, causing the cells to shrivel. Conversely, if a hypotonic intravenous solution is administered, water will move by osmosis from the bloodstream into the cells, causing them to swell. These actions can be easily remembered with the phrase "water follows salt," meaning water will move from an area of lower concentration of solutes to an area of higher concentration of solutes. See Figure 3.8[5] for an illustration of the effects of the intravenous administration of hypertonic and hypotonic fluid on red blood cells.

4. Connectivid-D. (2021). *Cellular tonicity* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Cellular_Tonicity.png
5. CNX OpenStax. (2016). *Figure 05 02 07* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Figure_05_02_07.jpg

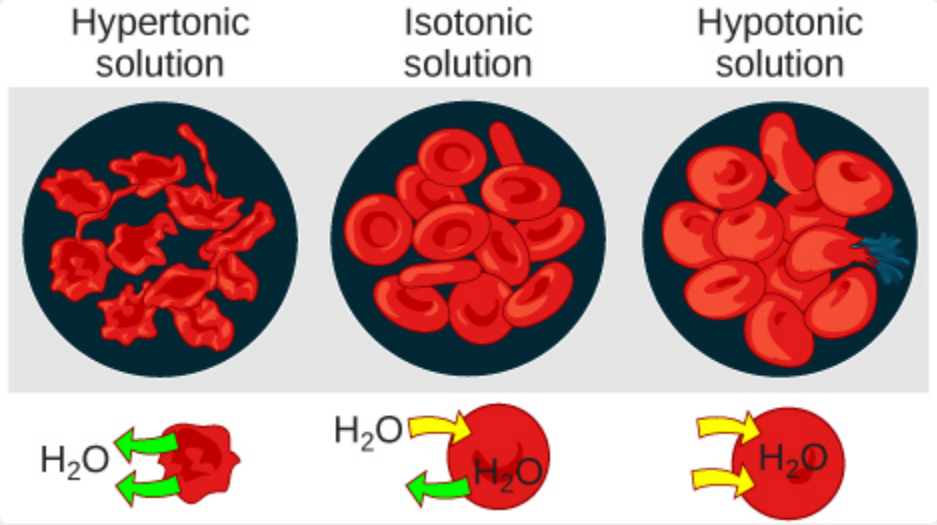


Figure 3.8 Effects of Hypertonic and Hypotonic Intravenous Fluids on Red Blood Cells

Videos

Watch the video "Hypertonic, Hypotonic, and Isotonic Solutions!" below to learn how different solution concentrations affect the movement of water across cell membranes.[6]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Watch the video "Osmosis and Water Potential" below to learn how water moves

6. BOGObiology. (2018, October 28). Hypertonic, hypotonic, and isotonic solutions! [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=rMa9MzP19zI

across cell membranes and how water potential influences the direction of that movement.[7]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Active Transport

Recall that diffusion causes movement of substances from an area of higher concentration to an area of lower concentration, which is called a concentration gradient. Active transport is used to move a substance against its concentration gradient across the cell membrane, often with the help of protein carriers. Active transport requires the use of cellular energy in the form of ATP.

Pumps

One of the most common types of active transport uses proteins that work as pumps. The word "pump" probably brings up thoughts of using energy to pump up the tire of a bicycle or a basketball. Similarly, energy from ATP is required for cell membrane proteins to transport substances (i.e., molecules or ions) across the membrane against their concentration gradients (i.e., from an area of low concentration to an area of high concentration).

An example of active transport is the **sodium-potassium pump**, which moves sodium

7. Amoeba Sisters. (2018, June 27). Osmosis and water potential (updated) [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=L-osEc07vMs

out of a cell while moving potassium into the cell. The sodium-potassium pump is an important ion pump found in the membranes of many types of cells. See Figure 3.9[8] for an image of the sodium-potassium pump.

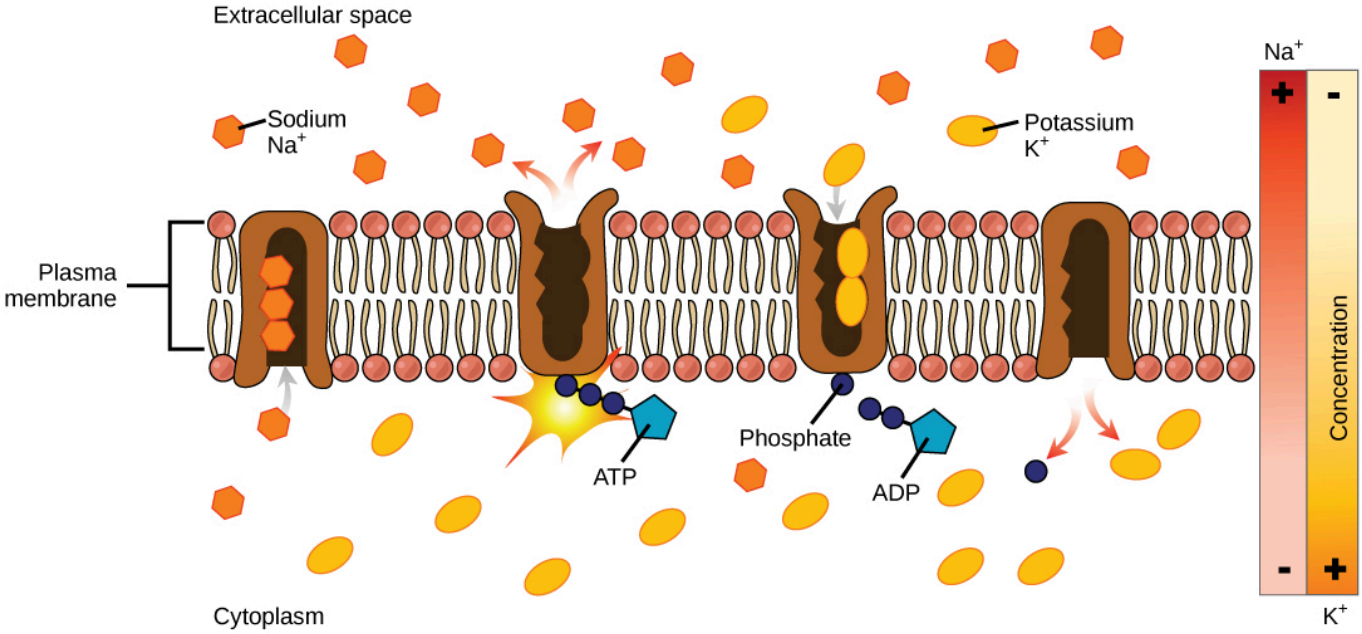


Figure 3.9 Sodium-Potassium Pump

Other Types of Active Transport

Endocytosis

Endocytosis (which means bringing "into the cell") is another type of active transport where cells take in materials from outside the cell. During endocytosis, the cell ingests material by enveloping it in a portion of its cell membrane and then pinching off that portion. Once pinched off, that portion of the membrane and its contents become an independent, intracellular vesicle. A **vesicle** is a membrane sac (i.e., a round and hollow organelle bounded by part of the cell membrane). Endocytosis often brings materials into the cell that must be broken down or digested.

There are three different types of endocytosis, which include phagocytosis,

8. CNX OpenStax. (2016). *Figure 05 03 03* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Figure_05_03_03.jpg

pinocytosis, and receptor-mediated endocytosis. See Figure 3.10[9] for an illustration of these types of endocytosis. Phagocytosis and pinocytosis bring in large portions of extracellular material, and they usually are not selective in the substances they bring into the cell. **Phagocytosis** (which means "cell eating") refers to endocytosis of large particles. For example, white blood cells patrol the body for unwanted foreign objects, such as invading bacteria, phagocytize them, and then digest them. **Pinocytosis** (which means "cell drinking") is the endocytosis of fluids. **Receptor-mediated endocytosis** regulates the endocytosis of specific substances by using a part of the cell membrane that has receptors for a certain substance. The substance being ingested has to attach to the cell's receptor first before it is engulfed by the cell. For example, iron is brought into red blood cells using receptor-mediated endocytosis.

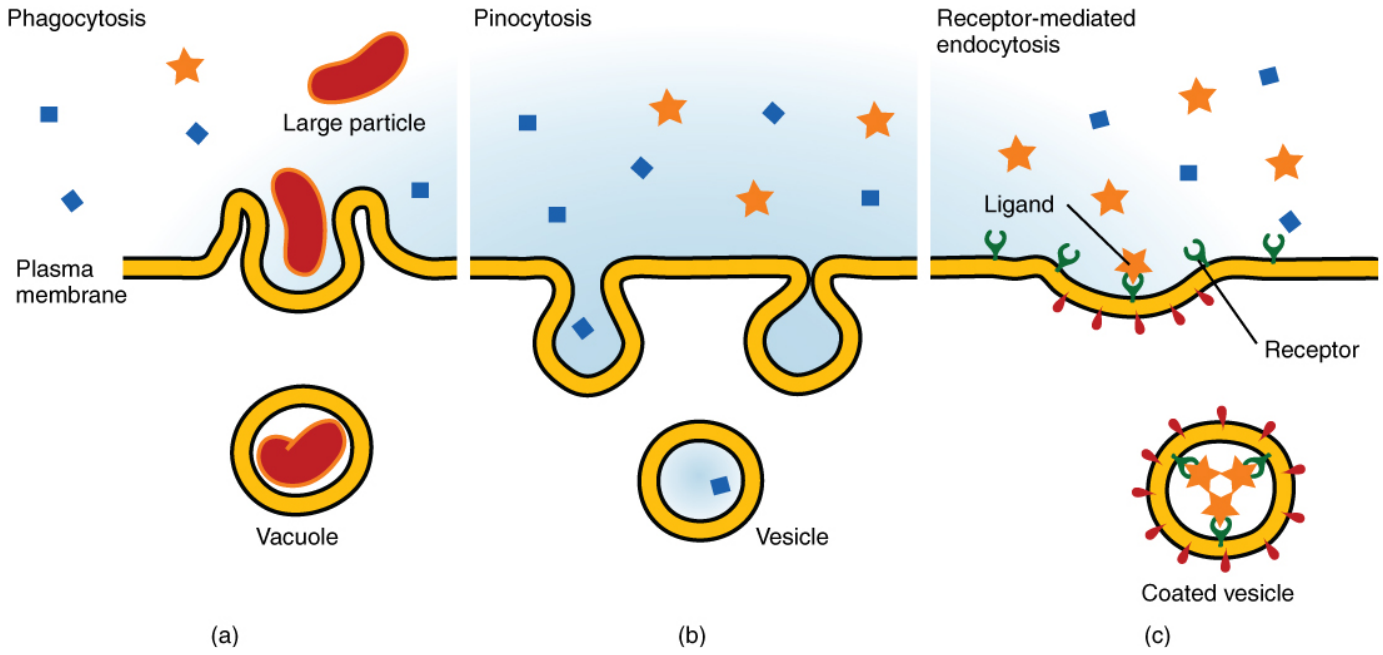


Figure 3.10 Endocytosis: (a) Phagocytosis, (b) Pinocytosis, and (c) Receptor-Mediated Endocytosis

Exocytosis

Exocytosis (which means "exiting or leaving the cell") is the opposite of endocytosis. Many cells make things that must be removed from the cell, like a factory makes a product for export. These substances are typically packaged into vesicles while inside the cell. The vesicle then merges with the cell membrane and releases its contents outside

9. OpenStax College. (2016). *0309 Three forms of endocytosis* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0309_Three_Forms_of_Endocytosis.jpg

of the cell. For example, cells in the stomach and pancreas secrete digestive enzymes through exocytosis to help break down the food eaten.[10]

See Figure 3.11[11] for an illustration of exocytosis.

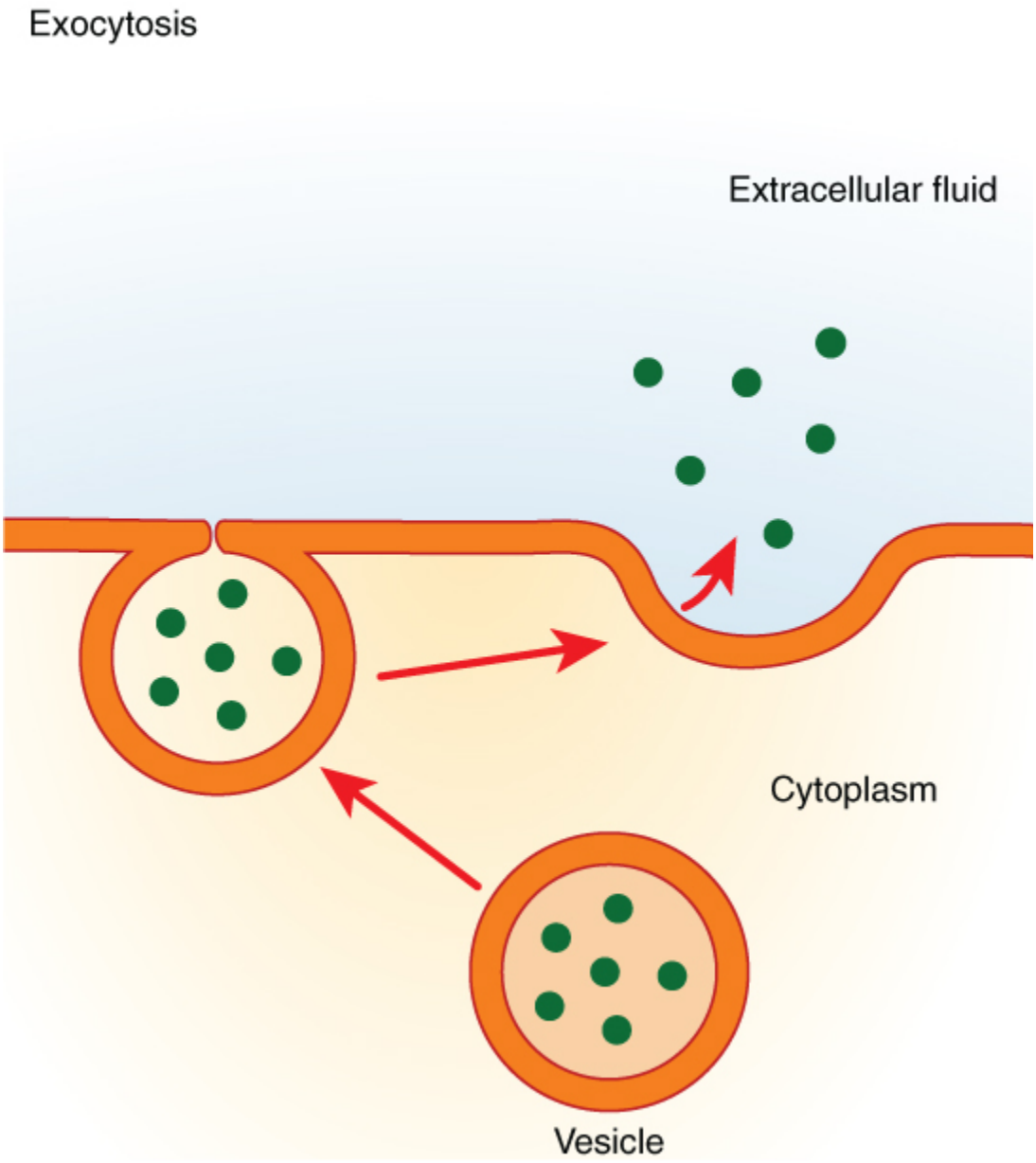


Figure 3.11 Exocytosis. Cell Substances Are Packaged into Vesicles, Which Then Merge with the Cell Membrane to Be Released Outside of the Cell

10. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

11. OpenStax College. (2016). *0310 Exocytosis* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0310_Exocytosis.jpg

Video

Watch the video “Cell Membrane & Transport Explained (Diffusion, Osmosis, Active Transport)” below to learn more about how substances move across the cell membrane.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.



3.4 Cytoplasm, Organelles, and Cytoskeleton

Now that we have discussed the cell membrane and substances crossing the cell membrane via diffusion, osmosis, and active transport, let's examine the inside of cells. All living cells in the human body contain many important parts, each with a very specific job.

Cytoplasm

The inside of a cell is called **cytoplasm**, which includes cytosol and organelles. **Cytosol** is a jelly-like substance that fills the cell and is made of water, salts, and proteins. All animal cells are **eukaryotic cells**, meaning they have a nucleus. Eukaryotic cells also contain several organelles. **Organelles**, which means "little organs," work together to keep the cell healthy and perform important functions. The **cytoskeleton**, also considered part of the cytoplasm, is a group of fibrous proteins that provide structural support for cells and perform other functions.

Organelles of the Cell

See Figure 3.12[1] for an illustration of primary organelles and structures in a human cell. This subsection will discuss the nucleus, endoplasmic reticulum, ribosomes, Golgi apparatus, lysosomes, mitochondria, centrosomes, and peroxisomes.

1. OpenStax College. (2016). *0312 Animal cell and components* [Diagram]. Wikimedia Commons. CC BY 4.0.https://commons.wikimedia.org/wiki/File:0312_Animal_Cell_and_Components.jpg

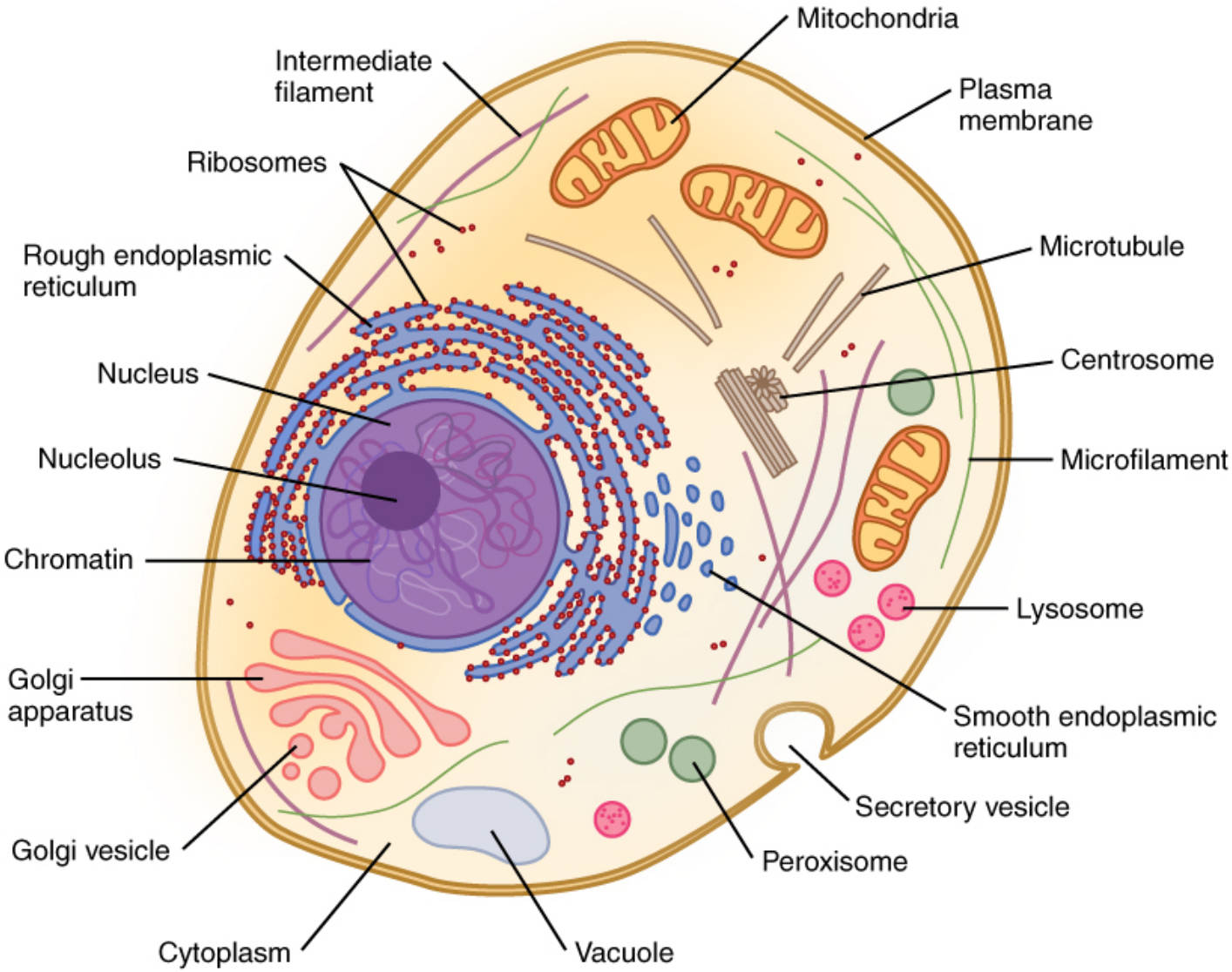


Figure 3.12 Human Cell

Nucleus

The **nucleus** is found in the center of the cell and contains the cell's DNA. The DNA is the genetic material that determines the entire structure and function of that cell, so the nucleus is often referred to as the control center of the cell. Inside the nucleus, the DNA exists in a loosely tangled form called **chromatin**. The **nuclear membrane** (or **nuclear envelope**) is the membrane covering the nucleus. It contains holes called **nuclear pores** that allow substances to enter or leave the nucleus. The **nucleolus** is a structure found

within the nucleus. Its function is to produce ribosomes (discussed later in this chapter) for the cell. See Figure 3.13[2] for an illustration of the structures inside the nucleus.

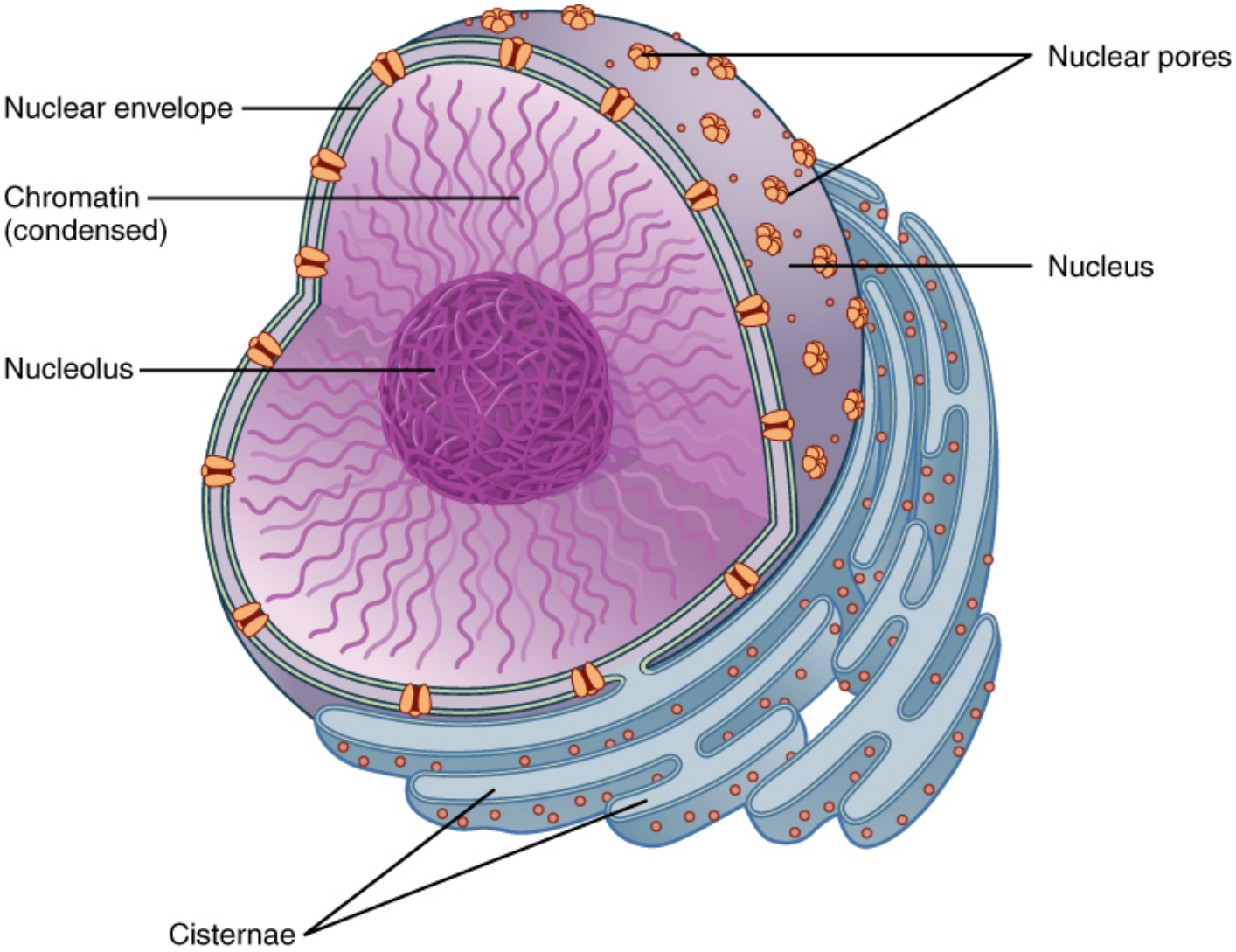


Figure 3.13 Nucleus

Endoplasmic Reticulum and Ribosomes

The **endoplasmic reticulum (ER)** is a system of channels that is continuous with the nuclear membrane covering the nucleus and is composed of the same lipid bilayer material. It provides passages throughout much of the cell that help with transporting, making, and storing materials. There are two parts to the endoplasmic reticulum, called

2. OpenStax College. (2016). *0318 Nucleus* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0318_Nucleus.jpg

the smooth and rough endoplasmic reticulum. The **smooth endoplasmic reticulum** makes lipids and phospholipids (the main component of the cell membrane). The **rough endoplasmic reticulum** is dotted with many ribosomes that attach to the endoplasmic reticulum, giving it a "rough" appearance. **Ribosomes** are organelles that make proteins. The rough ER will then modify the newly synthesized proteins produced by the ribosomes. See Figure 3.14[3] for an illustration of these parts of the endoplasmic reticulum.

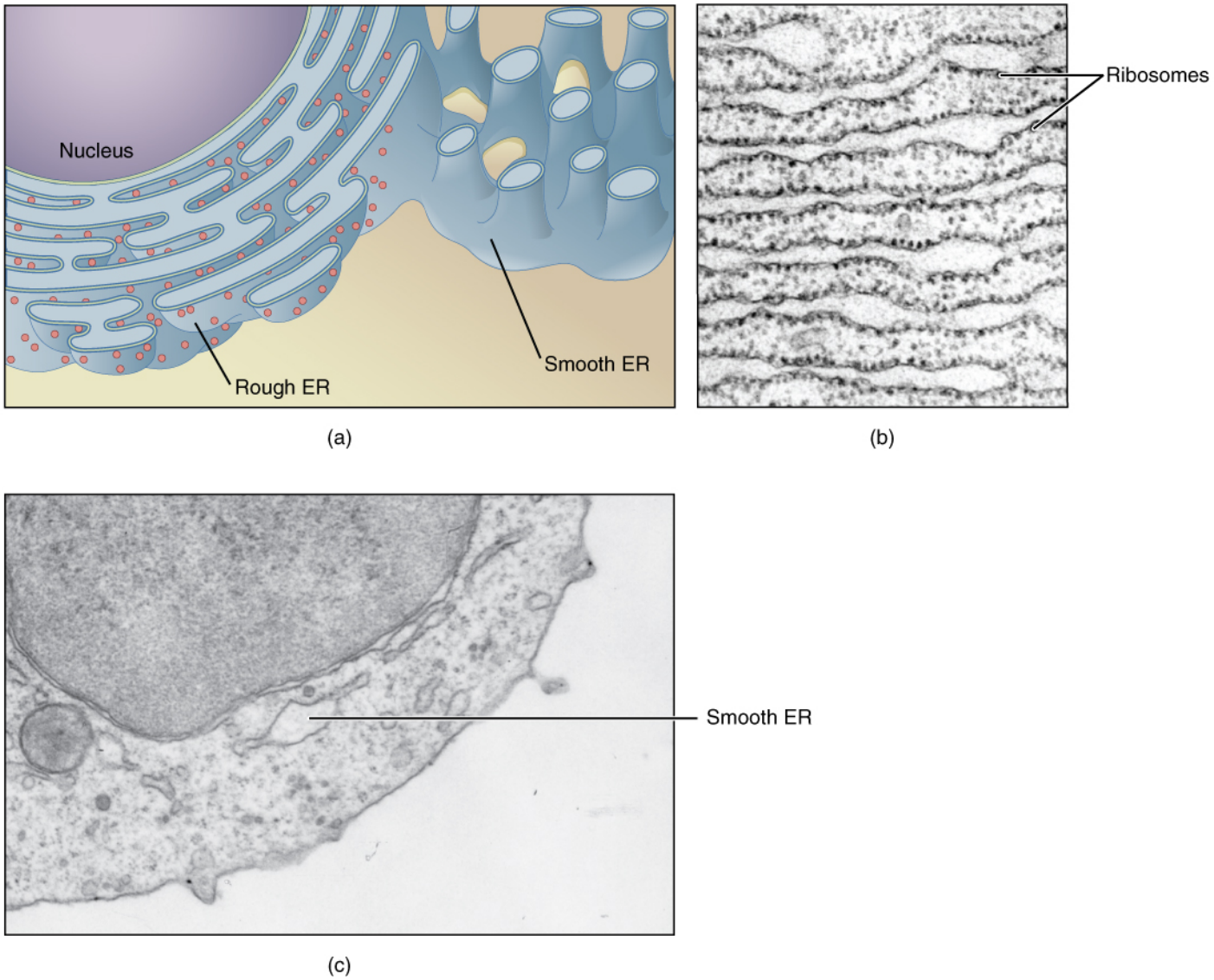


Figure 3.14 Endoplasmic Reticulum (ER): (a) Smooth and Rough Endoplasmic Reticulum, (b) Rough Endoplasmic Reticulum with Ribosomes on its Surface, and (c) Smooth Endoplasmic Reticulum

3. OpenStax. (2016). *0313 Endoplasmic reticulum* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0313_Endoplasmic_Reticulum.jpg

Golgi Apparatus

The **Golgi apparatus** is responsible for sorting, modifying, and shipping off the products that come from the rough ER, much like a post office. It also makes lysosomes. The Golgi apparatus looks like a stack of oddly shaped pancakes. See Figure 3.15[4] for an illustration of the Golgi apparatus.

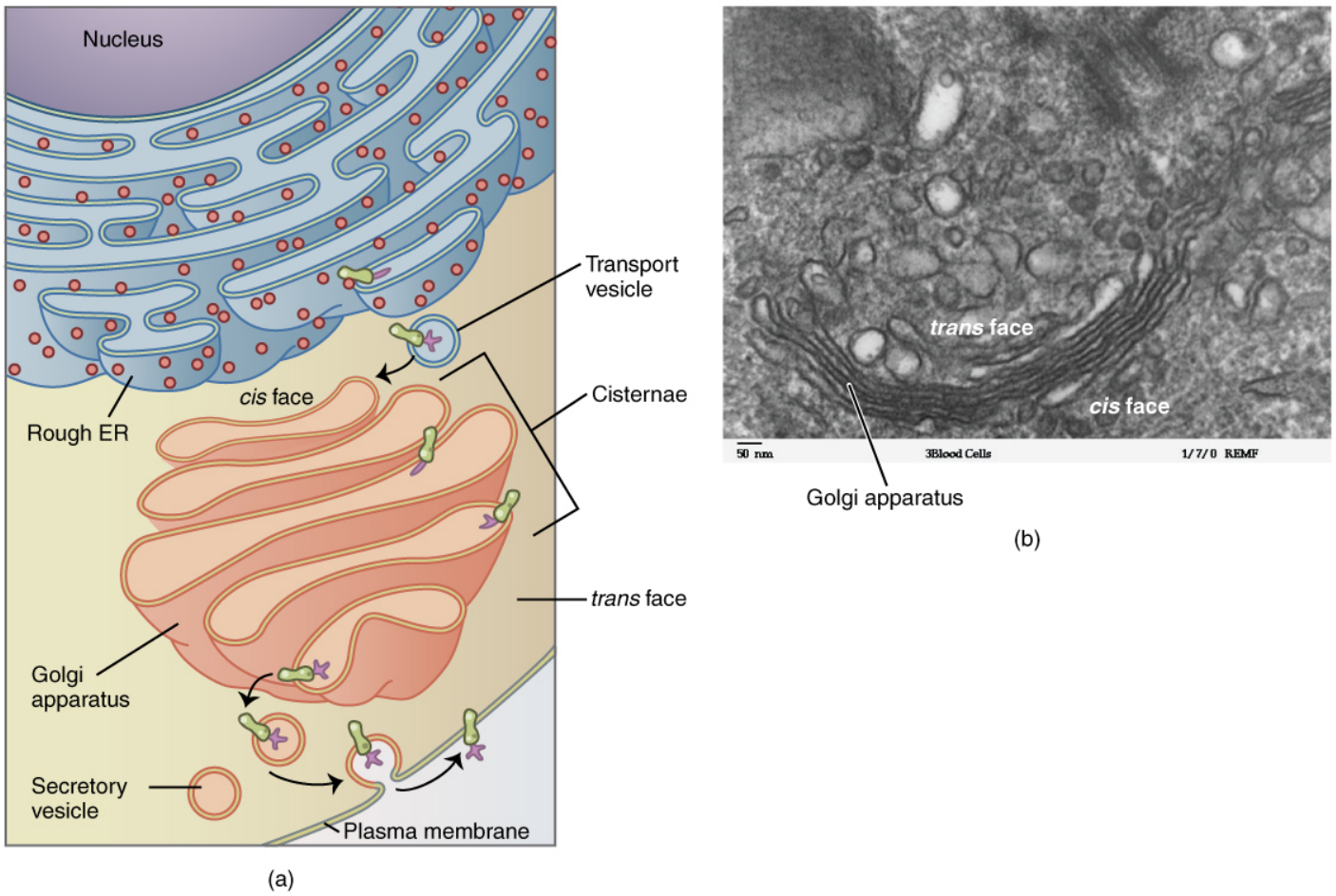


Figure 3.15 Golgi Apparatus: (a) The Golgi Apparatus Ships Products from the Rough Endoplasmic Reticulum; (b) An Electron Micrograph of the Golgi Apparatus

Lysosomes

A **lysosome** is an organelle that contains enzymes that break down and digest unneeded things, such as foreign material or a damaged organelle. For example, when

4. OpenStax College. (2016). *0314 Golgi apparatus* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0314_Golgi_Apparatus.jpg

a white blood cell phagocytizes a pathogen like a virus, the virus is digested by the enzymes released by lysosomes. See Figure 3.16[5] for an illustration of a lysosome inside a white blood cell digesting a particle.

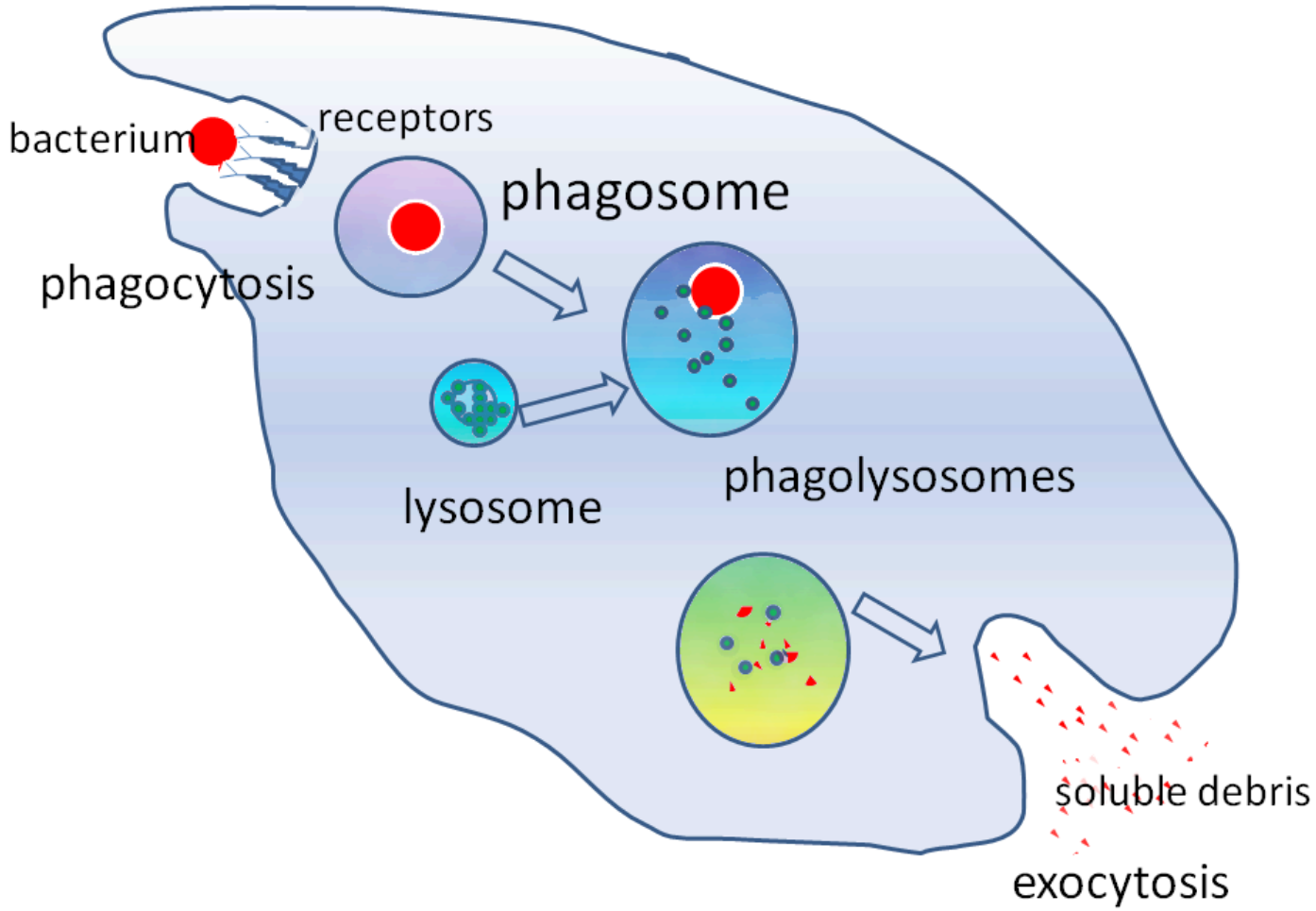


Figure 3.16 Lysosome Digestion

Mitochondria

A **mitochondrion** (the singular form of mitochondria) is a bean-shaped organelle that is the "energy supplier" of the cell. Mitochondria convert energy stored in nutrients (such as glucose) into adenosine triphosphate (ATP), using a process called cellular respiration, which provides usable energy to the cell. In fact, cellular respiration is the reason why your body requires oxygen. Without enough oxygen, cells can't generate enough ATP

5. Beards, G. (2009). *Phagocytosis2* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Phagocytosis2.png

to maintain life for very long. Cells constantly use ATP to function, so mitochondria are constantly producing ATP. Different cells have different numbers of mitochondria depending on their energy needs. For example, muscle cells have more mitochondria than bone cells. See Figure 3.17[6] for an illustration of mitochondria.

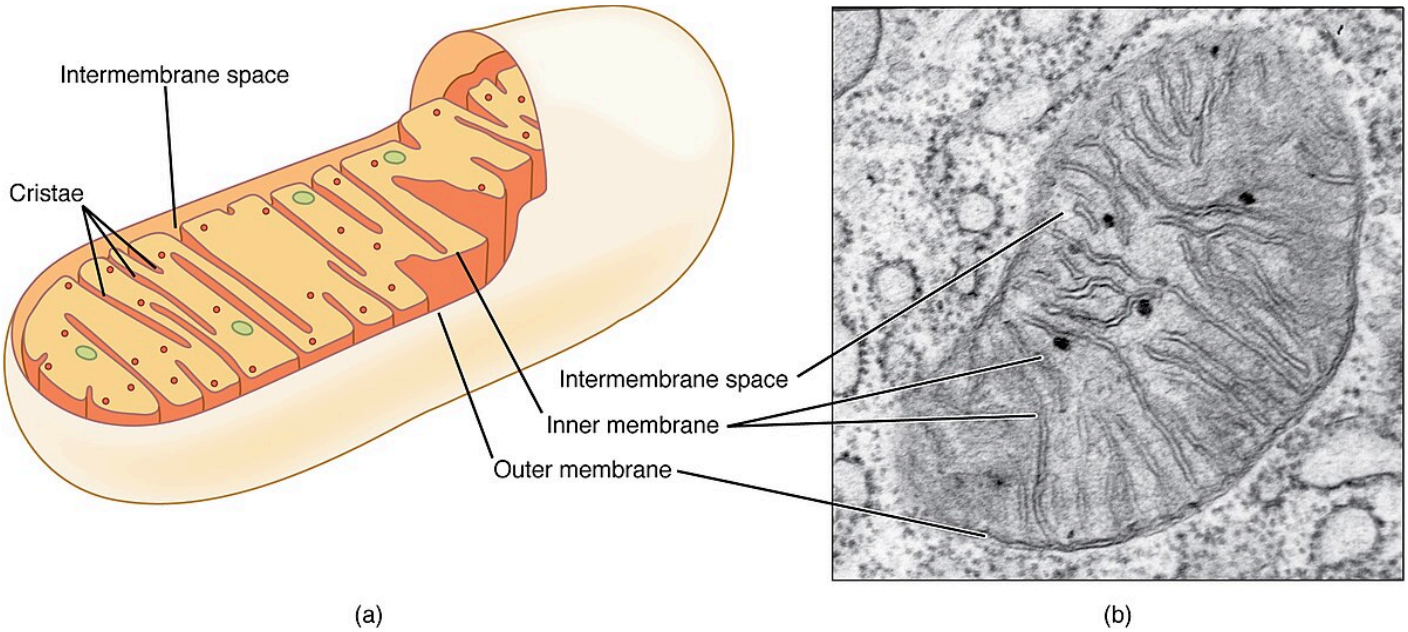


Figure 3.17 Mitochondria. The mitochondria are the energy-producing factories of the cell. (a) Along the inner membrane are various molecules that work together to produce ATP, the cell's major energy currency. (b) An electron micrograph of mitochondria (EM × 236,000).

Centrosomes

Centrosomes are a pair of cylindrical structures called **centrioles** that look like gears or pinwheels. Centrioles are made up of long microtubules made from the protein tubulin. They are positioned perpendicular to each other and located near the nucleus in the cell. Their function is to form a structure called the spindle during the process of cell division. See Figure 3.18[7] for an illustration of a centrosome.

6. OpenStax College. (2016). *0315 Mitochondrion new* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0315_Mitochondrion_new.jpg
7. Laboratoires Servier. (2019). *Centrosome_two centrioles* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Centrosome_-_Two_centrioles_–_Smart-Servier.jpg

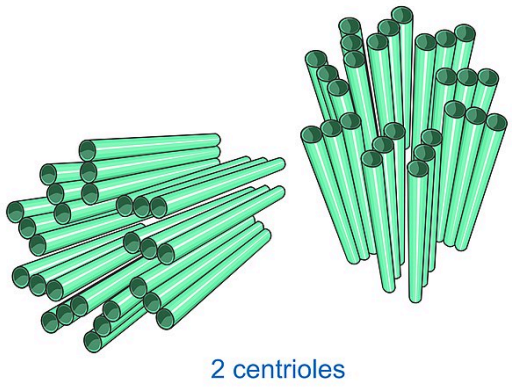


Figure 3.18 Centrosome

Peroxisomes

Like lysosomes, a **peroxisome** is an organelle that contains mostly enzymes. Peroxisomes perform different functions, including metabolizing lipids and detoxifying harmful substances. Peroxisomes are like tiny sewage treatment plants that neutralize harmful toxins so that they do not wreak havoc in the cells. For example, there are a high number of peroxisomes in the liver, an organ primarily responsible for detoxifying the blood before it travels throughout the body. See Figure 3.19[8] for an illustration of a peroxisome.

8. OpenStax College. (2016). *0316 Peroxisome* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0316_Peroxisome.jpg

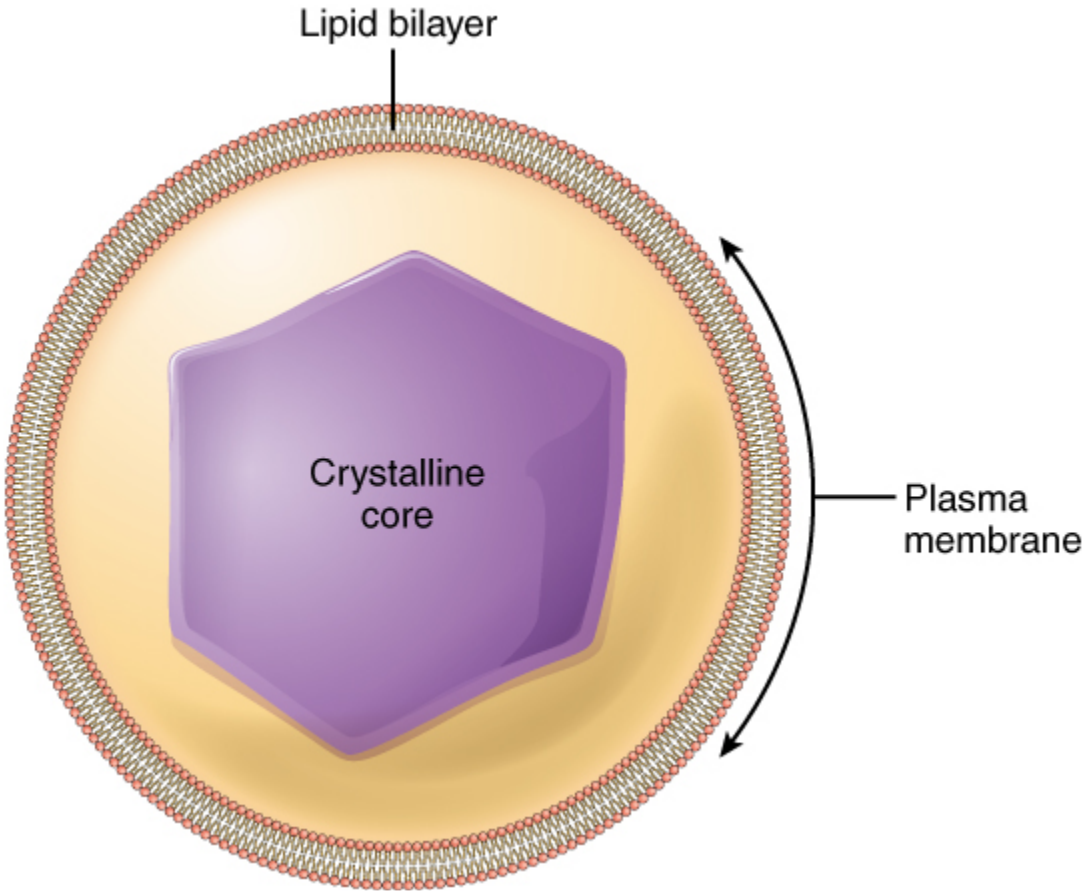


Figure 3.18 Peroxisome

Videos

Watch the video "Cell Structure Explained (Organelles and Functions)" below to learn more about cell organelles and their functions.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Watch the video “Cell Organelles for Anatomy and Physiology” below to learn about the structure and function of various cell organelles and how they contribute to overall cell activity.[9]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Cytoskeleton

Similar to how bones support the human body, the cytoskeleton helps support the cell. The **cytoskeleton** is a group of proteins that provide structural support for cells. It also helps with cell movement, reproduction, and the transportation of substances within the cell. The cytoskeleton consists of microtubules, microfilaments, and intermediate filaments.

Microtubules are the thickest of the three components and are made from a protein called tubulin. Microtubules perform several functions, including the following:

- Maintain the shape and structure of the cell
- Prevent the cell from being compressed or squashed
- Keep the organelles in the right places within the cell

9. Forciea, B. (2015, March 20). Cell organelles for anatomy and physiology [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=njiAmKZomIg

- Make up two cellular appendages used for motion:
  - **Cilia** are found on the surface of many cells of the body, including cells that line the airways of the respiratory system. Cilia move wastes such as dust, mucus, and bacteria up through the airways, away from the lungs and to the mouth. Cilia also help move egg cells from the ovary to the uterus in the female reproductive system.
  - **Flagella** are a tail-like structure for movement. The only cells in humans that have flagella are sperm cells.[10]

See Figure 3.20[11] for an illustration of the cytoskeleton.

10. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
11. CNX OpenStax. (2016). *OSC microbio 03 04 eukcell* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:OSC_Microbio_03_04_eukcell.jpg

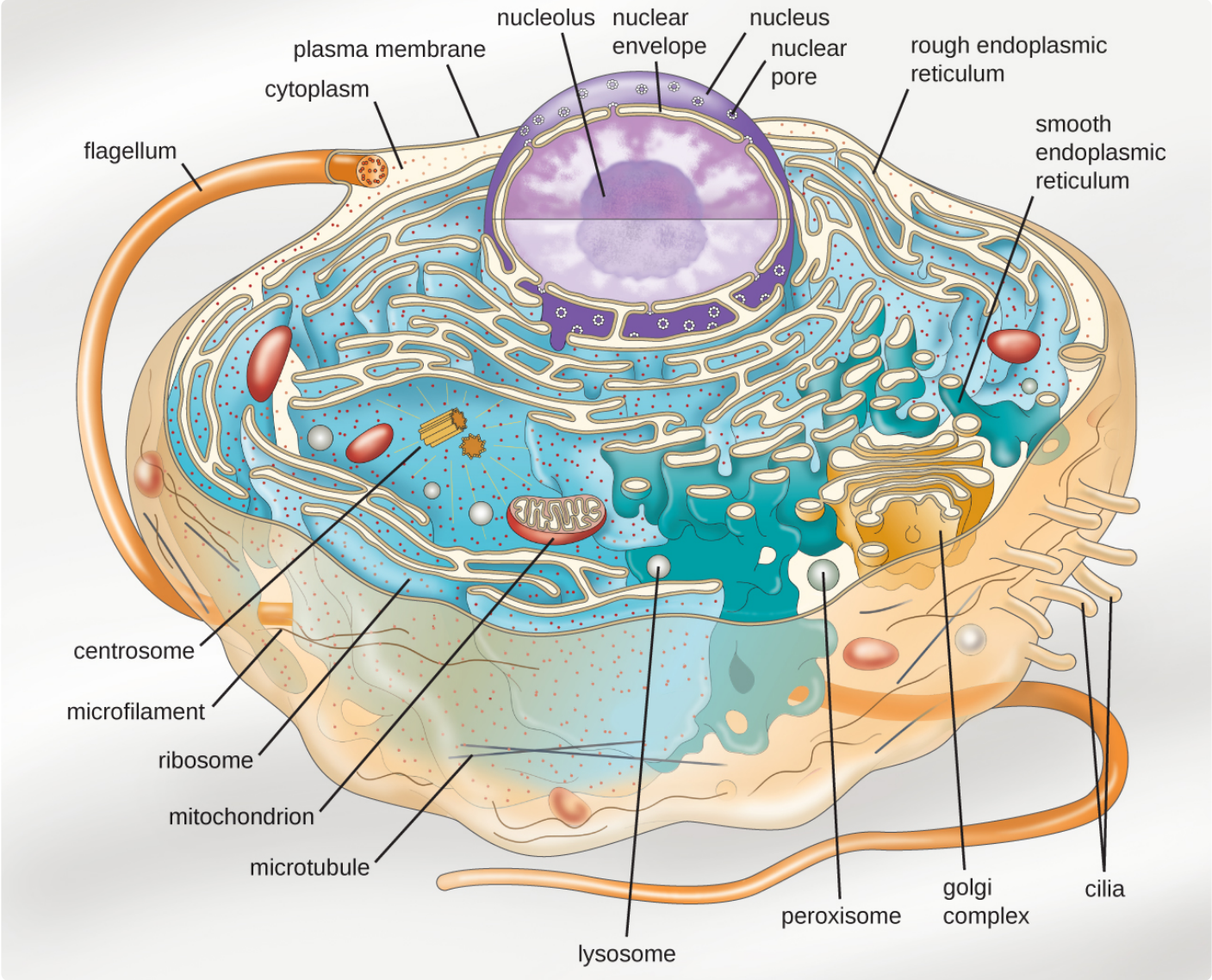


Figure 3.20 The Cytoskeleton

Microfilaments are the thinner cytoskeletal filaments, primarily composed of the protein actin. Muscle tissue is made up of actin fibers that, along with another protein called myosin, are responsible for muscle contraction.

Intermediate filaments are intermediate in thickness and made up of a protein called keratin. These filaments are wound together like a rope and help maintain cell shape and structure. See Figure 3.21[12] for an illustration of the components of the cytoskeleton.

12. OpenStax College. (2016). *0317 Cytoskeletal components* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0317_Cytoskeletal_Components.jpg

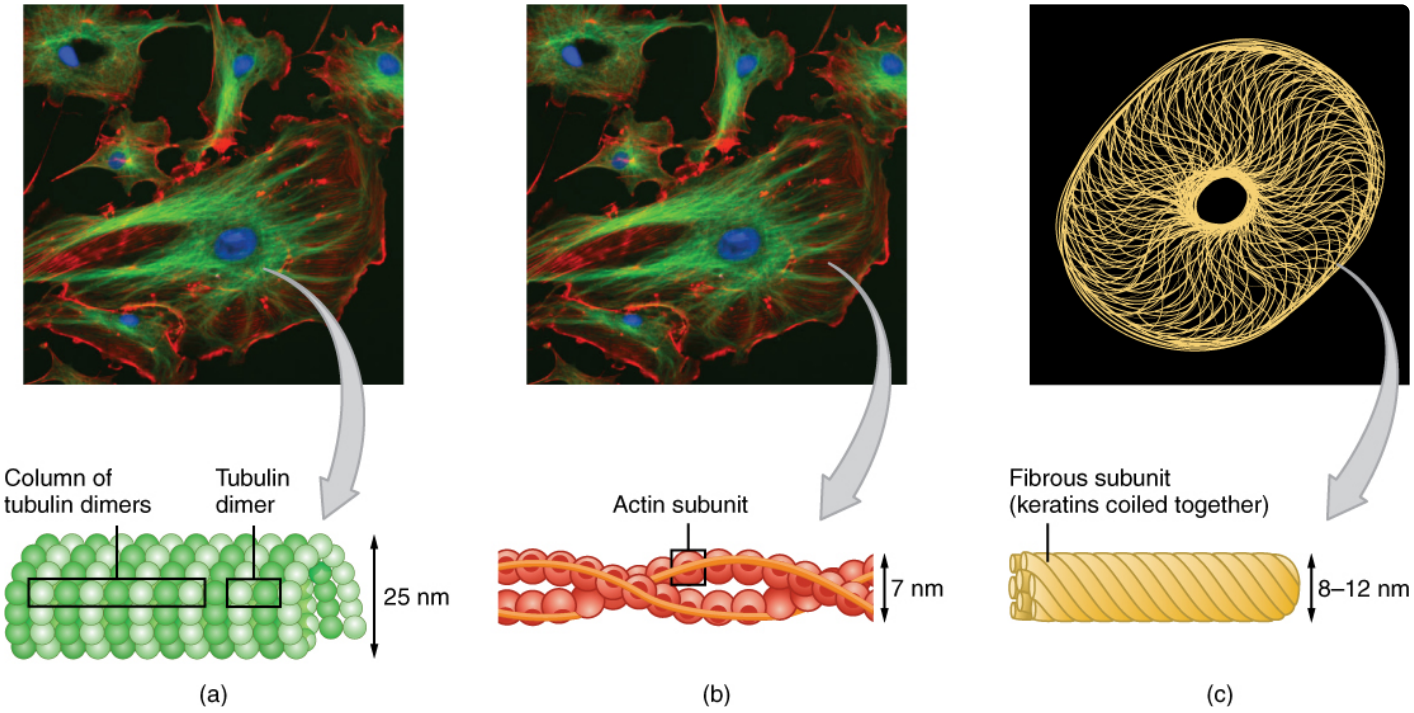


Figure 3.21 Components of the Cytoskeleton: (a) Microtubules, (b) Microfilaments, and (c) Intermediate Filaments

Wisc-Online Interactive Activity

Complete the interactive activity **"A Typical Animal Cell"** on Wisc-Online.

3.5 Cell Cycle

Beginning at conception, your cells have reproduced themselves many times during growth and development. Even in adulthood, most cells throughout the human body go through regular cell division to replace cells that are old or damaged (there are a few cells in the body that do not go through routine cell division, such as red blood cells, nerve cells, and some muscle cells).

A **somatic cell** is a general term for all human cells, except for egg and sperm, which are referred to as **germ (or sex) cells**. Somatic cells contain 46 individual chromosomes that pair together to make 23 pairs of **homologous** chromosomes (with *homo* meaning "same"). One member of each chromosome pair comes from each parent, so half of your chromosomes come from the egg and the other half from the sperm. The human is a **diploid** organism, having 23 homologous pairs of chromosomes in each of the somatic cells, or 46 total chromosomes.

Billions of cells in the human body divide every day. The **cell cycle** is an ordered series of events involving cell growth and cell division that produces two new daughter cells. Cells on the path to cell division proceed through a series of precisely timed and carefully regulated stages of growth, deoxyribonucleic acid (DNA) replication, and division that produce two genetically identical cells. The cell cycle consists of three major parts: interphase, mitosis, and cytokinesis. During interphase, the cell grows, and DNA is replicated. During the mitotic phase, the replicated DNA is separated, and in cytokinesis, the cytoplasm is divided as the cell splits into two new cells.

- **Interphase** is the time during the cell cycle when the cell is not dividing. Cells spend most of their time in interphase. Cells grow, carry out their normal activities, and prepare for cell division in this phase.
- **Mitosis** is the time during the cell cycle where the genetic material (DNA) is divided or "divvied up" in an organized series of steps or phases between the two newly forming daughter cells. It occurs relatively quickly, over one to two hours.
- **Cytokinesis** divides the cytoplasm into two new cells.

Interphase: Synthesis Phase

While in interphase, a cell grows and carries out its normal functions, in addition to

getting ready for division. Chromosomes are not visible during interphase because DNA is uncoiled into **chromatin**, a material that resembles coffee grounds.

Interphase is divided into three parts:

- **Growth 1 phase (G_1 phase)**: The cell is growing and performing its functions.
- **Synthesis phase (S phase)**: The cell enters the S phase when it is no longer functioning well and needs to divide. During this period, the cell replicates its DNA.
- **Growth 2 phase (G_2 phase)**: A phase where the cell continues to make preparations for mitosis.

During the synthesis phase (S phase) of interphase, the cell **replicates** its DNA in its nucleus (i.e., makes an identical copy) because one copy will be needed for each new cell that will be created during mitosis and cytokinesis. It also duplicates a microtubule-organizing structure called the centrosome. The centrosomes help separate DNA during the mitosis phase.

See Figure 3.22[1] for an illustration of the cell cycle.

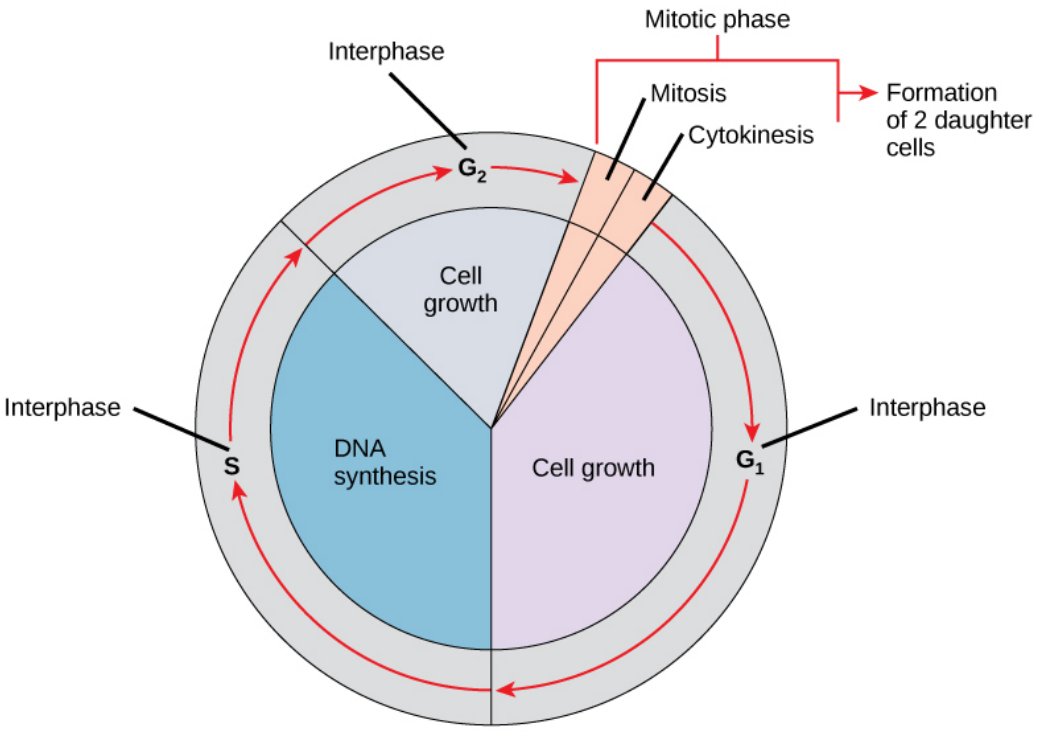


Figure 3.22 Cell Cycle. M is Mitosis, and Interphase is Subdivided into G1, S, and G2 Phases

1. CNX OpenStax. (2016). *Figure 10 02 01* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Figure_10_02_01.jpg

Mitosis and Cytokinesis Phases

The mitosis and cytokinesis phases represent cell division. During the **mitosis phase**, replicated chromosomes are separated and organized into two new nuclei. After mitosis, the cytoplasm divides into two new cells during **cytokinesis**.

Mitosis consists of four major phases called prophase, metaphase, anaphase, and telophase that are further described in the following subsections.

Prophase

Prophase is the longest phase of mitosis. The nucleus and nucleolus disappear, and the chromatin (the previously replicated DNA) condenses into visible X-shaped chromosomes with sister chromatids. Each copy of the chromosome is referred to as a **chromatid** that is physically attached to the other copy by a **centromere** at its center, resulting in its familiar "X" shape.

Recall that a typical human cell contains 46 chromosomes that are organized into 23 pairs of homologous chromosomes. See Figure 3.23[2] for an illustration of a homologous pair of chromosomes before and after DNA replication.

2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

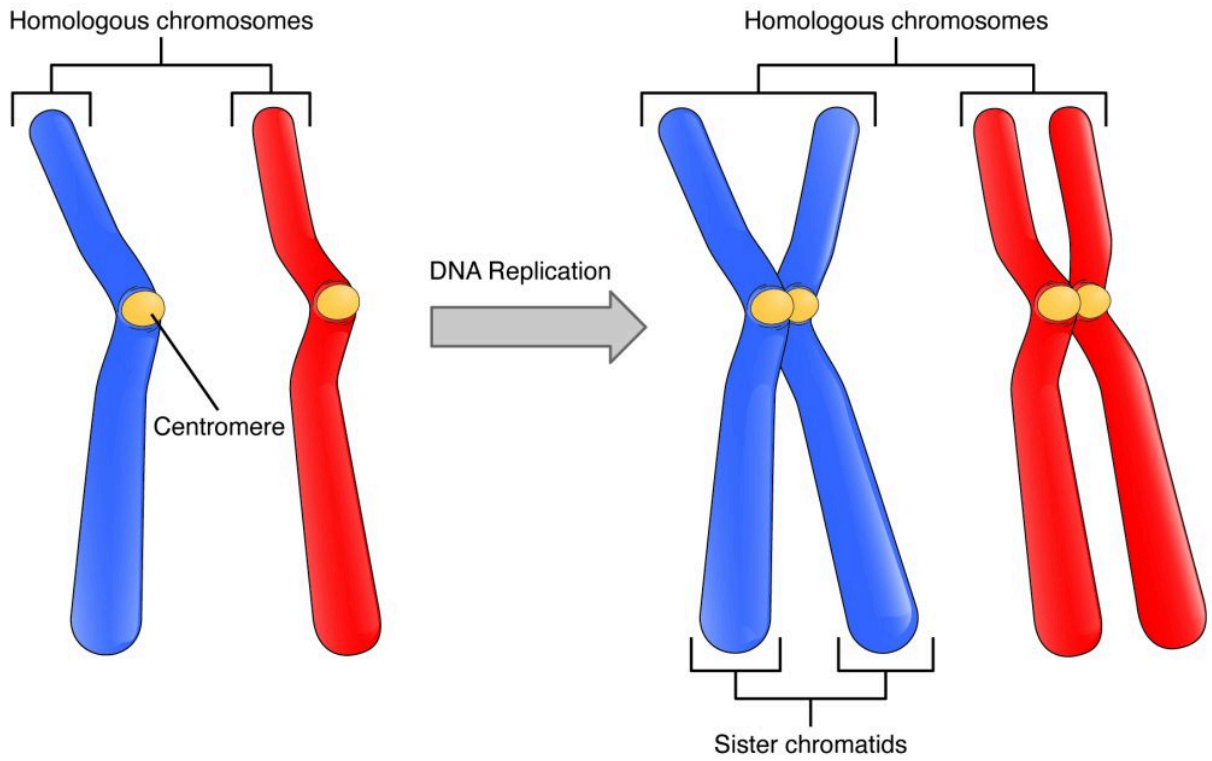


Figure 3.23 Homologous Pair of Chromosomes Before and After DNA Replication

In addition to the appearance of sister chromatids in the nucleus, changes also occur in the cytoplasm of the cell during prophase. The centrosomes begin to move to opposite poles of the cell and form **spindle fibers** that will elongate and fan out during the mitosis phase. Spindle fibers attach to the chromosomes and are used to support the division and movement of the sister chromatids during mitosis.

Metaphase

During **metaphase**, the centrosomes complete their movement to the opposite poles of the cell, and the chromatids line up in the middle of the cell, often called the equator. The lining up of chromatids at the equator results in one sister chromatid being on each side of the equator.

Anaphase

During **anaphase**, the spindle fibers separate the pairs of sister chromatids at their

centromere and pull them to opposite ends of the cell into two separate groups. Once separated from each other, each chromatid is now called a chromosome.

Telophase

During **telophase**, a nuclear membrane forms around each set of chromosomes. The chromosomes then spread out into loose chromatin, and the nucleus and nucleolus become visible again. The cell begins to develop a **cleavage furrow**, a band that squeezes the two cells apart until they separate.

Cytokinesis

Mitosis is followed by **cytokinesis**, the separation of the cytoplasm into two distinct daughter cells that are identical to each other, as well as to the original cell that underwent mitosis. The cleavage furrow that formed near the end of mitosis will continue pinching inwards until it splits the original cell into two new cells.

The phases of mitosis and cytokinesis are illustrated in Figure 3.24.[3]

3. OpenStax College. (2016). *0331 Stages of mitosis and cytokinesis* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0331_Stages_of_Mitosis_and_Cytokinesis.jpg

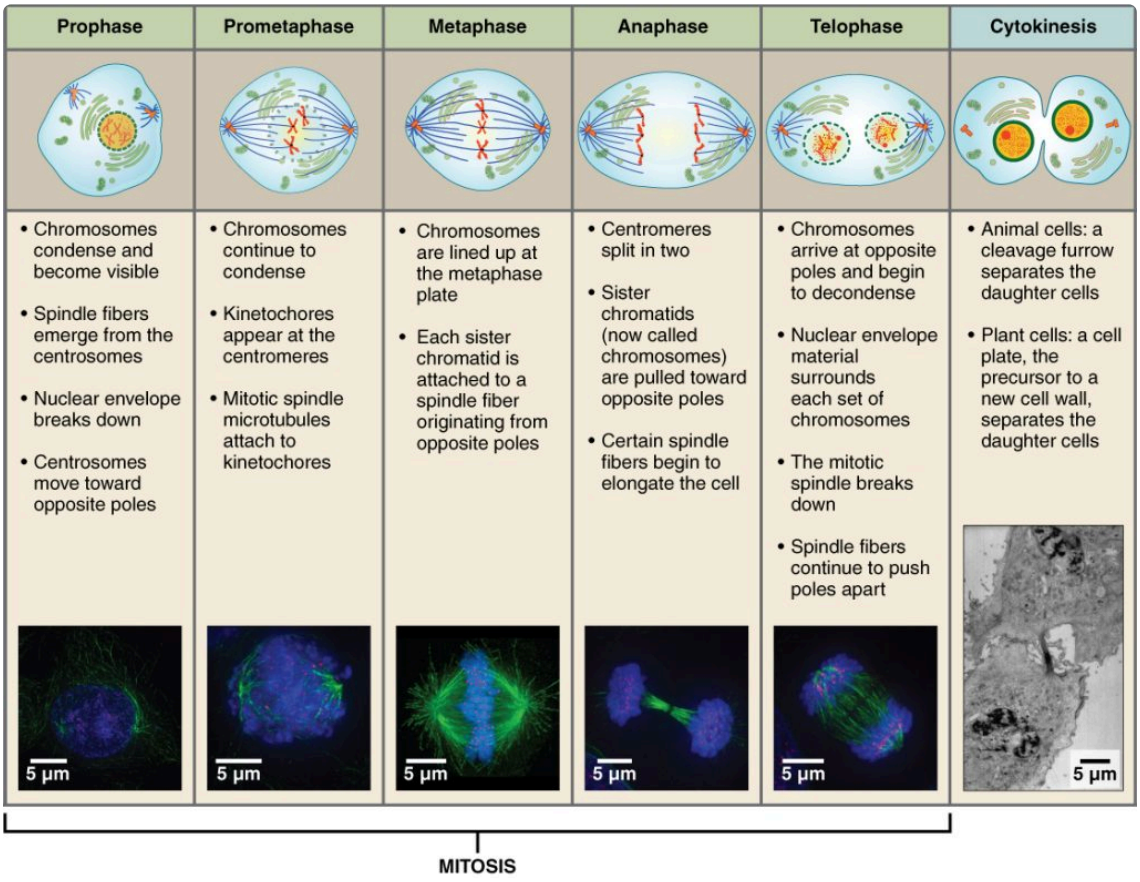


Figure 3.24 Phases of Mitosis and Cytokinesis

Videos

*]:pointer-events-auto [content-visibility:auto] supports-[content-visibility:auto]:[contain-intrinsic-size:auto_100lvh] R6Vx5W_threadScrollVars scroll-mb-[calc(var(--scroll-root-safe-area-inset-bottom,0px)+var(--thread-response-height))] scroll-mt-[calc(var(--header-height)+min(200px,max(70px,20svh)))]" dir="auto" data-turn-id="request-69f3891f-cad4-8328-be35-d4d3dbd28b71-28" data-testid="conversation-turn-48" data-scroll-anchor="false" data-turn="assistant">
Watch the video “Chromosomes vs Chromatids vs Chromatin (Different Forms

of DNA)" below to learn how DNA is organized into different structural forms and how these forms relate to cell division and genetic function.[4]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Watch the video "Mitosis: The Amazing Cell Process that Uses Division to Multiply! (Updated)" below to learn how cells divide through mitosis and the key stages involved in producing two identical daughter cells.[5]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

4. Nucleus Medical Media. (2021, November 5). *Chromosomes vs chromatids vs chromatin* (Different forms of DNA) [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=5bq1To_RKEo

5. Amoeba Sisters. (2018, October 30). *Mitosis: The amazing cell process that uses division to multiply! (Updated)* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=f-ldPgEfAHI

Cell Cycle Control

The cell cycle, from interphase through mitosis, is controlled by molecules within the cell, as well as by external triggers providing "stop" and "go" signals for the cell. Precise regulation of the cell cycle is important for the health of the body, and loss of cell cycle control can lead to uncontrolled cell division or cancer.

Mechanisms of Cell Cycle Control

As a cell moves through its cycle, each phase has certain processes that must be completed before the cell advances to the next phase. A **checkpoint** is a point in the cell cycle where the cell can either be allowed to continue to the next phase or stopped. See Figure 3.25[6] for an illustration of checkpoints during the cell cycle. At the G_1 checkpoint, the cell must be ready for DNA synthesis to occur. At the G_2 checkpoint, the cell must be fully prepared for mitosis. Even during mitosis, a crucial checkpoint in metaphase ensures that the cell is fully prepared to complete cell division. Cells proceed through the cell cycle under the control of a variety of regulatory proteins called cyclins. Each cyclin determines whether or not the cell is prepared to move to the next stage.

6. OpenStax College. (2016). *0332 Cell cycle with cyclins and checkpoints* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0332_Cell_Cycle_With_Cyclins_and_Checkpoints.jpg

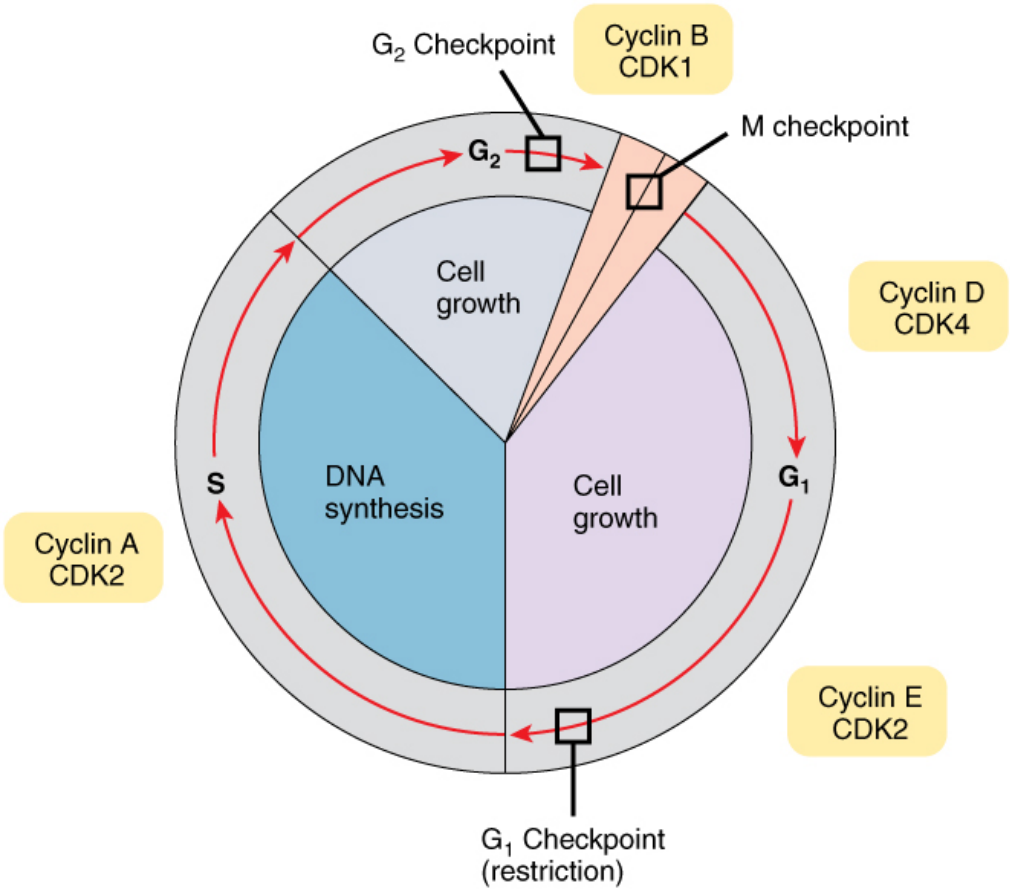


Figure 3.25 Checkpoints and Control of the Cell Cycle

Implications of a Cell Cycle Out of Control

Tumors and cancer are caused by abnormal cells that continuously multiply. If they continue to divide in an uncontrolled manner, these abnormal cells can damage the tissues around them, spread to other parts of the body, and eventually cause death to the individual.

In healthy cells, the tight control of the cell cycle prevents this overgrowth of abnormal cells from occurring. Failure to control the cell cycle can cause unwanted and excessive cell division, resulting in cancer. These control failures can be caused by inherited genetic abnormalities that disrupt the function of certain “stop” and “go” signals. Environmental factors, such as ultraviolet rays, can also damage DNA and cause malfunctioning of the signals. Often, a combination of both genetic and environmental factors leads to cancer. For example, someone who smokes and is also genetically predisposed to cancer is at higher risk for lung cancer.

Cell cycle control is an example of a homeostatic mechanism that maintains correct

cell function and health. While going through the phases of the cell cycle, molecules provide "stop" and "go" signals to regulate movement to the next phase. This homeostatic control of the cell cycle can be thought of like a car's cruise control. Cruise control will continually apply just the right amount of acceleration to maintain a desired speed, unless the driver hits the brakes, in which case the car will slow down. Similarly, the cell uses specific molecules that push the cell forward in the cell cycle. Normally, a cell that does not meet its checkpoints is programmed to self-destruct in a process called **apoptosis**. A delicate homeostatic balance controls the cell cycle and ensures that only healthy cells replicate.

If cells escape the normal control system, they can divide and grow excessively. Normally, the immune system will find and destroy these rogue cells. However, if these cells remain undetected, they can become tumors or cancer. If an abnormal growth of cells does not pose a threat to surrounding tissues, it is called **benign** and can often be surgically removed. However, if abnormal cells divide uncontrollably and invade nearby tissues, they are called **malignant**.[7]

If these abnormal cells spread to other places in the body, the cancer has **metastasized**.[8,9]

Video

*]:pointer-events-auto [content-visibility:auto] supports-[content-visibility:auto]:[contain-intrinsic-size:auto_100lvh] R6Vx5W_threadScrollVars scroll-mb-[calc(var(--scroll-root-safe-area-inset-bottom,0px)+var(--thread-response-height))] scroll-mt-[calc(var(--header-height)+min(200px,max(70px,20svh)))]" dir="auto" data-turn-id="request-69f3891f-cad4-8328-be35-d4d3dbd28b71-26" data-testid="conversation-turn-44" data-scroll-anchor="false" data-turn="assistant">
Watch the video **"3D Medical Animation – What is Cancer?"** below to learn how

7. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
8. National Cancer Institute. (n.d.). *NCI Dictionary of Cancer Terms: Malignancy*. https://www.cancer.gov/publications/dictionaries/cancer-terms/def/malignancy
9. National Cancer Institute. (n.d.). *NCI Dictionary of Cancer Terms: Metastatic*. https://www.cancer.gov/publications/dictionaries/cancer-terms/def/metastatic

cancer develops, how abnormal cells grow and spread, and how this process affects the body.[10]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

10. BioDigital, Inc. (2008, October 14). *3D medical animation – What is cancer?* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=LEpTTolebqo

3.6 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

3.7 Glossary

Active transport: Movement of molecules across the membrane requiring energy (ATP) to move substances against their concentration gradient (low to high concentration). (**Chapter 3.3**)

Amphipathic: Has both hydrophilic (water-attracting) and hydrophobic (water-repelling) regions. (**Chapter 3.2**)

Anaphase: The stage of mitosis where sister chromatids are pulled apart to opposite sides of the cell, ensuring each daughter cell gets a full set of chromosomes. (**Chapter 3.5**)

Apoptosis: Programmed cell death; a controlled process that allows the body to eliminate damaged or unnecessary cells, often during development or in response to DNA damage. (**Chapter 3.5**)

Benign: Refers to a tumor or growth that is noncancerous, noninvasive, and does not spread to other parts of the body. Benign tumors typically have a favorable prognosis. (**Chapter 3.5**)

Carrier proteins: Proteins that change their shape to move substances across the cell membrane. (**Chapter 3.2**)

Cell cycle: The series of stages through which a cell goes to prepare for division, involving growth, DNA replication, and cell division. It includes interphase, mitosis, and cytokinesis. (**Chapter 3.5**)

Cell membrane: Also called the plasma membrane, a selectively permeable structure that surrounds the cell, providing protection and regulating the movement of substances in and out. (**Chapter 3.2**)

Cell recognition proteins: Proteins that mark a cell's identity so that it can be recognized by other cells. (**Chapter 3.2**)

Centrioles: A pair of small cylinders made of microtubules located near the nucleus that form the spindle fibers necessary for cell division. (**Chapter 3.4**)

Centromere: The region where two sister chromatids are joined together. (**Chapter 3.5**)

Centrosomes: Regions near the nucleus that contain centrioles, involved in the

organization of the microtubules and spindle formation during cell division. (Chapter 3.4)

Channel proteins: Proteins that selectively allow materials, such as certain ions, to pass into or out of the cell. (Chapter 3.2)

Checkpoint: Control points in the cell cycle where the cell ensures that it is ready to proceed with DNA replication or cell division. If errors are detected, the cell cycle may be halted. (Chapter 3.5)

Chromatid: One of the two identical halves of a chromosome after DNA replication. (Chapter 3.5)

Chromatin: A complex of DNA and proteins (histones) found in the nucleus, which condenses into chromosomes during cell division. (Chapter 3.4, Chapter 3.5)

Cilia: Short, hair-like projections from the cell surface that are involved in the movement of the cell or the movement of substances along the cell surface. (Chapter 3.4)

Cleavage furrow: A groove that forms in the cell membrane during cytokinesis in animal cells, helping to divide the cell into two daughter cells. (Chapter 3.5)

Concentration gradient: A difference in the concentration of a substance across a space or membrane, driving diffusion and osmosis. (Chapter 3.3)

Cytokinesis: The final step of cell division, where the cytoplasm divides, and two distinct daughter cells are formed. (Chapter 3.5)

Cytoplasm: The gel-like substance inside the cell membrane, excluding the nucleus, that contains organelles and the cytosol, where most cellular processes occur. (Chapter 3.4)

Cytoskeleton: A network of protein fibers that provides structural support, facilitates cell movement, and plays a role in intracellular transport and cell division. (Chapter 3.4)

Cytosol: The gel-like fluid inside a cell where organelles, proteins, and molecules are suspended. (Chapter 3.2, Chapter 3.4)

Diffusion: The passive movement of molecules from an area of higher concentration to a lower concentration until equilibrium is reached. (Chapter 3.3)

Diploid: A cell that contains two full sets of chromosomes (2n), one set from each parent. (Chapter 3.5)

Dual receptor proteins: A membrane receptor that can bind to two different ligands or perform two distinct functions within a signaling pathway. (Chapter 3.2)

Endocytosis: A process where the cell engulfs substances by forming a vesicle, allowing the intake of large molecules. (**Chapter 3.3**)

Endoplasmic Reticulum (ER): An extensive network of membranes involved in protein and lipid synthesis. It comes in two forms: smooth and rough. (**Chapter 3.4**)

Eukaryotic cells: Cells that contain a nucleus and other membrane-bound organelles, such as mitochondria and the endoplasmic reticulum. (**Chapter 3.4**)

Exocytosis: A process where vesicles fuse with the plasma membrane to release substances outside the cell, used for removing waste or secreting proteins. (**Chapter 3.3**)

Extracellular fluid: Watery environments outside of the cell. (**Chapter 3.2**)

Extracellularly: Outside the cell. (**Chapter 3.2**)

Facilitated diffusion: A type of passive transport where molecules (e.g., glucose, ions) move across the membrane with the help of carrier or channel proteins. (**Chapter 3.3**)

Flagella: Long, whip-like structures that enable the cell to move. (**Chapter 3.4**)

Germ (or sex) cells: Reproductive cells (e.g., sperm and eggs) that carry half the genetic information (haploid) and combine during fertilization to form a zygote. (**Chapter 3.5**)

Glucose: A simple sugar that serves as the primary energy source for cells, used in cellular respiration to produce ATP. (**Chapter 3.3**)

Glucose transporter: A membrane protein that facilitates the movement of glucose into the cell through facilitated diffusion or active transport. (**Chapter 3.3**)

Glycoproteins: Proteins that have carbohydrate molecules attached that extend outside of the cell. (**Chapter 3.2**)

Golgi apparatus: A stack of membranous sacs involved in the modification, sorting, and packaging of proteins and lipids for secretion or delivery to other organelles. (**Chapter 3.4**)

Growth 1 phase (G1 phase): The first phase of interphase, where the cell grows, synthesizes proteins, and prepares for DNA replication. (**Chapter 3.5**)

Growth 2 phase (G2 phase): The final phase of interphase, where the cell continues to grow and prepares for mitosis by synthesizing proteins necessary for cell division. (**Chapter 3.5**)

Homologous: Refers to chromosomes that are similar in structure, size, and genetic content, one inherited from each parent. (**Chapter 3.5**)

Hydrophilic: Molecules or substances that are attracted to water and can dissolve or interact with it easily. (**Chapter 3.2**)

Hydrophobic: Molecules or substances that repel water and do not dissolve in it. (**Chapter 3.2**)

Hypertonic: A solution with a higher solute concentration outside the cell, causing water to move out of the cell, leading to cell shrinkage (crenation in animal cells). (**Chapter 3.3**)

Hypotonic: A solution with a lower solute concentration outside the cell, causing water to move into the cell, which may lead to cell swelling or bursting (lysis in animal cells). (**Chapter 3.3**)

Integral proteins: Proteins that are embedded in the membrane. (**Chapter 3.2**)

Intercellular fluid: The fluid found inside cells, making up about two-thirds of the total body water; also called cytosol. (**Chapter 3.2**)

Intermediate filaments: Protein fibers that provide structural support and mechanical strength to the cell, helping to maintain its shape and resist stress. (**Chapter 3.4**)

Interphase: The phase of the cell cycle where the cell grows, replicates DNA, and prepares for mitosis. (**Chapter 3.5**)

Ion channel proteins: Membrane proteins that form pores in the cell membrane, allowing specific ions (e.g., Na^+, K^+, Ca^{2+}, Cl^-) to pass through. (**Chapter 3.2**)

Ions: Charged particles (positively or negatively) that are essential for cellular processes, such as nerve signaling and muscle contraction (e.g., Na^+, K^+, Ca^{2+}, Cl^-). (**Chapter 3.3**)

Isotonic: A solution in which the concentration of solutes is equal inside and outside the cell, resulting in no net movement of water across the membrane. (**Chapter 3.3**)

Ligand: A molecule that binds to a receptor protein to initiate a biological response. (**Chapter 3.2**)

Lysing: The rupturing of a cell due to excessive water intake in a hypotonic environment. (**Chapter 3.3**)

Lysosome: An organelle containing digestive enzymes that break down waste, cellular debris, and foreign substances. (**Chapter 3.4**)

Malignant: Refers to a tumor or growth that is cancerous, capable of invading

surrounding tissues and spreading to other parts of the body (a process known as metastasis). (Chapter 3.5)

Metaphase: The stage of mitosis where chromosomes align in the middle of the cell along the metaphase plate. (Chapter 3.5)

Metastasized: Refers to the process by which cancer cells spread from their original (primary) site to other parts of the body, forming secondary tumors. (Chapter 3.5)

Microfilaments: Thin protein fibers that help support the cell's shape and assist with movement. (Chapter 3.4)

Microtubules: Hollow protein structures that form part of the cytoskeleton and are involved in intracellular transport and cell division. (Chapter 3.4)

Mitochondria: Organelles known as the powerhouse of the cell, responsible for ATP production through cellular respiration. (Chapter 3.4)

Mitosis: A process of cell division in which a single cell divides to produce two identical daughter cells, maintaining the same chromosome number as the original cell. (Chapter 3.5)

Mitosis phase: The phase of the cell cycle in which the nucleus divides into two identical nuclei, each containing the same number of chromosomes. (Chapter 3.5)

Nuclear envelope: A double membrane surrounding the nucleus, containing nuclear pores that regulate the passage of materials between the nucleus and cytoplasm. (Chapter 3.4)

Nuclear membrane: The double-layered membrane that surrounds the nucleus, separating the nuclear contents from the cytoplasm. (Chapter 3.4)

Nuclear pores: Protein complexes embedded in the nuclear envelope that regulate the transport of molecules (such as RNA and proteins) between the nucleus and cytoplasm. (Chapter 3.4)

Nucleolus: A dense structure within the nucleus responsible for ribosome production. (Chapter 3.4)

Nucleus: The control center of the cell, containing genetic material (DNA) and regulating cell activities. (Chapter 3.4)

Nutrients: Substances needed for cell survival and function, including carbohydrates, proteins, fats, vitamins, and minerals. (Chapter 3.3)

Organelles: Specialized structures within a cell that perform specific functions (e.g., mitochondria, Golgi apparatus, lysosomes). (Chapter 3.4)

Osmosis: The passive movement of water molecules across a selectively permeable membrane from a region of lower solute concentration to a region of higher solute concentration. (**Chapter 3.3**)

Passive transport: The movement of substances across the cell membrane without requiring energy, including diffusion, facilitated diffusion, and osmosis. (**Chapter 3.3**)

Peripheral proteins: Proteins that are attached to the surface of the cell membrane and participate in cell signaling and structural support. (**Chapter 3.2**)

Peroxisome: Membrane-bound organelles that contain enzymes for the breakdown of fatty acids and the detoxification of hydrogen peroxide. (**Chapter 3.4**)

Phagocytosis: A type of endocytosis where the cell engulfs large particles or microorganisms, forming a vesicle that fuses with a lysosome for digestion. (**Chapter 3.3**)

Phospholipid: A molecule with a hydrophilic head and two hydrophobic tails that makes up the cell membrane. (**Chapter 3.2**)

Pinocytosis: A type of endocytosis where the cell engulfs extracellular fluid and dissolved substances into small vesicles. (**Chapter 3.3**)

Plasma membrane: Another term for the cell membrane; a selectively permeable barrier that controls the movement of substances in and out of the cell. (**Chapter 3.2**)

Prophase: The first stage of mitosis, where chromatin condenses into chromosomes, the nuclear envelope breaks down, and spindle fibers begin to form. (**Chapter 3.5**)

Receptor: Proteins in the cell membrane that bind to specific molecules (ligands) to trigger a cellular response. (**Chapter 3.2**)

Receptor-mediated endocytosis: A specialized form of endocytosis where specific molecules bind to cell-surface receptors, triggering vesicle formation to bring them inside. (**Chapter 3.3**)

Replicates: The process of duplicating a molecule, cell, or organelle to create an exact replica. (**Chapter 3.5**)

Ribosomes: Small organelles that synthesize proteins by translating messenger RNA (mRNA). (**Chapter 3.4**)

Rough endoplasmic reticulum (RER): A type of endoplasmic reticulum covered with ribosomes, responsible for protein synthesis and modification. (**Chapter 3.4**)

Selective permeability: The ability of the cell membrane to regulate which substances can enter or exit the cell. (**Chapter 3.3**)

Semipermeable: A property of the cell membrane that allows certain molecules to pass through while restricting others, maintaining internal balance; also known as selectively permeable. (**Chapter 3.3**)

Simple diffusion: The movement of small, nonpolar molecules across the membrane from a higher to a lower concentration without the help of membrane proteins. (**Chapter 3.3**)

Smooth endoplasmic reticulum: The part of the ER lacking ribosomes, involved in lipid synthesis, detoxification, and calcium storage. (**Chapter 3.4**)

Sodium-potassium pump: A transport protein that actively moves sodium ions out of the cell and potassium ions into the cell, maintaining cellular ion balance. (**Chapter 3.3**)

Somatic cell: Any cell that is not involved in reproduction, containing a full set of chromosomes (diploid, 2n). Examples include skin cells, muscle cells, and liver cells. (**Chapter 3.5**)

Spindle fibers: Microtubules that form during mitosis and help separate chromosomes. (**Chapter 3.5**)

Synthesis phase (S phase): The phase of interphase where the cell replicates its DNA, ensuring each daughter cell receives an identical set of chromosomes. (**Chapter 3.5**)

Telophase: The final stage of mitosis, where chromosomes reach opposite ends of the cell, the nuclear envelope reforms, and the chromosomes decondense into chromatin. (**Chapter 3.5**)

Vesicle: A small, membrane-bound sac that transports substances within or outside the cell. (**Chapter 3.3**)

Wastes: Unwanted byproducts of cellular metabolism that must be removed to maintain homeostasis, such as carbon dioxide (CO_2) and urea. (**Chapter 3.3**)

PART IV

CHAPTER 4 STRUCTURE AND FUNCTION OF TISSUES

4.1 Introduction

Chapter Competency

Correlate the structure of tissues with their functions.

Learning Objectives

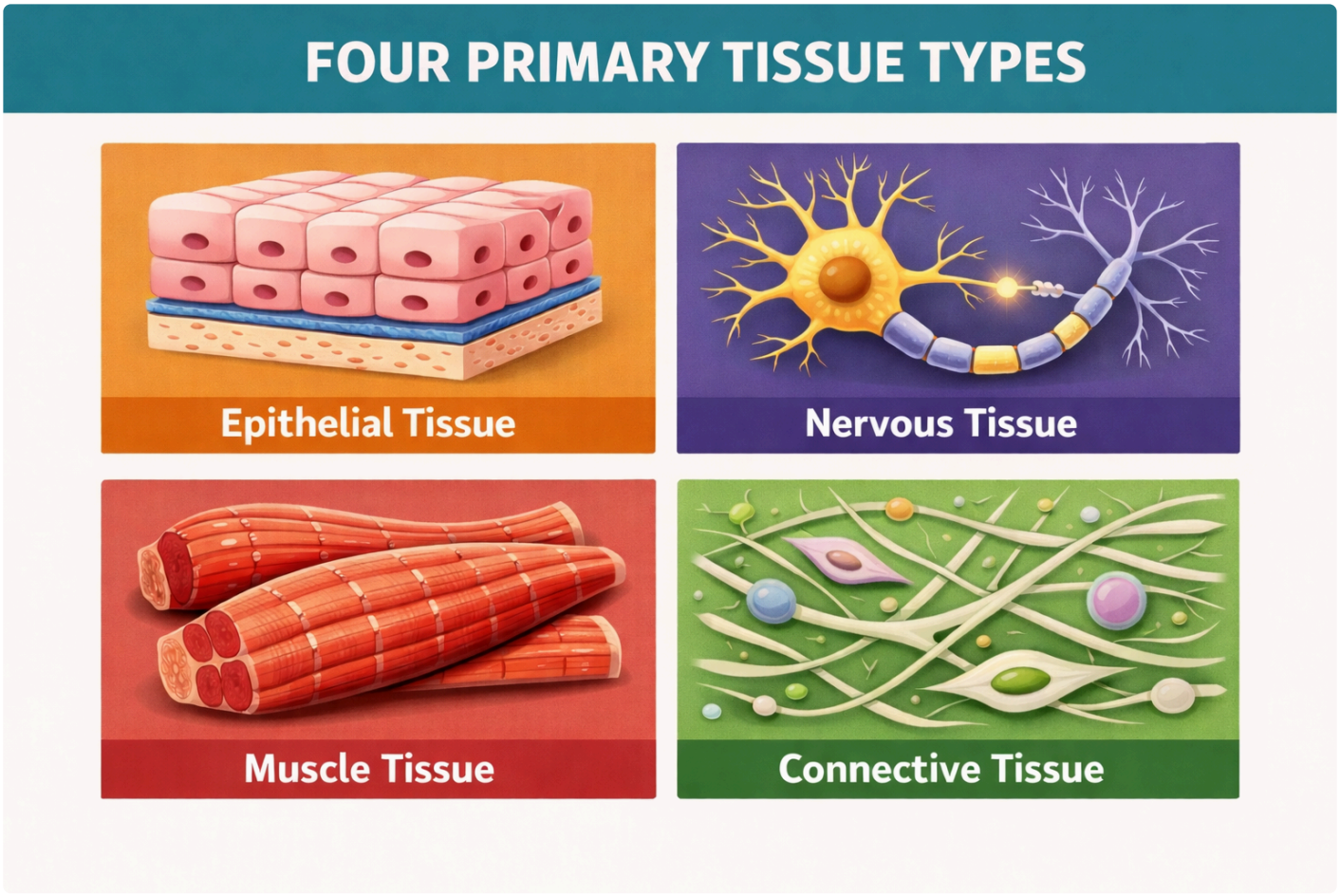
- Identify tissue based on the structural components.
- Distinguish among the four types of tissues.
- Relate structural components with tissue functions.

Imagine you are working as a surgical technologist assisting during a surgical procedure. As the surgeon makes an incision, different tissues are encountered, including skin, connective tissue, muscle, blood vessels, and nerves. Each tissue has a unique structure and function, and each responds differently to cutting, stretching, bleeding, repair, and healing. To support safe patient care in the operating room, you must understand how tissues are organized and how their structures relate to their functions.

Tissues are groups of similar cells that work together to perform specific functions. Although the human body contains many specialized cells, these cells are organized into four primary tissue types: epithelial, connective, muscle, and nervous tissue. Each tissue type has unique structural features that allow it to protect surfaces, support and connect body parts, produce movement, or transmit electrical signals.

In this chapter, you will explore the structure and function of the four primary tissue types. You will learn how epithelial tissue covers surfaces, lines cavities, and forms glands. You will examine how connective tissue supports, protects, stores energy, and transports substances throughout the body. You will also study muscle tissue, which produces movement, and nervous tissue, which sends and receives electrical signals. As you compare these tissue types, you will see how microscopic structure relates directly to function.

By mastering these concepts, you will gain a deeper understanding of how cells work together to form tissues, how tissues contribute to organs and body systems, and how changes in tissue structure can affect health. This foundation will prepare you to better understand later chapters on the integumentary, skeletal, muscular, nervous, cardiovascular, and other body systems.



4.1 Four Primary Tissue Types of the Human Body

[1]

1. OpenAI. (2026, March 1). *Four primary tissue types of the human body* [Large language model prompt]. ChatGPT.

4.2 Categories of Tissues

The term **tissue** is used to describe a group of cells that work together in the human body. Although there are many types of cells in the body, they are organized into four main categories of tissues:

- Epithelial
- Connective
- Muscle
- Nervous

See Figure 4.2[1] for an illustration of these four categories of tissues.

1. OpenStax College. (2013). *401 Types of tissue* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:401_Types_of_Tissue.jpg

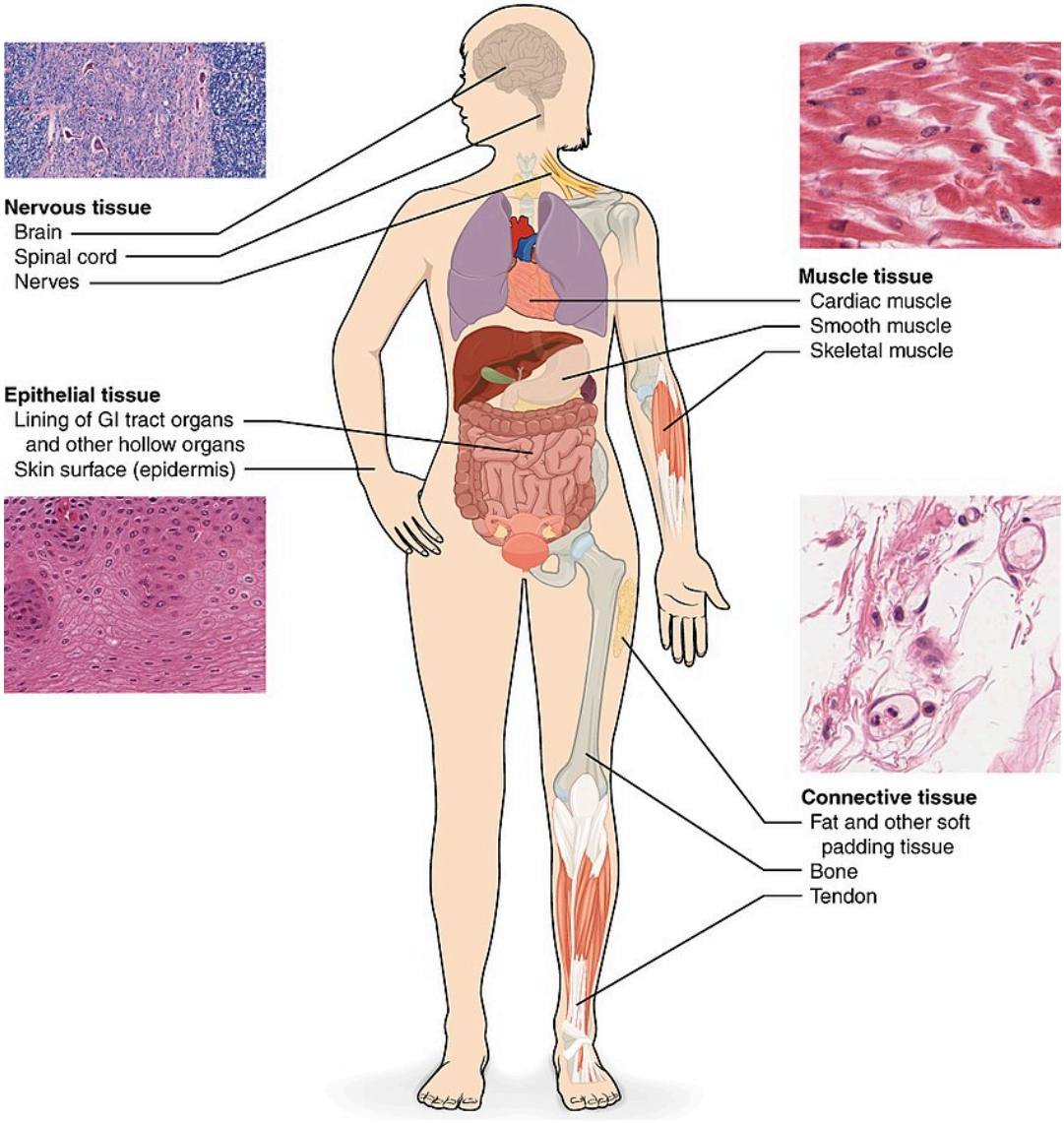


Figure 4.2 Four Categories of Tissues

Each category of tissue has specific functions that contribute to the overall health and maintenance of the body. **Histology** is the study of tissues, including their appearance, organization, and function. The remaining subsections of this section will discuss these four categories of tissue.

Epithelial Tissue

Epithelial tissue, also referred to as **epithelium**, is a large sheet of cells that cover surfaces of the body that are exposed to the surrounding environment (such as the skin),

line the insides of organs and blood vessels, internal body cavities and passageways, and form certain glands. For this reason, epithelium can be remembered as a "covering."

Epithelial tissue is primarily composed of cells, with little to no material between the cells. The **apical surface** is the top layer of the epithelial tissue that is exposed to the environment. The **basal surface** is the bottom layer that is attached to a **basement membrane**, which connects the epithelial tissue to structures deep in the tissue.

Epithelial tissue is mostly **avascular**, meaning it doesn't have a blood supply. Therefore, nutrients must diffuse or be absorbed from the underlying tissue or from the surface of the epithelial tissue. This contributes to its role as a barrier, preventing infectious material from directly entering the bloodstream from the environment.

Epithelial tissue goes through rapid **mitosis** (cell division) to replace damaged and/or dead cells. The deepest layer of the tissue is the only one that divides, and as cells get pushed closer to the surface, they flatten out and die. The sloughing off of dead cells is a characteristic of surface epithelium and allows our skin, airways, and digestive tracts to rapidly replace damaged cells with new cells.

Functions of Epithelial Tissue

There are three main functions of epithelial tissue, including protection, secretion, and movement:

- Protection: Epithelial tissue's main job is to protect the body from physical, chemical, and biological wear and tear. Epithelial cells act as a physical barrier because all substances that enter the body must cross an epithelium.
    - For example, the skin on your hands protects the tissues underneath from damage when you handle or touch something.
- Secretion: Many epithelial cells are capable of secretion and release mucus and chemicals onto their apical surfaces.
    - For example, the epithelium of the small intestine releases digestive enzymes to help digest food, and cells lining the respiratory tract secrete mucus that traps dust and bacteria.
- Movement: Some epithelial cells help move particles and secretions in the body. Cilia are tiny hair-like extensions of the apical cell membrane of these types of epithelial tissue. **Cilia** beat in unison and move fluids, as well as trapped particles.
    - For example, respiratory airways have a ciliated epithelium that sweeps particles of dust and pathogens trapped in the mucus up toward the throat, where they

can be swallowed and broken down in the acidic environment of the stomach. In the Fallopian tubes, the cilia help move the oocyte (egg cell) from the ovary to the uterus.

Classifications of Epithelial Tissues

Epithelial tissues are classified based on two characteristics: the number of cell layers and the shape of the cells in these layers.

Layers of epithelial tissue can be classified as simple, stratified, or pseudostratified:

- **Simple epithelium**: Simple epithelium has one layer of cells.
- **Stratified epithelium**: Stratified epithelium has more than one layer of cells.
  - **Transitional epithelium**: Transitional epithelium is a specialized type of stratified epithelium in which the shape of the cells can change.
- **Pseudostratified epithelium**: Pseudostratified epithelium (where the term *pseudo* means "false") contains a single layer of cells that appears like more than one layer due to the various locations of cell nuclei in different areas of the layer. These "staggered" nuclei make this tissue look as though it has more than one layer of cells.

Simple and stratified epithelium contains the following types of cells:

- **Squamous epithelium**: Squamous cells are irregular-shaped, flat, thin cells. They look "squashed."
- **Cuboidal epithelium**: Cuboidal cells are box- or cube-shaped cells.
- **Columnar epithelium**: Columnar cells are rectangular-shaped cells, meaning they are taller than they are wide. They look like little columns or rectangles standing on end.

Pseudostratified epithelium only contains columnar cells.

See Figure 4.3[2] for an illustration of different types of cell layers and cell types.

2. OpenStax College. (2013). *403 Epithelial tissue* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:403_Epithelial_Tissue.jpg

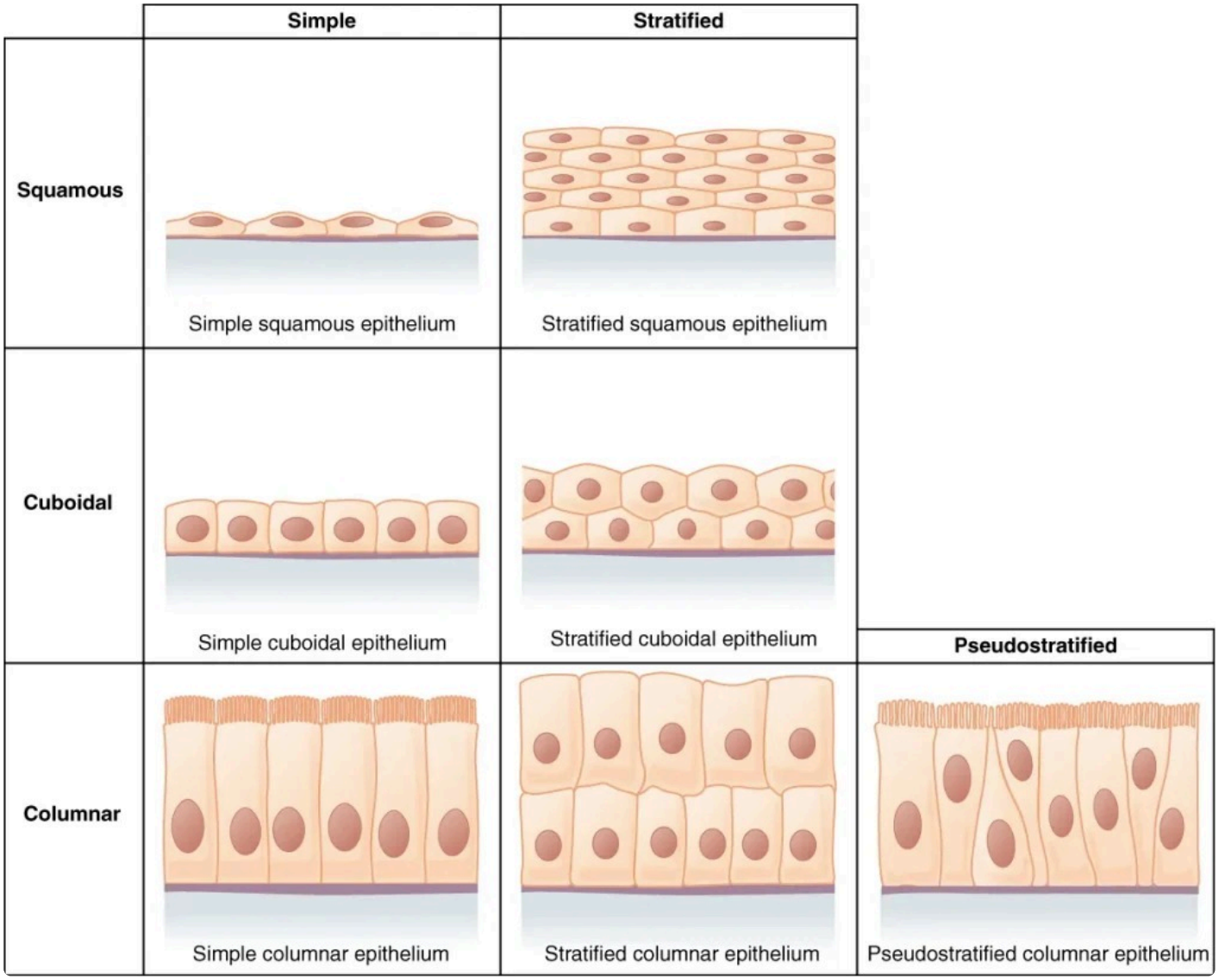


Figure 4.3 Cell Layers and Cell Types

Simple Epithelium

Simple epithelium has one layer of cells with different or unique shapes that reflect tissue function. Simple epithelium can be further divided into squamous, cuboidal, or columnar types of cells:

- **Simple squamous epithelium**: A single layer of irregular-shaped cells that are thin and flat, like the scales of a fish. Nuclei are similar to cells and are flat, horizontal, and oval.
    - For example, **endothelium** is composed of simple squamous epithelium tissue that lines blood vessels. Air sacs in the lungs and blood capillary walls also contain

simple squamous epithelium. This very thin layer of squamous cells allows oxygen and carbon dioxide to easily diffuse across during gas exchange.

- **Simple cuboidal epithelium**: A single layer of cells that are cube or box-shaped. Their nuclei are round and located near the center of the cell.
  - For example, kidney tubules and sweat glands are made of simple cuboidal epithelium tissue. Their cuboidal shape is important for secretion and absorption.
- **Simple columnar epithelium**: A single layer of cells that are rectangular shaped. The nuclei are elongated and located near the bottom (basal surface) of the cells.
  - For example, some parts of the digestive system are composed of non-ciliated simple columnar epithelium. Like the cuboidal epithelium, these cells are active in absorption and secretion.
  - Another example is ciliated columnar epithelium. These simple columnar epithelial cells have cilia on their apical surfaces and are found in parts of the respiratory system and the lining of the Fallopian tubes in the female reproductive system.
- **Pseudostratified columnar epithelium**: A single layer of columnar cells that appear to be stratified (i.e., have multiple layers) but consist of a single layer of irregularly shaped and different-sized cells. The nuclei appear in different areas of the cells, giving the tissue the appearance of multiple layers, but all the cells are in contact with the basal surface. However, some columnar cells do not reach the apical surface.
  - For example, pseudostratified columnar epithelium is found in the respiratory tract, where some of these cells also have cilia.

Both simple and pseudostratified columnar epithelia may also contain additional types of cells. For example, the **goblet cell**, a mucous-secreting cell (also called a "gland"), is found in the columnar epithelial cells of mucous membranes. See Figure 4.4[3] for an illustration of a goblet cell.

3. OpenStax Anatomy and Physiology. (2016). *404b Goblet cell* [Photograph]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:404b_Goblet_Cell_new.jpg

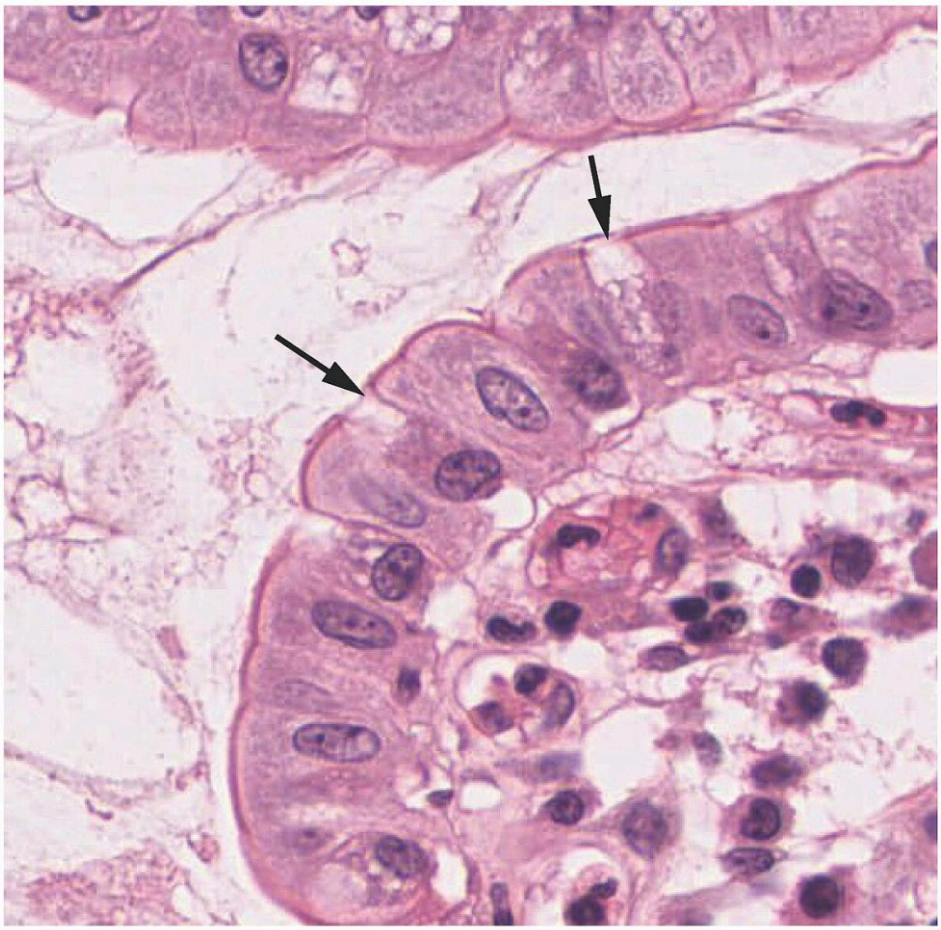


Figure 4.4 Goblet Cell

Stratified Epithelium

Stratified epithelium consists of two or more layers of cells. This epithelium protects the body against physical and chemical wear and tear. Stratified epithelium is named by the shape of its apical layer of cells (i.e., those closest to the surface) and includes the following types of cells:

- **Stratified squamous epithelium**: The apical cells of stratified squamous epithelium are squamous, whereas the basal layer contains either columnar or cuboidal cells. This is the most common type of stratified epithelium in the human body and is often found in areas that encounter friction. The top layer may or may not be covered with dead cells filled with **keratin** (a protein that makes skin strong).
  - For example, skin is composed of keratinized stratified squamous epithelium, but the lining of the mouth is composed of nonkeratinized stratified

squamous epithelium.

- **Stratified cuboidal epithelium** and **stratified columnar epithelium**: Stratified cuboidal epithelium consists of two to three layers of cube-shaped cells. Stratified columnar epithelium is composed of two layers of column-shaped cells. These two tissue types are rare in the human body and are found only in certain glands and ducts.
  - For example, stratified columnar epithelium is found in the urethra.
- **Transitional stratified epithelium**: Transitional stratified epithelium consists of apical cells that change shape in response to certain conditions.
  - For example, the urinary bladder is lined with transitional stratified epithelium. When the bladder is empty, the cells in the apical layer are cuboidal. As the bladder fills with urine, the apical cells transition from cuboidal to squamous. The transitional stratified epithelium appears thicker and multilayered when the bladder is empty, and more stretched out and less stratified when the bladder is full.

Figure 4.5[4] summarizes the locations and functions of simple, stratified, and pseudostratified epithelium.

4. OpenStax College. (2013). *423 Table 04 02 summary of epithelial tissue cells* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:423_Table_04_02_Summary_of_Epithelial_Tissue_CellsN.jpg

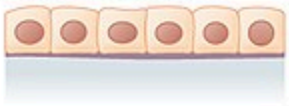
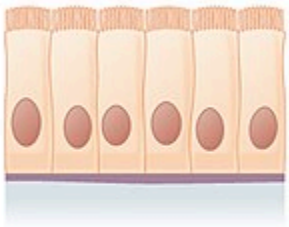
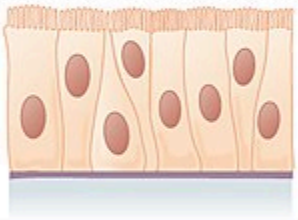
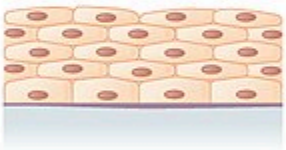
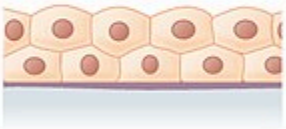
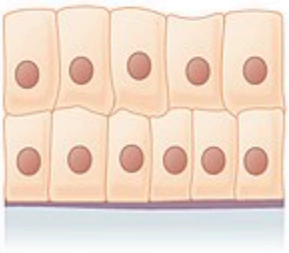
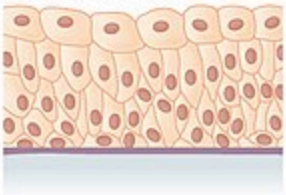
Cells	Location	Function
Simple squamous epithelium 	Air sacs of lungs and the lining of the heart, blood vessels, and lymphatic vessels	Allows materials to pass through by diffusion and filtration, and secretes lubricating substance
Simple cuboidal epithelium 	In ducts and secretory portions of small glands and in kidney tubules	Secretes and absorbs
Simple columnar epithelium 	Ciliated tissues are in bronchi, uterine tubes, and uterus; smooth (nonciliated tissues) are in the digestive tract, bladder	Absorbs; it also secretes mucous and enzymes
Pseudostratified columnar epithelium 	Ciliated tissue lines the trachea and much of the upper respiratory tract	Secretes mucus; ciliated tissue moves mucus
Stratified squamous epithelium 	Lines the esophagus, mouth, and vagina	Protects against abrasion
Stratified cuboidal epithelium 	Sweat glands, salivary glands, and the mammary glands	Protective tissue
Stratified columnar epithelium 	The male urethra and the ducts of some glands	Secretes and protects
Transitional epithelium 	Lines the bladder, uretha, and the ureters	Allows the urinary organs to expand and stretch

Figure 4.5 Location and Functions of Simple and Pseudostratified Epithelium

Glandular Epithelium

A **gland** is a structure made up of one or more cells that can synthesize (make) and secrete substances. Most glands are made up of groups of epithelial cells. Glands are classified as endocrine or exocrine:

- **Endocrine glands**: Endocrine glands are ductless glands that release secretions called hormones directly into the blood (with *endo* meaning "inside"). **Hormones** are released into the bloodstream and transported to cells with receptors for that particular hormone.
  - Examples of endocrine glands include the pituitary gland, thyroid gland, adrenal gland, and pancreas.
  - Examples of hormones include the human growth hormone (hGH), insulin, adrenaline, melatonin, estrogen, and testosterone.
- **Exocrine glands**: Exocrine glands release secretions through a duct (or tube) that opens to the surface (with *exo* meaning "outside").
  - Examples of secretions from exocrine glands are mucous, sweat, saliva, digestive enzymes, and breast milk

Connective tissue is the second category of tissue. **Connective tissue**, as its name implies, connects cells and organs to help protect, support, and bind together all parts of the body. Most of the body is composed of connective tissue. The basic structure of connective tissues is cells embedded in a matrix, similar to how fruit pieces appear in gelatin salad. **Matrix** is made up of a ground substance (or "filler") and almost always contains protein fibers. Matrix can be a fluid, gel, or solid.

Classification of Connective Tissue

Connective tissue comes in many forms that are classified based on the characteristics of their cells, matrix, and fibers.

Cells

Different types of cells found in connective tissue include the following:

- **Fibroblasts**: Fibroblasts secrete substances that combine with fluids to form the matrix. They are the most abundant cells in connective tissue and are present in all

types.

- **Adipocytes**: Adipocytes store fat. The number and type of adipocytes depend on their location and vary among individuals.
- **Mesenchymal cells**: Mesenchymal cells are adult stem cells. These cells can differentiate into any type of connective tissue cell that is needed for the repair and healing of damaged tissue.
- **Macrophages**: Macrophages are large cells that develop from white blood cells called monocytes. Macrophages are an important part of the immune system that defends the body against **pathogens**, disease-causing organisms, such as bacteria and fungi.
- **Mast cells**: When irritated or damaged, mast cells release histamine, which causes vasodilation and increased blood flow at the site of injury or infection, along with itching, swelling, and redness.

See Figure 4.6[5] for an illustration of different types of cells in connective tissue.

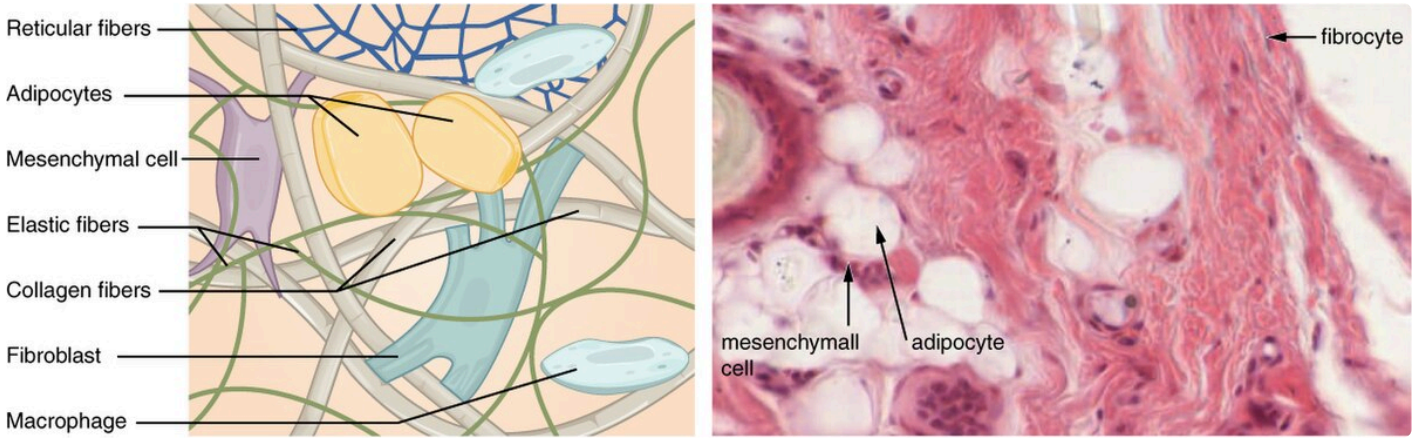


Figure 4.6 Different Types of Cells in Connective Tissue

Matrix

Matrix is a second component used to classify connective tissue that is secreted by fibroblasts. It is composed of a gel-like material called ground substance that is clear and viscous.

5. OpenStax College. (2013). *408 Connective tissue* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:408_Connective_Tissue.jpg

Protein Fibers

Protein fibers are a third component used to classify connective tissue. Three main types of protein fibers include collagen, elastic, and reticular fibers:

- **Collagen fibers** are made from fibrous protein subunits linked together to form a long and straight fiber. Collagen fibers, while flexible, have great strength, resist stretching, and give ligaments and tendons their characteristic resilience and strength.
- **Elastic fibers** contain the protein **elastin**, along with smaller amounts of other proteins and glycoproteins. The main property of elastin is that it returns to its original shape after being stretched or compressed. Elastic fibers are found in elastic tissues in the skin and the elastic ligaments of the vertebral column.
- **Reticular fibers** are formed from the same protein subunits as collagen fibers, but these fibers remain narrow and are arranged in a branching pattern. They are found throughout the body but are most abundant in the reticular tissue of soft organs, such as the liver and spleen.

Functions of Connective Tissues

Connective tissues perform many functions in the body. Major functions include the following:

- Support and connect tissues: For example, tendons attach muscles to bones, and bones support the soft tissues of the body.
- Protect: For example, fibrous capsules and bones protect delicate organs.
- Transport: For example, fluids, nutrients, wastes, and chemical messengers are moved throughout the body by blood and lymph.
- Storage: For example, adipose cells store surplus energy in the form of fat and help insulate the body.

Categories of Connective Tissue

There are three categories of connective tissue based on the types of their cells, the characteristics of their matrix, and the types of protein fibers found within the matrix. These categories include connective tissue proper, supportive, and fluid.

Connective tissue proper includes loose connective tissue and dense connective tissue. Both subtypes of tissue have a variety of cell types and protein fibers suspended in a matrix. Dense connective tissue is reinforced by bundles of fibers that provide tensile strength, elasticity, and protection. In loose connective tissue, the fibers are loosely organized, leaving large spaces in between. **Supportive connective tissue** includes bone and cartilage that provide structure and strength to the body and protect soft tissues. In bone connective tissue, the matrix is rigid and described as calcified because of the deposited calcium salts. **Fluid connective tissue** includes blood and lymph that contain specialized cells that circulate throughout the body in a watery fluid containing salts, nutrients, and dissolved proteins. See Table 4.1 for a table summarizing the major types of connective tissue. Each of these categories of connective tissue is described in further detail in the following subsections.

Table 4.1. Types of Connective Tissue

Connective Tissue Proper	Supportive Connective Tissue	Fluid Connective Tissue
Loose Connective Tissue • Areolar • Adipose • Reticular Dense Connective Tissue • Dense regular • Elastic • Dense irregular	Cartilage • Hyaline • Fibrocartilage • Elastic Bone • Compact • Spongy	Blood Lymph

Loose Connective Tissue

Loose connective tissue is found between many organs to absorb shock and connect tissues together. In loose connective tissue, the protein fibers are loosely organized, leaving large spaces between them. There are three types of loose connective tissue: adipose, areolar, and reticular.

Adipose tissue contains mostly fat storage cells with only a small amount of matrix. In

addition to fat storage, adipose tissue also insulates the body and protects organs from injury. See Figure 4.7[6] for an image of adipose tissue.

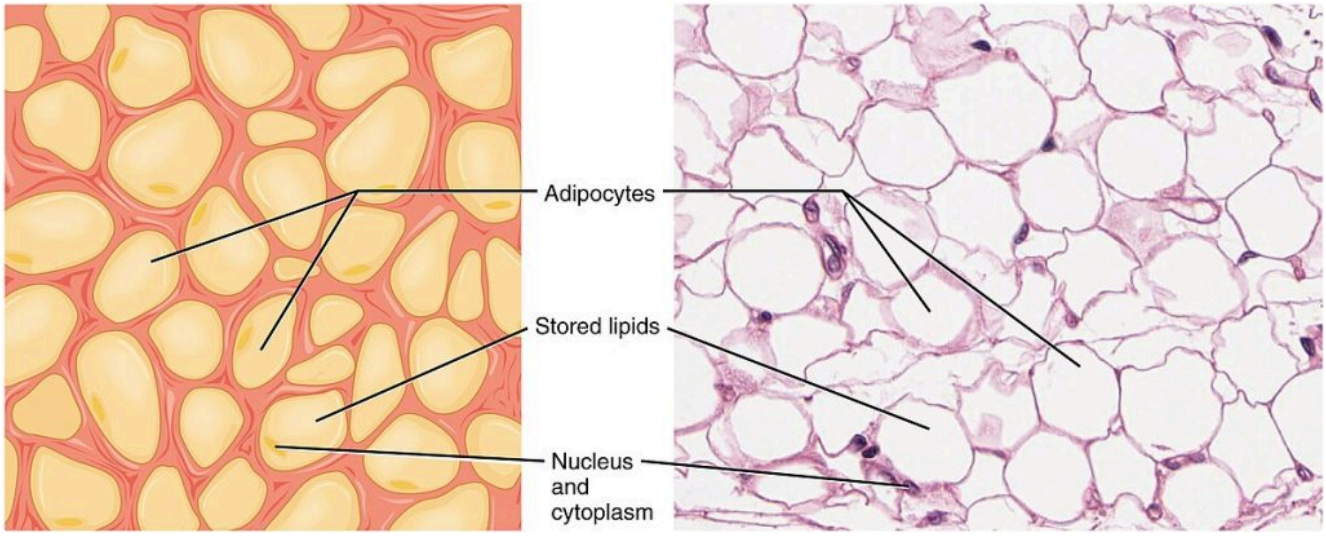


Figure 4.7 Adipose Tissue

Areolar tissue fills the spaces between muscle fibers, surrounds blood and lymph vessels, and supports organs in the abdominal cavity. Areolar tissue is found underneath most epithelial tissues and is the connective tissue component of epithelial membranes. See Figure 4.8[7] for an image of areolar tissue.

6. OpenStax College. (2013). *409 Adipose tissue* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:409_Adipose_Tissue.jpg
7. Berkshire Community College Bioscience Image Library. (2018). *Connective tissue loose aerolar (39977986150)* [Photograph]. Wikimedia Commons. CC0. https://commons.wikimedia.org/wiki/File:Connective_Tissue_Loose_Aerolar_(39977986150).jpg

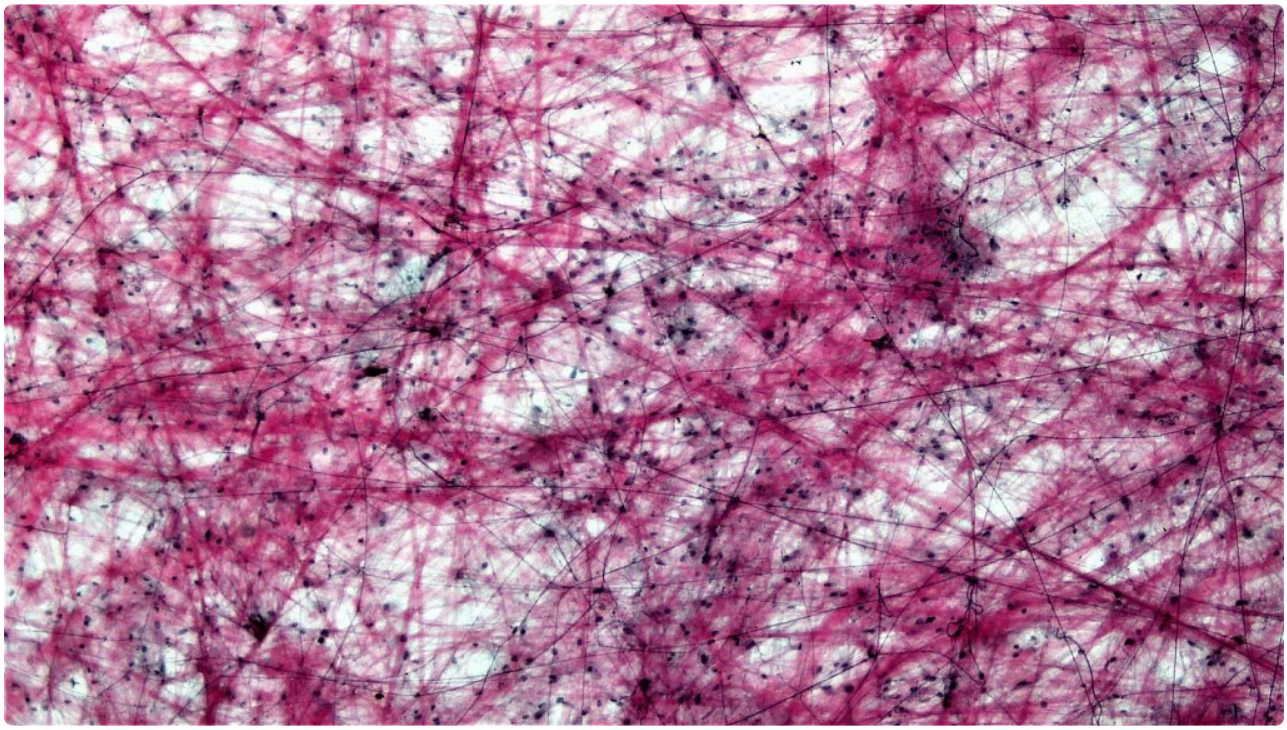


Figure 4.8 Areolar Tissue

Reticular tissue is a mesh-like, supportive framework for soft organs such as the spleen and the liver. Reticular cells produce the reticular fibers that form a network for other cells to attach. It derives its name from the Latin word *reticulus*, which means "little net." See Figure 4.9[8] for an image of reticular tissue.

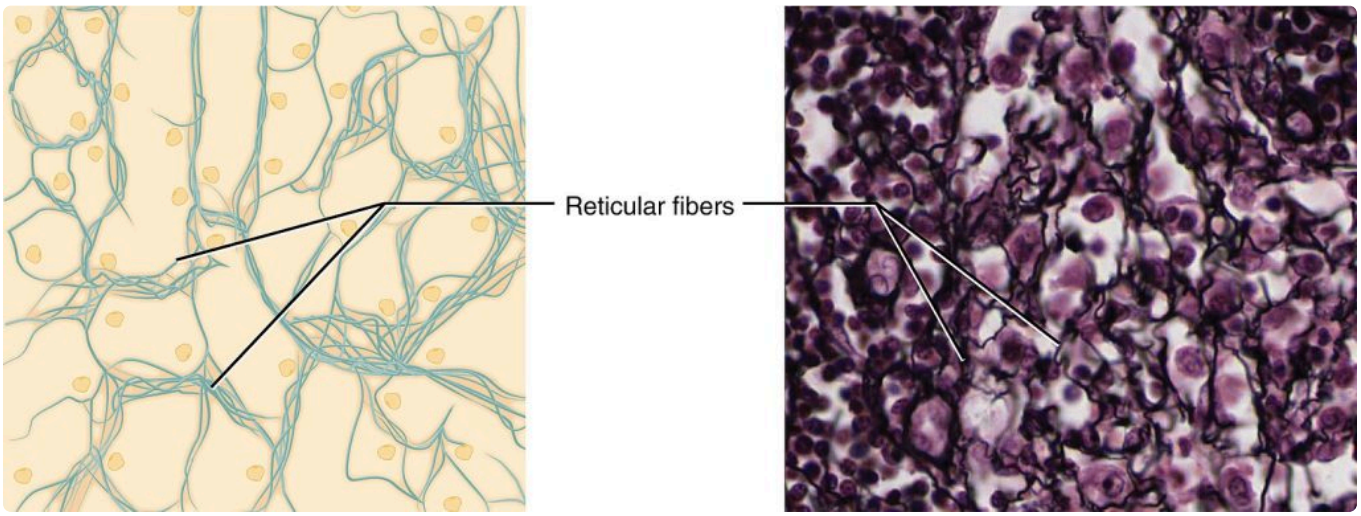


Figure 4.9 Reticular Tissue

8. OpenStax College. (2013). *410 Reticular tissue* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:410_Reticular_Tissue.jpg

Dense Connective Tissue

Dense connective tissue is reinforced by bundles of fibers that provide strength, elasticity, and protection. Dense connective tissue contains more collagen fibers than loose connective tissue, so it has a greater resistance to stretching. There are two major categories of dense connective tissue: dense regular connective tissue and dense irregular connective tissue.

- **Dense regular connective tissue** has fibers arranged in parallel lines. This parallel arrangement gives the tissue excellent tensile (straight-line) strength, making it very strong and resistant to stretching. However, it has poor shear strength, meaning it does not handle sideways (perpendicular) forces well. When forces are applied across the fibers—such as in many knee injuries—the tissue is more likely to tear. Dense regular connective tissue also has a limited blood supply, which slows healing after injury. Tendons and ligaments are composed of this type of connective tissue.
    - **Dense regular elastic tissue** contains elastin fibers, in addition to collagen fibers, which allows the ligament to return to its original length after stretching. The ligaments in the vocal cords and between the vertebrae are elastic.
- **Dense irregular connective tissue** fibers are randomly organized. This arrangement gives the tissue greater strength in all directions. In some tissues, fibers crisscross and form a mesh. The dermis of the skin is an example of dense, irregular connective tissue rich in collagen fibers.
    - **Dense irregular elastic tissues** give arterial walls the strength and the ability to regain their original shape after stretching.

See Figure 4.10[9] for images comparing regular dense connective tissue to irregular dense connective tissue.

9. OpenStax College. (2013). *411 Reg dense-irregular dense* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:411_Reg_Dense-Irregular_Dense.jpg

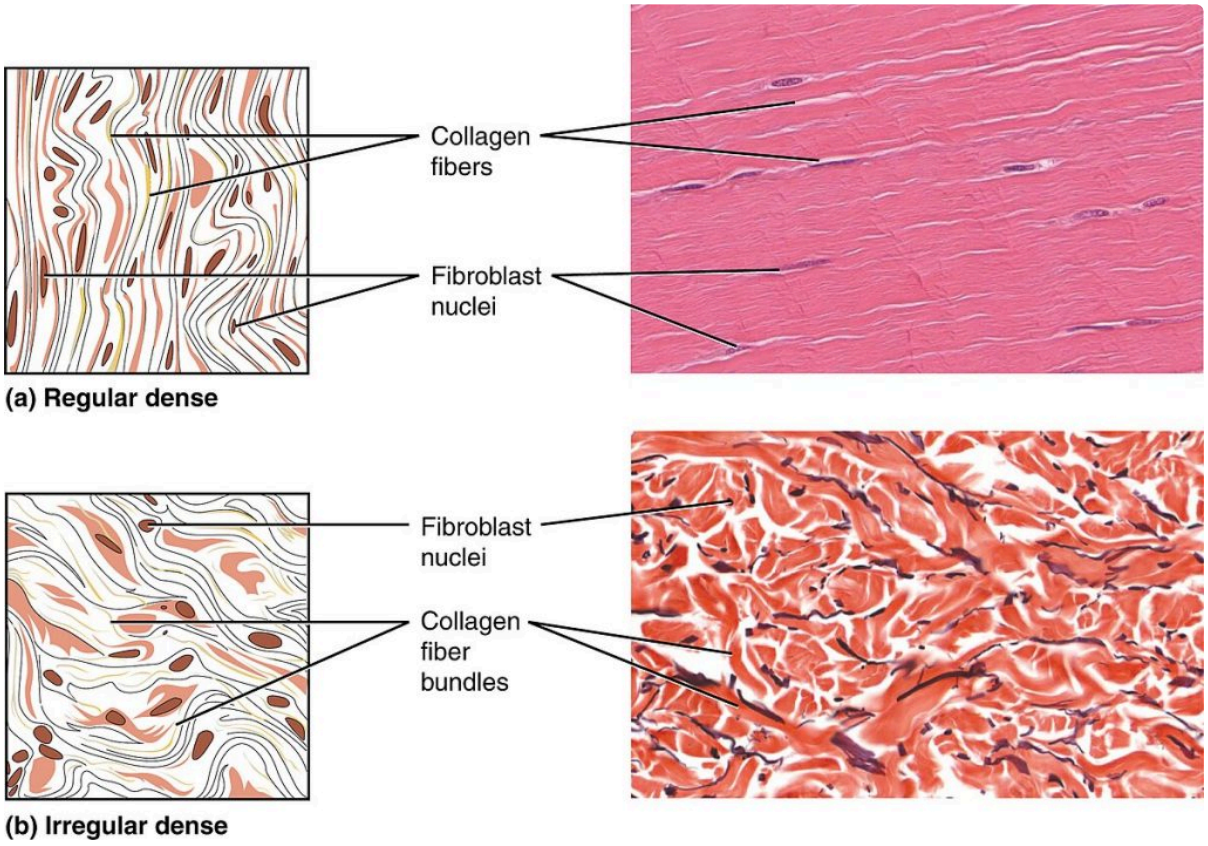


Figure 4.10 Regular (a) and Irregular (b) Dense Connective Tissue

Supportive Connective Tissue

Supportive connective tissue provides structure and strength to the body and protects soft tissues. It is characterized by a few distinct cell types and densely packed protein fibers in a matrix. Two major forms of supportive connective tissue are bone and cartilage.

Bone

Bone is the hardest connective tissue. It provides protection to internal organs and supports the body. Bone's hard extracellular matrix contains mostly collagen fibers in a mineralized ground substance. Without collagen, bones would be brittle and shatter easily. Without minerals, bones would flex and provide little support. Unlike cartilage, bone is highly vascularized and can recover from injuries in a relatively short time. Bone is divided into two main types:

- **Compact bone** (also known as cortical bone) is solid and has a lot of structural

strength. It is arranged into basic units called osteons. To learn more about compact bone **osteons**, refer to the "Skeletal System" chapter.

- **Spongy bone** (also known as cancellous bone) looks like a sponge under the microscope. It contains empty spaces and is lighter than compact bone. It is found in the interior of some bones and at the ends of long bones.

See Figure 4.11[10] for an image of compact bone tissue.

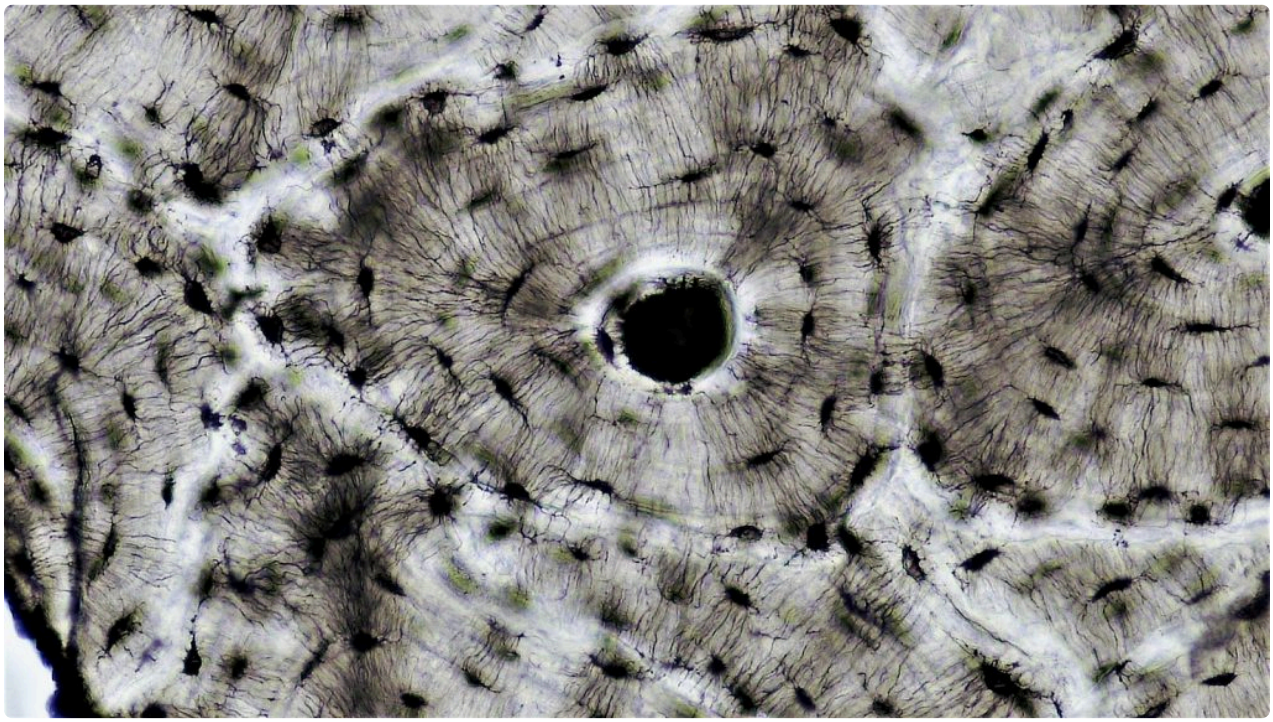


Figure 4.11 Bone Tissue

Cartilage

Embedded within the cartilage matrix are **chondrocytes**, or cartilage cells. Cartilage tissue is avascular (without a blood supply), so all nutrients must diffuse through the matrix to reach the chondrocytes. This characteristic results in the very slow healing of injured cartilage tissue.

Three main types of cartilage tissue are hyaline cartilage, fibrocartilage, and elastic cartilage:

10. Berkshire Community College Bioscience Image Library. (2018). *Connective tissue compact bone (41068142774)* [Photograph]. Wikimedia Commons. CC0. https://commons.wikimedia.org/wiki/File:Connective_Tissue_Compact_Bone_(41068142774).jpg

- **Hyaline cartilage** is the most common type of cartilage in the body. The surface of hyaline cartilage is smooth. It is strong and flexible and is found in the rib cage, the nose, and the ends of long bones.
- **Fibrocartilage** is the strongest of the three cartilage types. It is tough because it has thick bundles of collagen fibers in its matrix. Examples of fibrocartilage are menisci in the knee joint and the intervertebral discs between the vertebrae.
- **Elastic cartilage** contains elastic fibers, as well as collagen. This tissue gives support, as well as elasticity. For example, the external ear contains elastic cartilage. Tug gently at your earlobe and notice how it returns to its original shape.

  See Figure 4.12[11] for illustration of these types of cartilage.

11. OpenStax College. (2013). *412 Types of cartilage-new* [Diagram]. Wikimedia College. CC BY 3.0. https://commons.wikimedia.org/wiki/File:412_Types_of_Cartilage-new.jpg

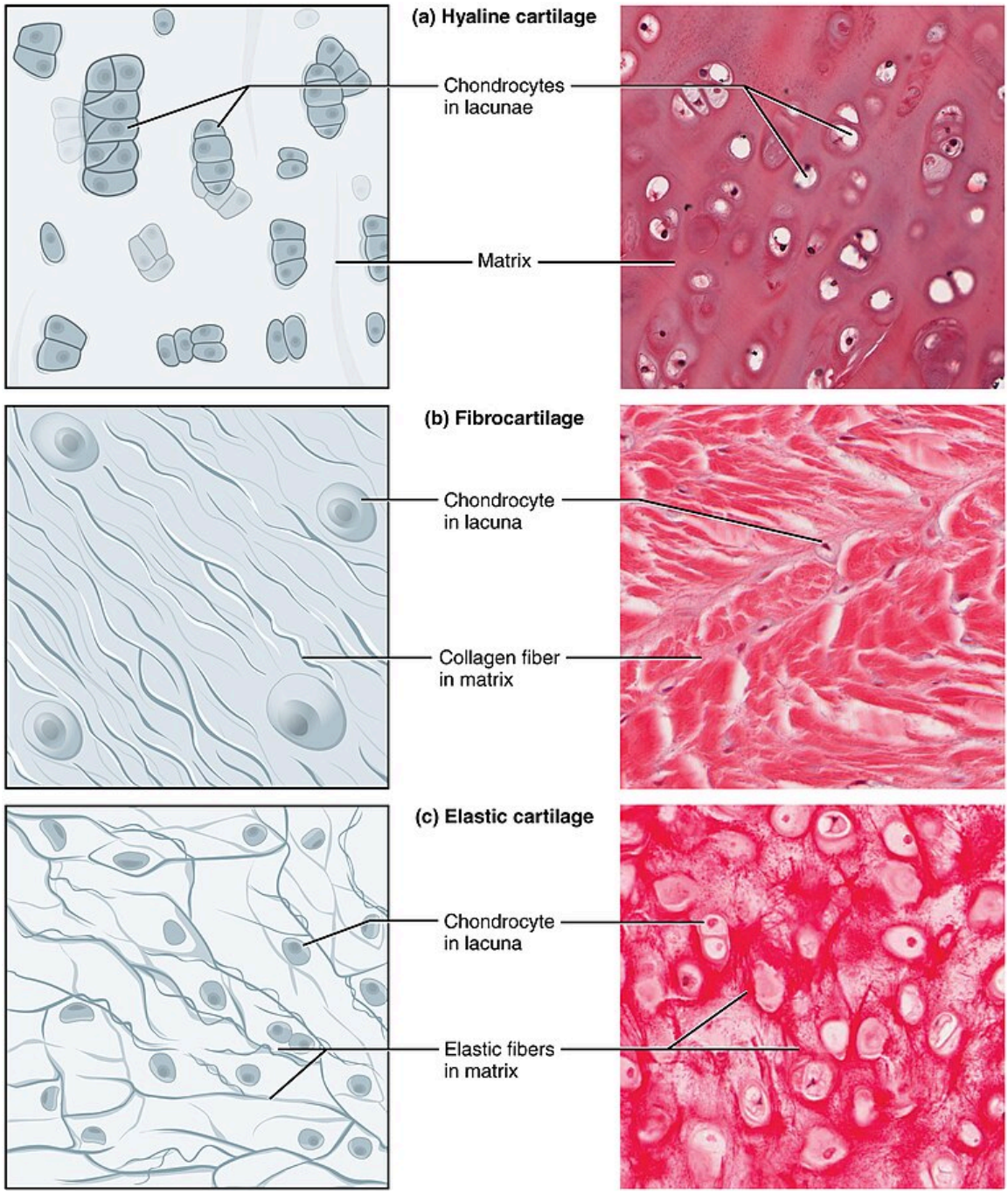


Figure 4.12 Types of Cartilage

Fluid Connective Tissue

Fluid connective tissue has various specialized cells that circulate in a watery fluid containing salts, nutrients, and dissolved proteins. The two types of fluid connective tissues are blood and lymph.

Blood

In blood, cells circulate in a liquid matrix. The cells circulating in the blood are all derived from stem cells located in bone marrow.

- **Erythrocytes**: Erythrocytes, also called red blood cells (RBCs), transport oxygen and some carbon dioxide.
- **Leukocytes**: Leukocytes, also called white blood cells (WBCs), are responsible for defending against potentially harmful microorganisms.
- **Thrombocytes**: Thrombocytes, commonly called platelets, are involved in blood clotting.

Nutrients, salts, and wastes are also dissolved in this liquid matrix and transported through the body.

See Figure 4.13[12] for an image of blood cells.

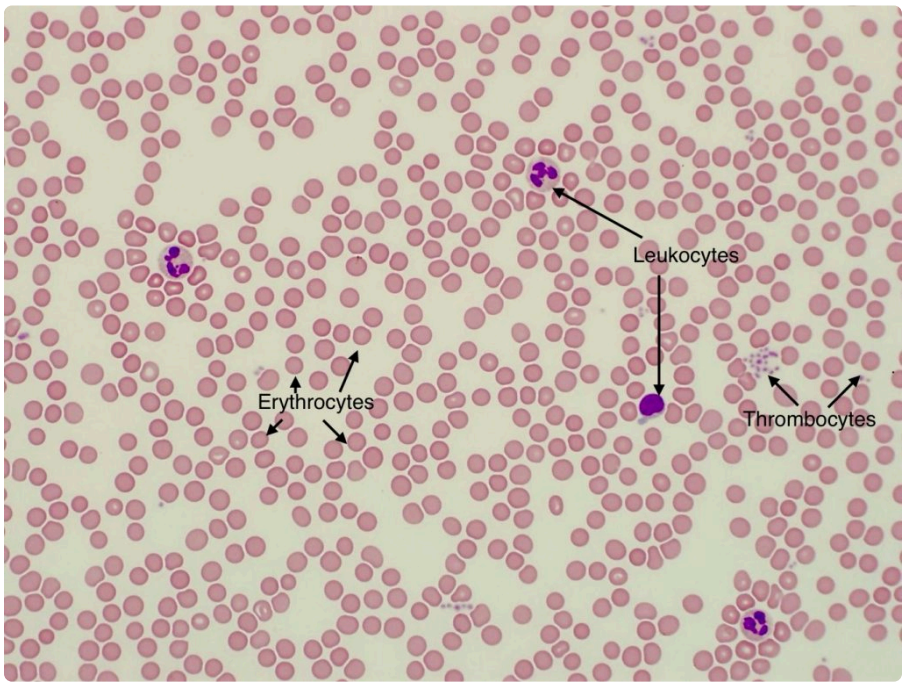


Figure 4.13 Blood Cells

12. "Labelled Blood Slide" Mary Bauer. (n.d.). *Labelled blood slide* [Photograph]. Chippewa Valley Technical College. CC BY 3.0.

Lymph

Lymph is a clear, colorless fluid that plays a vital role in the body's immune system. It is composed of a liquid matrix that contains leukocytes (white blood cells). Excess fluid is collected from the body tissues by lymphatic capillaries and travels through lymph nodes, where it is filtered and cleaned before returning to the bloodstream. This process helps to protect the body from infections.

Tissue Membranes

A **tissue membrane** is a thin layer or sheet of cells that covers the outside of the body (for example, skin), the organs (for example, pericardium), internal passageways that lead to the exterior of the body (for example, mucosa of the stomach), and the lining of the movable joint cavities. There are two basic types of tissue membranes: connective tissue and epithelial membranes. See Figure 4.14[13] for an image of tissue membranes.

13. OpenStax College. (2013). *413 Types of membranes* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:413_Types_of_Membranes.jpg

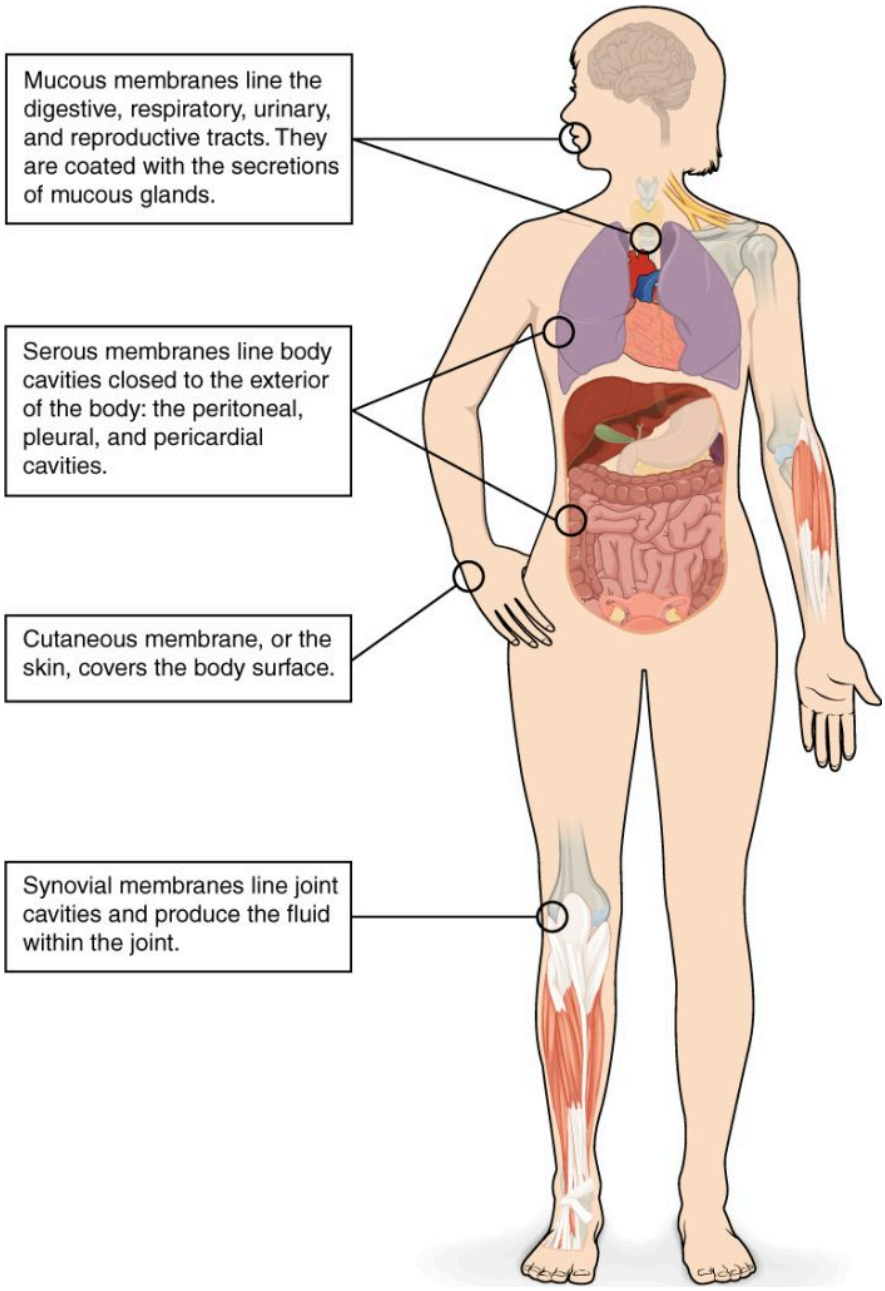


Figure 4.14 Tissue Membranes

Connective Tissue Membranes

The **connective tissue membranes** are formed solely from connective tissue. These membranes encapsulate organs, such as the kidneys, and line our movable joints. A **synovial membrane** is a type of connective tissue membrane that lines the cavity of a freely movable joint. For example, synovial membranes surround the joints of the shoulder, elbow, and knee. Synovial membranes secrete synovial fluid, a natural

lubricant that enables the bones of a joint to move freely against one another without much friction.

Epithelial Membranes

The **epithelial membrane** is composed of epithelium attached to a layer of connective tissue, for example, your skin. The **mucous membrane** is also a combination of connective and epithelial tissues. Sometimes called mucosae, these epithelial membranes line the body cavities and hollow passageways that open to the external environment and include the digestive, respiratory, urinary, and reproductive tracts. Mucus covers the epithelial layer. The underlying connective tissue, called the **lamina propria** (literally meaning "own layer"), helps support the fragile epithelial layer.

A **serous membrane** is an epithelial membrane that lines cavities that do not open to the outside, and they cover the organs located within those cavities. Serous fluid is a watery, slippery fluid that lubricates the membrane and reduces abrasion and friction between organs. Serous membranes are identified according to location. Three serous membranes line the thoracic cavity: the two pleura that cover the lungs and the pericardium that covers the heart. A fourth, the peritoneum, is the serous membrane that lines the abdominopelvic cavity and covers the organs found there.

The skin is an epithelial membrane also called the **cutaneous membrane**. It is a stratified squamous epithelial membrane resting on top of connective tissue. The apical surface of this membrane is exposed to the external environment and is covered with dead, keratinized cells that help protect the body.

Muscle Tissue

Muscle tissue is the third category of tissue.

Functions of Muscle Tissue

Muscle tissue is characterized as an excitable tissue that responds to electrical stimulation and contracts to produce movement.

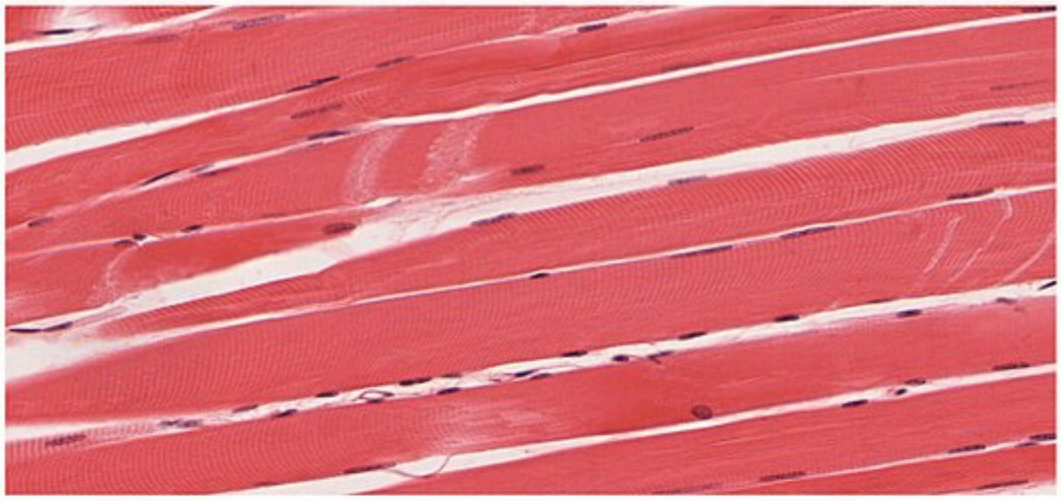
Types of Muscle Tissue

There are three major types of muscle tissue:

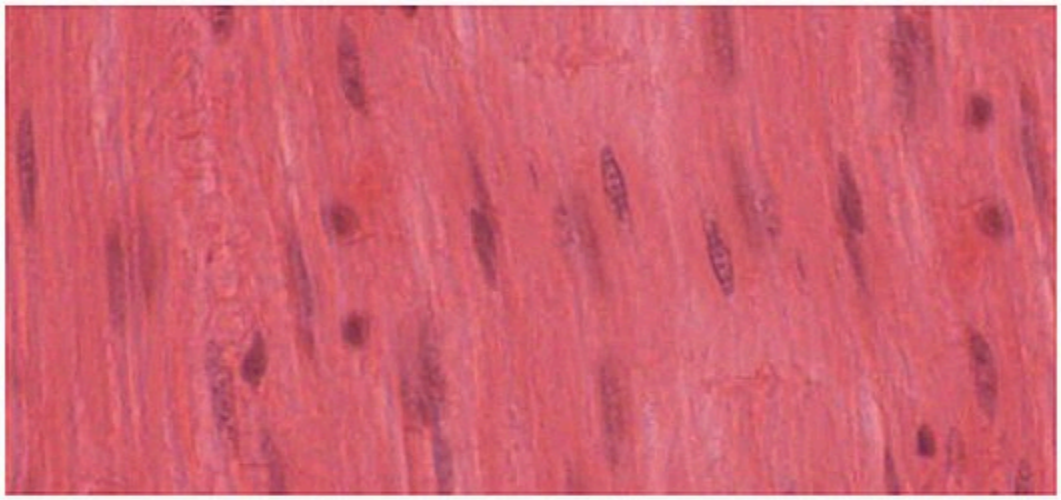
- **Skeletal Muscle**: Skeletal muscle is voluntary, meaning you can consciously control it. For example, muscles in the arms and legs are skeletal muscles. Skeletal muscle tissue is arranged in bundles surrounded by connective tissue. Under the light microscope, muscle cells appear striated with many nuclei squeezed along the sarcolemmas (cell membranes). The striations are due to the regular arrangement of the contractile proteins actin and myosin, along with structural proteins.
- **Smooth Muscle**: Smooth muscle is involuntary, meaning you cannot choose to control it. For example, the muscles in the intestines and blood vessels are smooth muscle. Each smooth muscle cell is spindle-shaped with a single nucleus and no visible striations.
- **Cardiac muscle**: Cardiac muscle is also involuntary and makes up the contractile walls of the heart. The cells of cardiac muscle are called cardiomyocytes. They are single cells with a single centrally located nucleus that also appear striated under the microscope.

Read more details about muscle tissue in the "**Muscular System**" chapter. See Figure 4.15[14] for an image of muscle tissue.

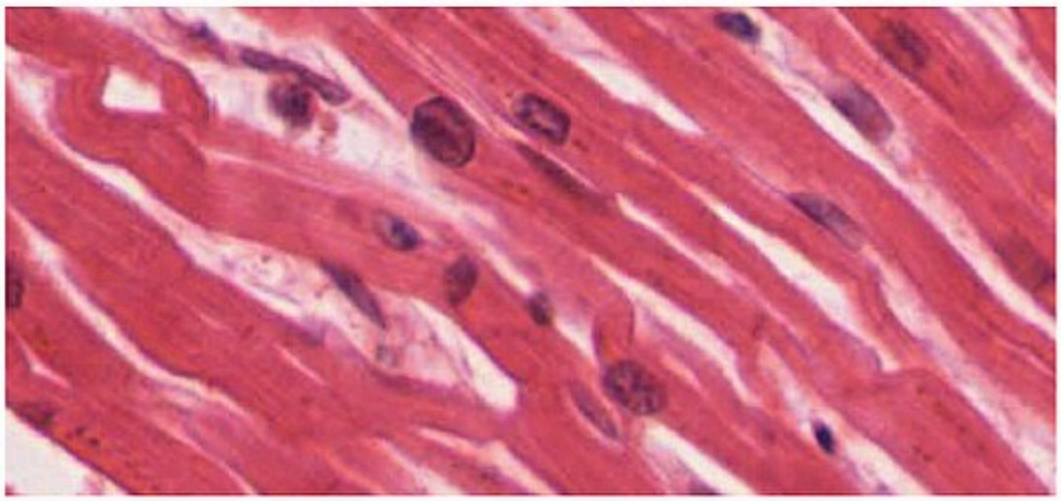
14. OpenStax College. (2013). *414 Skeletal smooth cardiac* [Photograph]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:414_Skeletal_Smooth_Cardiac.jpg



(a)



(b)



(c)

Figure 4.15 Muscle Tissue: (a) Skeletal, b) Smooth, and c) Cardiac

Video

Watch the video “Muscle Tissue Explained (Movement and Contraction)” below to learn more about the types and functions of muscle tissue.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Nervous Tissue

Nervous tissue is the fourth category of tissue.

Functions of Nervous Tissue

Nervous tissue is characterized as being excitable and capable of sending and receiving electrical signals throughout the body.

Types of Nervous Tissue

There are two main classes of nervous tissue, called neurons and neuroglia:

- **Neurons**: Neurons collect sensory information from the environment, send motor commands to muscles, and transmit electrical signals called nerve impulses throughout the body.
- **Neuroglia** (also called glial cells) include several different types of cells that each play an essential role in supporting neurons.[15]

Read more details about nervous tissue in the "**Nervous System**" chapter. See Figure 4.16[16] for an image of neurons.

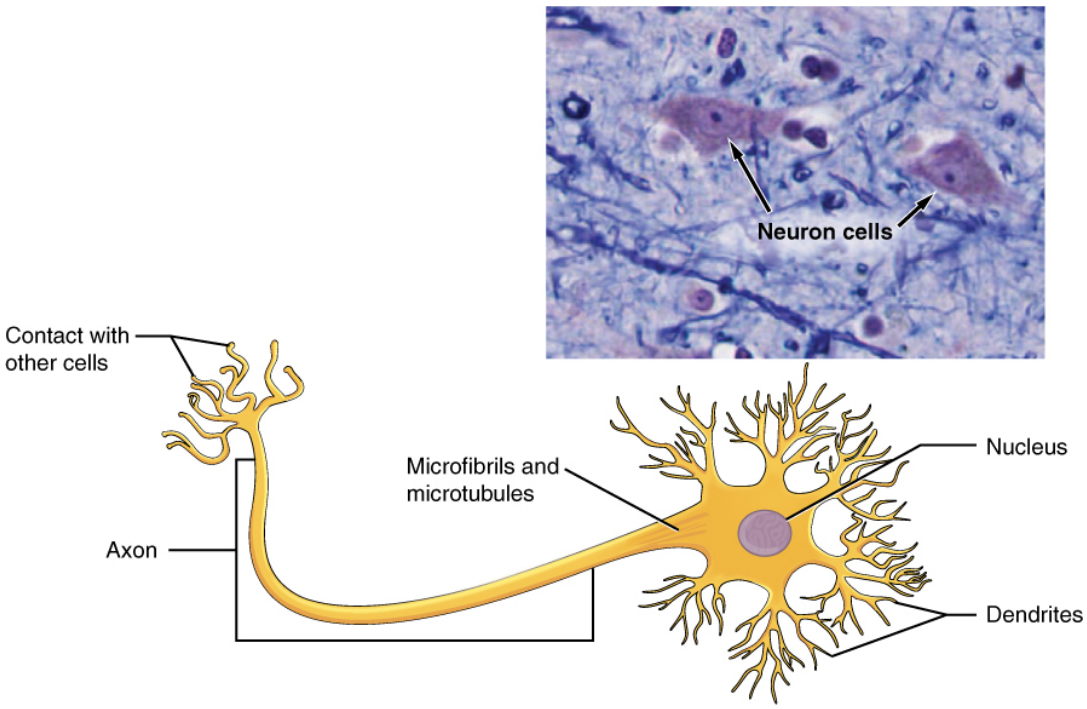


Figure 4.16 Neurons

15. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

16. OpenStax College. (2013). *415 Neuron* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:415_Neuron.jpg

4.3 Tissue Disorders

Lupus

Lupus is a disease that occurs when your body's immune system attacks your own tissues and organs (autoimmune disease). Inflammation caused by lupus can affect many different body systems, including joints, skin, kidneys, blood cells, brain, heart, and lungs. Lupus can be difficult to diagnose because its signs and symptoms often mimic those of other ailments. The most distinctive sign of lupus—a facial rash that resembles the wings of a butterfly unfolding across both cheeks—occurs in many but not all cases of lupus. Some people are born with a tendency toward developing lupus, which may be triggered by infections, certain drugs, or even sunlight. While there's no cure for lupus, treatments can help control symptoms.[1]

Marfan's Syndrome

Marfan syndrome is an inherited disorder that affects connective tissue, the fibers that support and anchor your organs and other structures in your body. Marfan syndrome most commonly affects the heart, eyes, blood vessels, and skeleton. People with Marfan syndrome are usually tall and thin with unusually long arms, legs, fingers, and toes. The damage caused by Marfan syndrome can be mild or severe. If the aorta — the large blood vessel that carries blood from your heart to the rest of your body — is affected, the condition can become life-threatening. Treatment usually includes medications to keep blood pressure low to reduce the strain on the aorta. Regular monitoring to check for damage progression is vital. Many people with Marfan syndrome eventually require preventive surgery to repair the aorta.[2]

1. Mayo Clinic. (2022). *Lupus*. https://www.mayoclinic.org/diseases-conditions/lupus/symptoms-causes/syc-20365789
2. Mayo Clinic. (2022). *Marfan syndrome*. https://www.mayoclinic.org/diseases-conditions/marfan-syndrome/symptoms-causes/syc-20350782

Tissues and Cancer

Cancer is a generic term for many diseases in which cells escape regulatory signals. Uncontrolled growth, invasion into adjacent tissues, and colonization of other organs, if not treated early enough, are its hallmarks. Health suffers when tumors "rob" blood supply from the "normal" organs.

A **mutation** is defined as a permanent change in the DNA of a cell. Changes in DNA may be caused by environmental agents, infectious agents, or errors in the replication of DNA that can accumulate with age. Many mutations do not cause any noticeable change in the functions of a cell. However, some mutations may cause a cell to start to divide abnormally. A tumor, a mass of abnormal cells, forms in the tissue. Many tumors are benign, meaning they do not metastasize (spread) or cause disease. A tumor becomes malignant, or cancerous, when it grows beyond its tissue and metastasizes to other organs. See Figure 4.17[3] for an illustration of the development of cancer.

3. OpenStax College. (2013). *418 Development of cancer* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:418_Development_of_Cancer.png

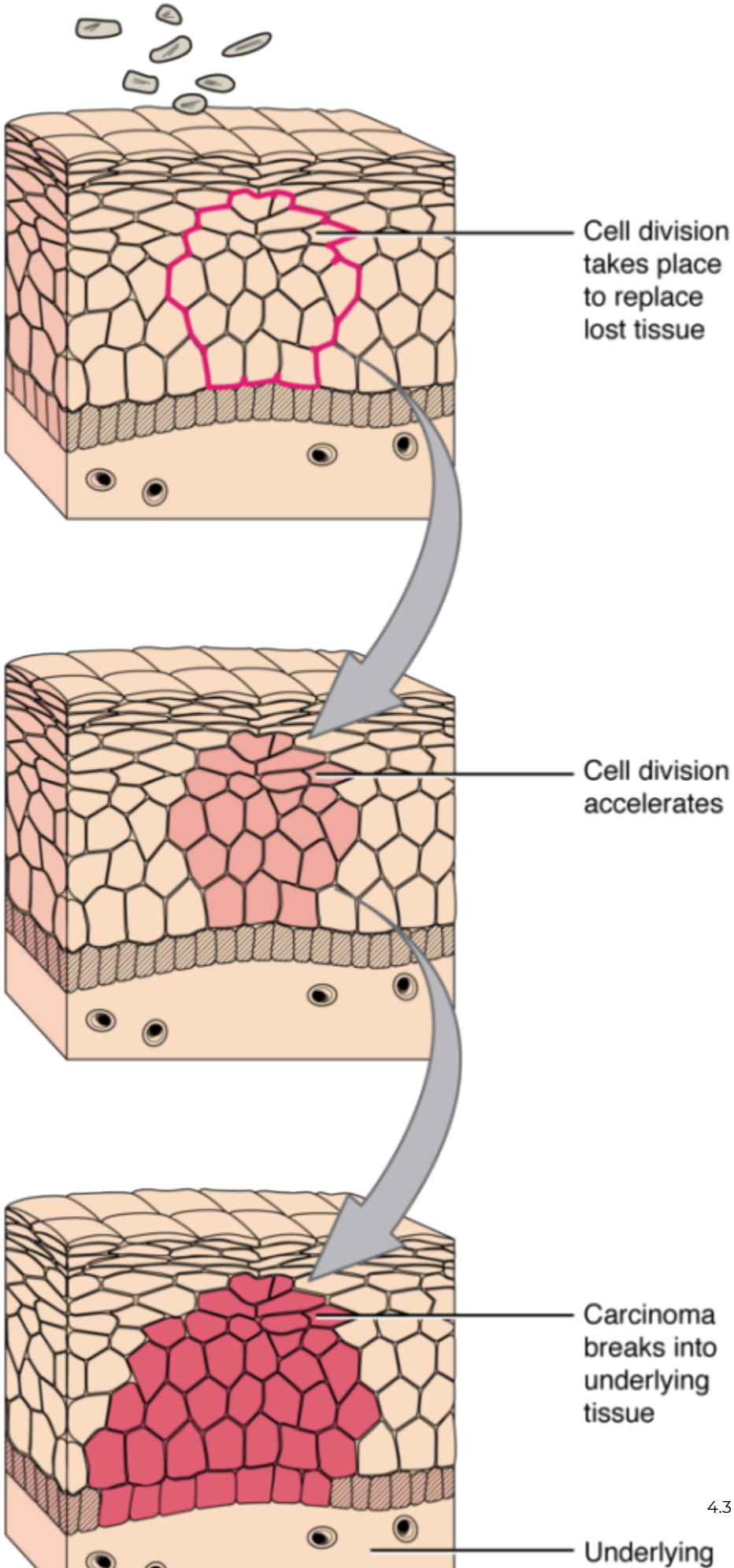

Cell division takes place to replace lost tissue
Cell division accelerates
Carcinoma breaks into underlying tissue
Underlying

Figure 4.17 Development of Cancer

The specific names of cancers reflect the tissue of origin. Cancers derived from epithelial cells are referred to as **carcinomas**. Cancer in myeloid tissue or blood cells forms **myelomas**. **Leukemias** are cancers of white blood cells, whereas **sarcomas** derive from connective tissue.

Cancer treatments vary depending on the disease's type and stage. Traditional approaches, including surgery, radiation, chemotherapy, and hormonal therapy, aim to remove or kill rapidly dividing cancer cells.

Video

Watch the video "Cancer Cells Explained (Cell Growth and Tumor Development)" below to learn more about abnormal cell growth and tumor development.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

4.4 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.



4.5 Glossary

Adipocytes: Fat cells that store energy in the form of lipids. (Chapter 4.2)

Adipose tissue: A type of connective tissue composed mainly of adipocytes that stores fat and provides insulation and cushioning. (Chapter 4.2)

Apical surface: The exposed top layer of epithelial cells that faces the external environment. (Chapter 4.2)

Areolar tissue: A loose connective tissue that provides support and flexibility to surrounding structures. (Chapter 4.2)

Avascular: Lacking blood vessels. (Chapter 4.2)

Basal surface: The bottom layer of epithelial cells that attaches to the basement membrane. (Chapter 4.2)

Basement membrane: A thin, fibrous layer that anchors epithelial tissue to underlying connective tissue. (Chapter 4.2)

Cancer: A generic term for many diseases in which cells escape regulatory signals. (Chapter 4.3)

Carcinomas: Cancers derived from epithelial cells. (Chapter 4.3)

Cardiac muscle: Involuntary, striated muscle tissue found only in the heart. (Chapter 4.2)

Chondrocytes: Cartilage cells. (Chapter 4.2)

Cilia: Hair-like structures on the surface of some cells that help move fluids or mucus. (Chapter 4.2)

Collagen fibers: Strong, fibrous proteins that provide structural support in connective tissues. (Chapter 4.2)

Columnar epithelium: A type of epithelial tissue composed of column-shaped cells. (Chapter 4.2)

Compact bone: Dense, hard bone tissue that provides strength and support; also known as cortical bone. (Chapter 4.2)

Connective tissue: Tissue that connects, supports, and binds other tissues and organs. (Chapter 4.2)

Connective tissue membrane: A type of body membrane that is made entirely of connective tissue, unlike epithelial membranes (like mucous or serous membranes) that include both epithelial and connective tissue layers. (**Chapter 4.2**)

Connective tissue proper: A classification of connective tissue that includes loose and dense connective tissues. (**Chapter 4.2**)

Cuboidal epithelium: A type of epithelial tissue composed of cube-shaped cells. (**Chapter 4.2**)

Cutaneous membrane: A stratified squamous epithelial membrane resting on top of connective tissue. (**Chapter 4.2**)

Dense irregular connective tissue: Connective tissue with randomly arranged collagen fibers that provide strength in multiple directions. (**Chapter 4.2**)

Dense irregular elastic tissue: A type of connective tissue with irregularly arranged elastic fibers that allow for flexibility. (**Chapter 4.2**)

Dense regular connective tissue: A type of connective tissue with tightly packed, parallel collagen fibers that provide strength in one direction. (**Chapter 4.2**)

Dense regular elastic tissue: A specialized connective tissue that contains elastic fibers, allowing for stretch and recoil. (**Chapter 4.2**)

Elastic cartilage: A flexible type of cartilage that contains both elastic fibers and collagen. It provides support while maintaining elasticity, allowing structures to return to their original shape after bending. An example is found in the external ear. (**Chapter 4.2**)

Elastic fibers: Fibers composed of elastin that provide elasticity to tissues. (**Chapter 4.2**)

Elastin: A protein that gives connective tissues their elasticity. (**Chapter 4.2**)

Endocrine glands: Glands that secrete hormones directly into the bloodstream. (**Chapter 4.2**)

Endothelium: Simple squamous epithelium tissue that lines the blood vessels. (**Chapter 4.2**)

Epithelial membrane: Membrane composed of epithelium attached to a layer of connective tissue. (**Chapter 4.2**)

Epithelial tissue: A tissue type that covers body surfaces and lines cavities. (**Chapter 4.2**)

Epithelium: A layer of epithelial cells that covers internal and external surfaces of the body. (**Chapter 4.2**)

Erythrocytes: Red blood cells responsible for oxygen transport. (**Chapter 4.2**)

Exocrine glands: Glands that release their secretions through ducts to the surface of an organ or tissue. (**Chapter 4.2**)

Fibroblasts: Cells that produce fibers and matrix in connective tissue. (**Chapter 4.2**)

Fibrocartilage: The strongest type of cartilage, known for its toughness due to thick bundles of collagen fibers in its matrix. It provides strength and shock absorption in high-stress areas, such as the menisci of the knee joint and the intervertebral discs between vertebrae. (Chapter 4.2)

Fluid connective tissue: A type of connective tissue, including blood and lymph, that transports substances. (**Chapter 4.2**)

Gland: A structure that secretes substances for various functions. (**Chapter 4.2**)

Goblet cell: A mucus-secreting cell found in epithelial tissue. (**Chapter 4.2**)

Histology: The study of tissues. (**Chapter 4.2**)

Hormones: Chemical messengers secreted by endocrine glands. (**Chapter 4.2**)

Hyaline cartilage: The most common type of cartilage in the body. It has a smooth surface, providing strength and flexibility. This cartilage is found in the rib cage, nose, and at the ends of long bones, where it helps cushion joints and support structural integrity. (**Chapter 4.2**)

Keratin: A structural protein found in skin, hair, and nails. (**Chapter 4.2**)

Lamina propria: Underlying layer of connective tissue that helps to support the epithelial layer. (**Chapter 4.2**)

Leukemias: Cancers of white blood cells. (**Chapter 4.3**)

Leukocytes: White blood cells involved in the immune response. (**Chapter 4.2**)

Loose connective tissue: A connective tissue with loosely arranged fibers that provide support and flexibility. (**Chapter 4.2**)

Lupus: A disease that occurs when your body's immune system attacks your own tissues and organs (autoimmune disease). (**Chapter 4.3**)

Lymph: A fluid that circulates in the lymphatic system and aids immune function. (**Chapter 4.2**)

Macrophages: Immune cells that engulf and digest pathogens and debris. (Chapter 4.2)

Marfan syndrome: An inherited disorder that affects connective tissue. (Chapter 4.3)

Mast cells: Cells that release histamine and other chemicals during inflammation. (Chapter 4.2)

Matrix: The extracellular material in connective tissues that is composed of fibers and ground substance. (Chapter 4.2)

Mesenchymal cells: Stem cells that can differentiate into various connective tissue types. (Chapter 4.2)

Mitosis: A type of cell division that results in two identical daughter cells. (Chapter 4.2)

Mucous membrane: A membrane layer that is composed of a combination of connective and epithelial tissues. (Chapter 4.2)

Muscle tissue: Tissue that contracts to produce movement. (Chapter 4.2)

Mutation: Permanent change in the DNA of a cell. (Chapter 4.3)

Myelomas: Cancer in the myeloid tissue or blood cells. (Chapter 4.3)

Neuroglia: Supportive cells in the nervous system. (Chapter 4.2)

Neurons: Nerve cells that transmit electrical signals. (Chapter 4.2)

Osteons: Structural units of compact bone. (Chapter 4.2)

Pathogens: Disease-causing microorganisms. (Chapter 4.2)

Protein fibers: Structural fibers found in connective tissues, including collagen, elastic, and reticular fibers. (Chapter 4.2)

Pseudostratified columnar epithelium: A type of epithelial tissue that appears layered but consists of a single layer of cells with varying heights. (Chapter 4.2)

Pseudostratified epithelium: Epithelial tissue that looks stratified but is actually a single layer. (Chapter 4.2)

Reticular fibers: Thin collagen fibers that form a supportive network in tissues. (Chapter 4.2)

Reticular tissue: A type of connective tissue with a network of reticular fibers that supports cells. (Chapter 4.2)

Sarcomas: Cancers of the connective tissues. (Chapter 4.3)

Serous membrane: An epithelial membrane that lines cavities that do not open to the outside and covers the organs located within those cavities. (**Chapter 4.2**)

Skeletal muscle: Voluntary, striated muscle tissue attached to bones. (**Chapter 4.2**)

Simple columnar epithelium: A single layer of column-shaped epithelial cells. (**Chapter 4.2**)

Simple cuboidal epithelium: A single layer of cube-shaped epithelial cells. (**Chapter 4.2**)

Simple epithelium: A single layer of epithelial cells. (**Chapter 4.2**)

Simple squamous epithelium: A single layer of flat epithelial cells. (**Chapter 4.2**)

Smooth muscle: Involuntary, nonstriated muscle tissue found in the walls of organs. (**Chapter 4.2**)

Spongy bone: Porous bone tissue that provides structural support and houses bone marrow; also known as cancellous bone. (**Chapter 4.2**)

Squamous epithelium: Flat, scale-like epithelial cells. (**Chapter 4.2**)

Stratified columnar epithelium: Multiple layers of columnar epithelial cells. (**Chapter 4.2**)

Stratified cuboidal epithelium: Multiple layers of cube-shaped epithelial cells. (**Chapter 4.2**)

Stratified epithelium: Multiple layers of epithelial cells. (**Chapter 4.2**)

Stratified squamous epithelium: Multiple layers of flat epithelial cells that provide protection. (**Chapter 4.2**)

Supportive connective tissue: Connective tissue that provides structural support, including bone and cartilage. (**Chapter 4.2**)

Synovial membrane: A type of connective tissue membrane that lines the cavity of a freely movable joint. (**Chapter 4.2**)

Thrombocytes: Platelets involved in blood clotting. (**Chapter 4.2**)

Tissue: A group of similar cells that perform a specific function. (**Chapter 4.2**)

Tissue membrane: A thin layer or sheet of cells that covers the outside of the body (for example, skin), the organs (for example, pericardium), internal passageways that lead to the exterior of the body (for example, mucosa of the stomach), and the lining of the movable joint cavities. (**Chapter 4.2**)

Transitional epithelium: A type of epithelium that can stretch and change shape. (**Chapter 4.2**)

Transitional stratified epithelium: Stratified epithelium that allows for stretching and shape changes. (**Chapter 4.2**)

PART V

CHAPTER 5 INTEGUMENTARY SYSTEM

5.1 Introduction to the Integumentary System

Chapter Competency

Analyze how components of the integumentary system function in the body.

Learning Objectives

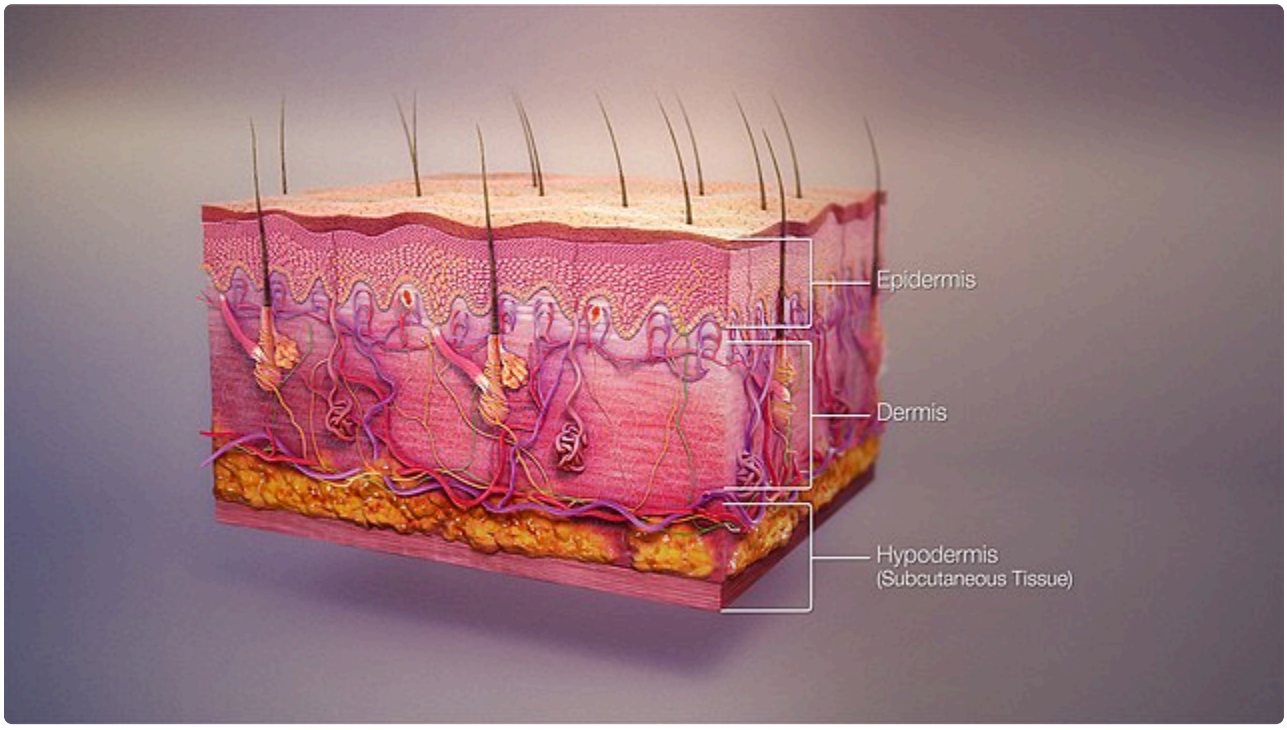
- Identify the structural components of the integumentary system.
- Correlate the structural components of the integumentary system with their functions.
- Identify the major chemical secretions of the integumentary system.
- Illustrate the relationships among the components of the integumentary system.
- Summarize the functions of the integumentary system.

Imagine you are working as a nurse caring for a patient who has been admitted with a pressure injury, surgical incision, or burn. During your assessment, you examine the color, temperature, texture, moisture, and integrity of the patient's skin. You also consider whether the wound is healing properly, whether signs of infection are present, and how the skin is helping protect the body from further injury. To provide safe and effective care, you must understand the structures of the integumentary system and how they function together.

The **integumentary system** includes the skin and its accessory structures, such as hair, nails, sweat glands, oil glands, and sensory receptors. As the largest organ system in the body, the integumentary system forms a protective barrier between the internal body and the external environment. It helps prevent water loss, protects against pathogens and ultraviolet radiation, regulates body temperature, supports sensation, and participates in wound healing.

In this chapter, you will explore the major functions and anatomy of the integumentary system. You will learn about the layers of the skin, including the epidermis, dermis, and hypodermis, and examine how accessory structures such as hair, nails, sudoriferous glands, sebaceous glands, and sensory receptors contribute to normal function. You will also study the process of wound healing and common skin disorders, including conditions that affect pigmentation, glands, hair, nails, and skin integrity.

By mastering these concepts, you will gain a deeper understanding of how the skin protects the body, maintains homeostasis, detects sensory information, and repairs itself after injury. This foundation will help you connect tissue structure and function to patient assessment, wound care, infection prevention, temperature regulation, and disorders of the integumentary system.



5.1 The Skin Layers

[1]

1. Scientificanimations.com. (2020). *3D medical animation of the skin layers* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:3D_medical_animation_skin_layers.jpg

5.2 Major Functions of the Integumentary System

The skin and accessory structures have four main functions:[1]

- Protection: The skin protects the body from outside elements (wind, rain, and ultraviolet radiation exposure); **dehydration** (excessive water loss); and entry of dirt, microbes, or harmful chemicals into the body.
- Sensation: The epidermis, dermis, and hypodermis contain sensory nerve structures that detect touch, temperature, vibration, pressure, and pain. These receptors are more concentrated on the tips of the fingers, making them most sensitive to touch. Sensory receptors help us interpret our environment and react accordingly.
- Thermoregulation: The integumentary system helps to change body temperature. See Figure 5.2[2] for an illustration of thermoregulation. Thermoregulation is achieved by performing the following functions:
  - Body temperature is decreased by the following actions:
    - Evaporation of sweat removes heat. **Convection** (air moving across the sweaty skin) lifts heat off the skin.
    - Blood vessels in the skin are dilated to move warm blood near the surface of the body to offload heat.
  - Body temperature is increased by the following actions:
    - Shivering occurs, with muscle contractions producing heat.
    - Blood vessels in the skin are constricted to keep warm blood deep within the body and maintain a higher core body temperature.
- Vitamin D Production: The skin makes vitamin D when it is exposed to UV radiation. The liver and kidneys work with the skin to produce the active form of vitamin D, which is needed for the body to absorb calcium and phosphorus from the foods that you eat.

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. CNX OpenStax. (2016). *Figure 33 03 04* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Figure_33_03_04.png

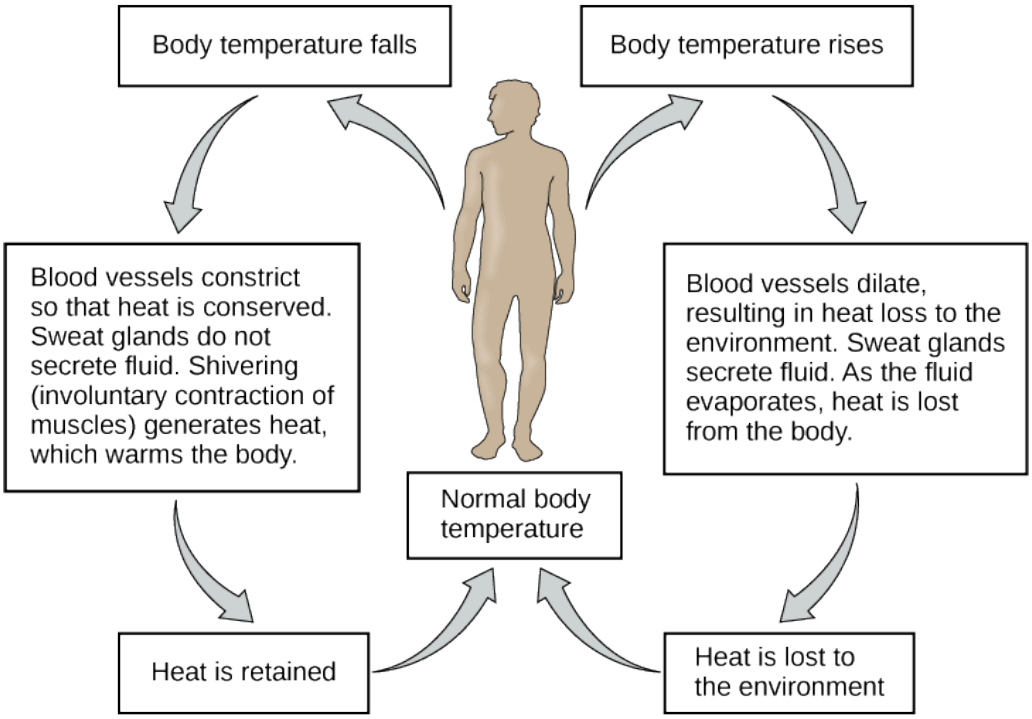


Figure 5.2 Thermoregulation

5.3 Anatomy of the Integumentary System

Layers of the Integumentary System

The skin is made up of multiple layers of cells and tissues that are anchored to deeper structures by connective tissue. The main layers found in the skin are the epidermis and dermis. The hypodermis connects these two layers to the tissues underneath.

See Figure 5.3[1] for an illustration of the integumentary system.

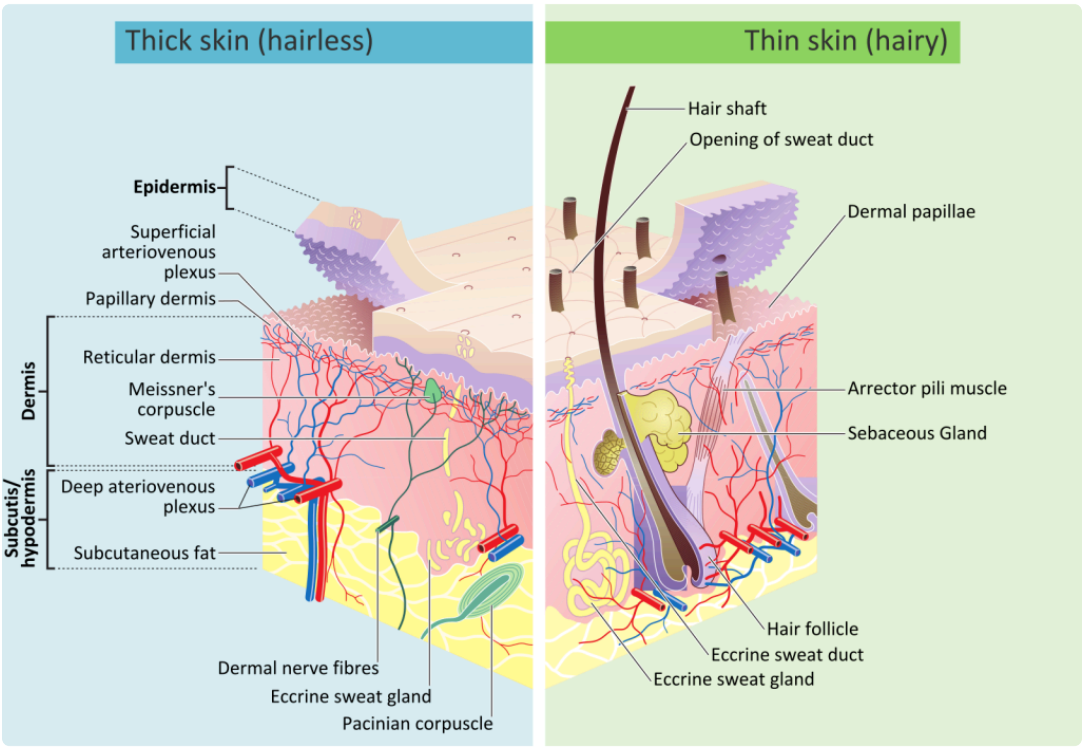


Figure 5.3 Layers and Accessory Structures of the Skin

1. Madhero88, & M.Komorniczak. (2012). *Skin layers* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Skin_layers.svg

Epidermis

The **epidermis** is the top layer of skin exposed to the outside world. It is composed of stratified squamous epithelium. The epidermis is **avascular**, meaning it does not have a blood supply. See Figure 5.4[2] for an image of the epidermis.

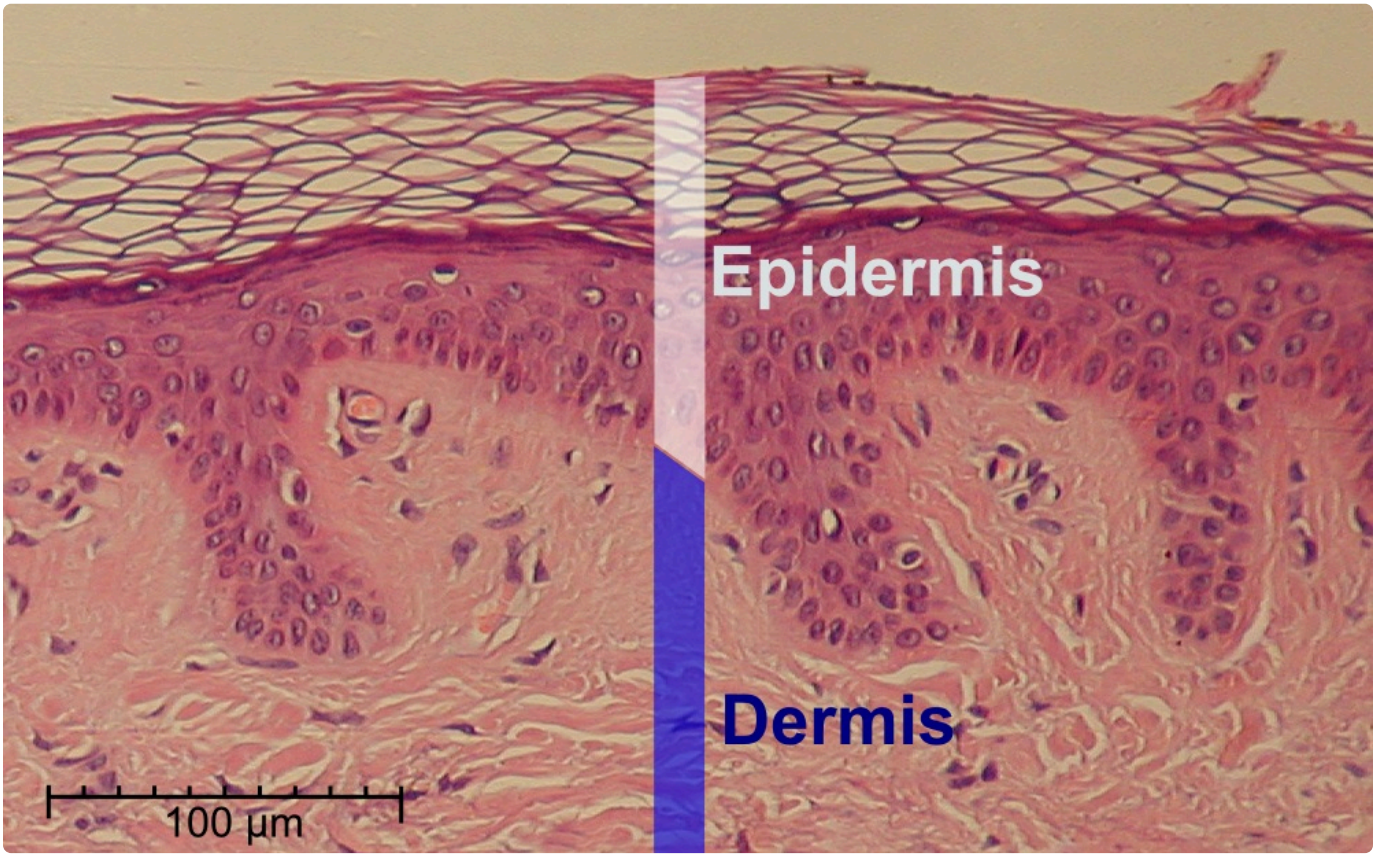


Figure 5.4 Epidermis

Layers of the Epidermis

The epidermis is composed of four to five layers of epithelial cells, depending on its location in the body. Skin that has four layers of cells is referred to as "thin skin." From superficial to deep, these layers are the stratum corneum, stratum granulosum, stratum spinosum, and stratum basale. Most skin in the body is thin skin. "Thick skin" is found only on the palms of the hands, fingertips, and the soles of the feet. It has a fifth layer, called the stratum lucidum, located between the stratum corneum and the

2. Fama Clamosa & Mikael Häggström. (2010). *Epidermis-delimited* [Diagram]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Epidermis-delimited.JPG

stratum granulosum. The cells in all of the layers except the stratum basale are called keratinocytes. A **keratinocyte** is a cell that makes and stores the protein keratin. **Keratin** is a protein that gives hair, nails, and skin their hardiness and water-resistant properties. The keratinocytes in the stratum corneum are dead and regularly slough away, being replaced by cells from the deeper layers. See Figure 5.5[3] for an illustration of the layers of the epidermis discussed below.

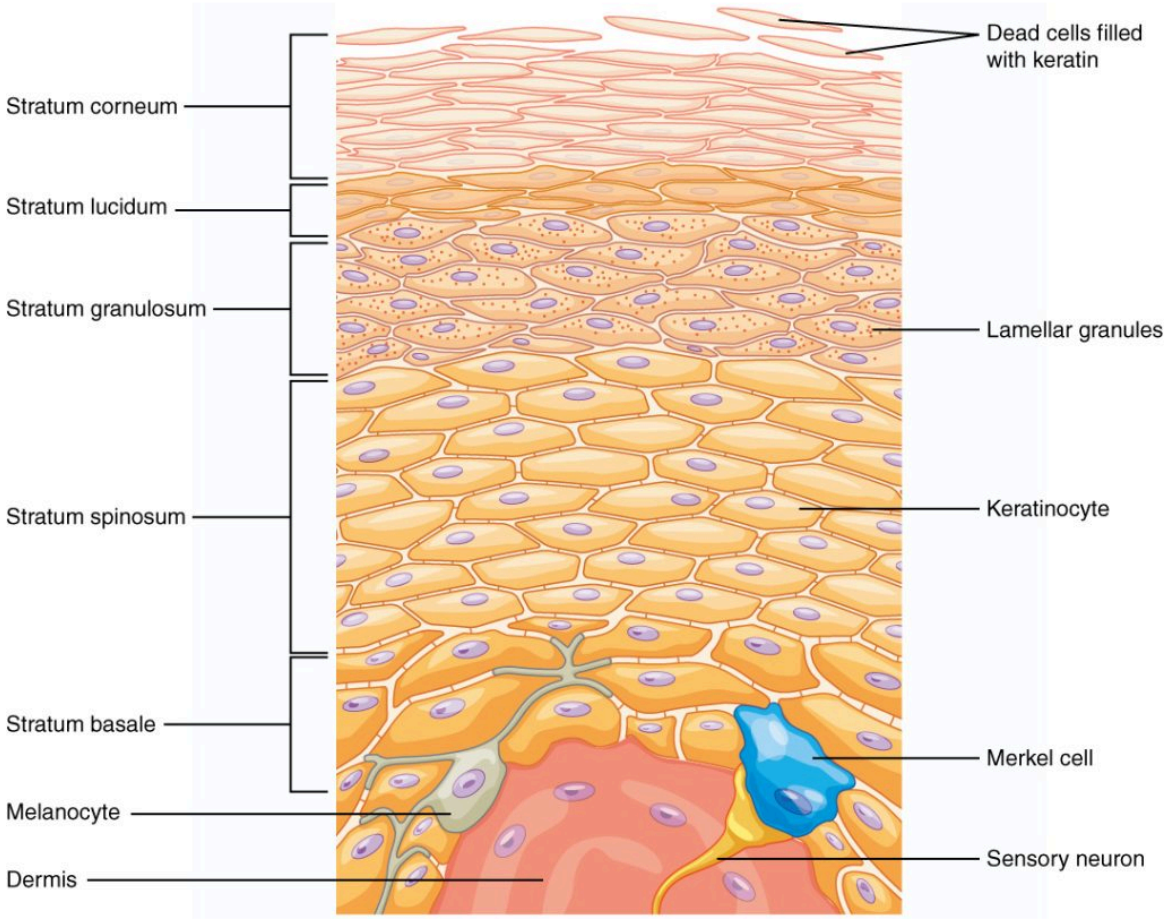


Figure 5.5 Layers of the Epidermis

Stratum Corneum

The **stratum corneum** is the most superficial layer of the epidermis that is exposed to the outside environment. The name is based on **cornification** (increased keratinization) of the cells in this layer. There are 15 to 30 layers of dead cells in the stratum corneum. The dry, dead layers prevent microbes from getting into the body and prevent dehydration

3. OpenStax College. (2013). *502 Layers of epidermis* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:502_Layers_of_epidermis.jpg

of underlying tissues. This layer also provides protection from injury to the underlying layers. Cells in this layer are continuously shed and replaced by cells pushed up from the deeper layers of the epidermis.

Stratum Lucidum

Stratum lucidum is a smooth, **translucent** (clear) layer of the epidermis located just below the stratum corneum. This thin layer of cells is found only in areas of the body with thick skin: the palms of the hands, the fingertips, and the soles of the feet. The keratinocytes that compose the stratum lucidum are dead, flattened cells.

Stratum Granulosum

The **stratum granulosum** has a grainy appearance caused by changes to the keratinocytes as they are pushed up through the epidermis. This layer is three to five cell layers thick, and the cells are flatter with thick cell membranes. They generate large amounts of keratin, allowing the stratum granulosum layer to repel water. Keratinocytes start to die in this layer because they are getting too far away from the blood supply located deeper in the skin.

Stratum Spinosum

The **stratum spinosum** is named for its spiny appearance due to protruding cell processes that connect the cells in this layer together (this spiny appearance is only seen when the epidermis is stained). The stratum spinosum has eight to ten layers of keratinocytes, as well as **Langerhans cells**, a type of macrophage that ingests bacteria, foreign particles, and even damaged cells. The keratinocytes make keratin and release a water-repelling substance that helps prevent water loss, making the skin relatively waterproof. The stratum spinosum provides strength and flexibility to the skin.

Stratum Basale

The **stratum basale** (also called the stratum germinativum) is the deepest epidermal layer. The cells in the stratum basale attach to the dermis with collagen fibers, referred to as the basement membrane. The stratum basale is a single layer of cells primarily made of basal cells. A **basal cell** is a stem cell that makes the keratinocytes of the epidermis. All keratinocytes are produced from this single layer of cells, which are constantly going

through mitosis to produce new cells. As new cells are formed, the existing cells are pushed up and away from the stratum basale.

Two other cell types found among the basal cells in the stratum basale are Merkel cells and melanocytes.

- **Merkel cells** function as a receptor to perceive touch. These cells are especially abundant on the surfaces of the hands and feet.
- **Melanocytes** produce the pigment melanin. **Melanin** gives hair and skin their color and also helps protect cells of the epidermis from ultraviolet (UV) radiation damage.

Thin and Thick Skin

Thin skin covers most areas of the body (except for the soles, fingertips, and palms). Thin skin is missing the stratum lucidum layer, so it contains four layers of epidermal cells. Hair, sebaceous glands, and arrector pili muscles are also found in thin skin.

Thick skin is found on the soles of the feet, fingertips, and palms of the hands. The epidermis in these areas is thicker because these body parts are used continuously and require extra protection. Thick skin contains all five layers of epidermal cells. Hair and its associated structures (sebaceous glands and arrector pili) are absent in thick skin.

See Figure 5.6[4] for images of thin and thick skin.

4. Mary Bauer. (n.d.). *Thin and thick skin laboratory photos* [Photograph]. Chippewa Valley Technical College. CC BY 3.0.

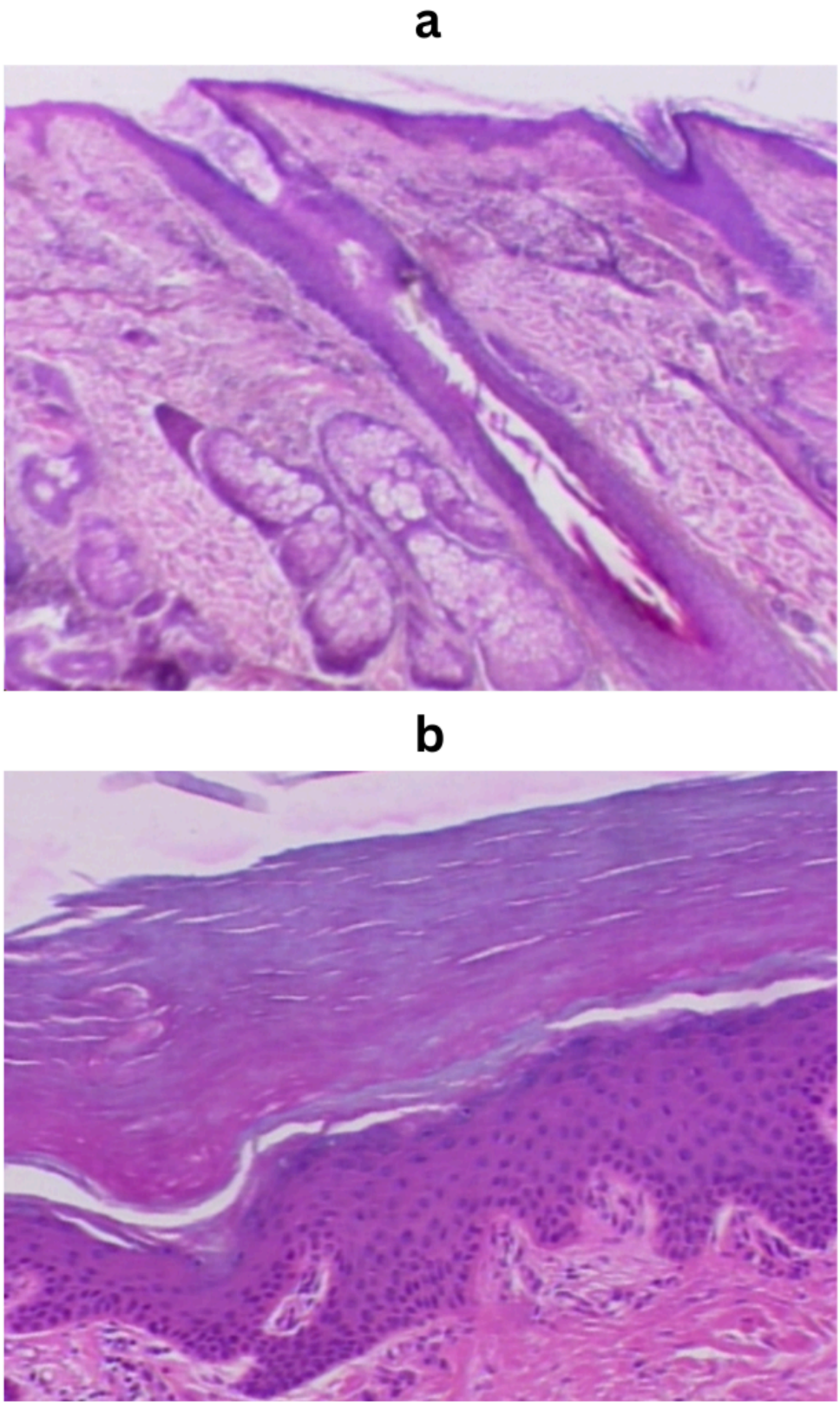


Figure 5.6 (a) Thin Skin and (b) Thick Skin

Video

Watch the video "Skin Structure Explained (Epidermis Overview)" below to learn more about the structure and function of the epidermis.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Dermis

Deep to the epidermis layer is the **dermis** (where *derma-* means "skin"). Sometimes referred to as the "true skin," the dermis is the skin layer that contains blood and lymph vessels, nerves, and other structures such as hair follicles and sweat glands.

The dermis is made up of two regions of connective tissue called the papillary and reticular layers. See Figure 5.7.[5] for an image of the layers of the dermis discussed below.

5. OpenStax College. (2013). *506 Layers of the dermis* [Photograph]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:506_Layers_of_the_Dermis.jpg

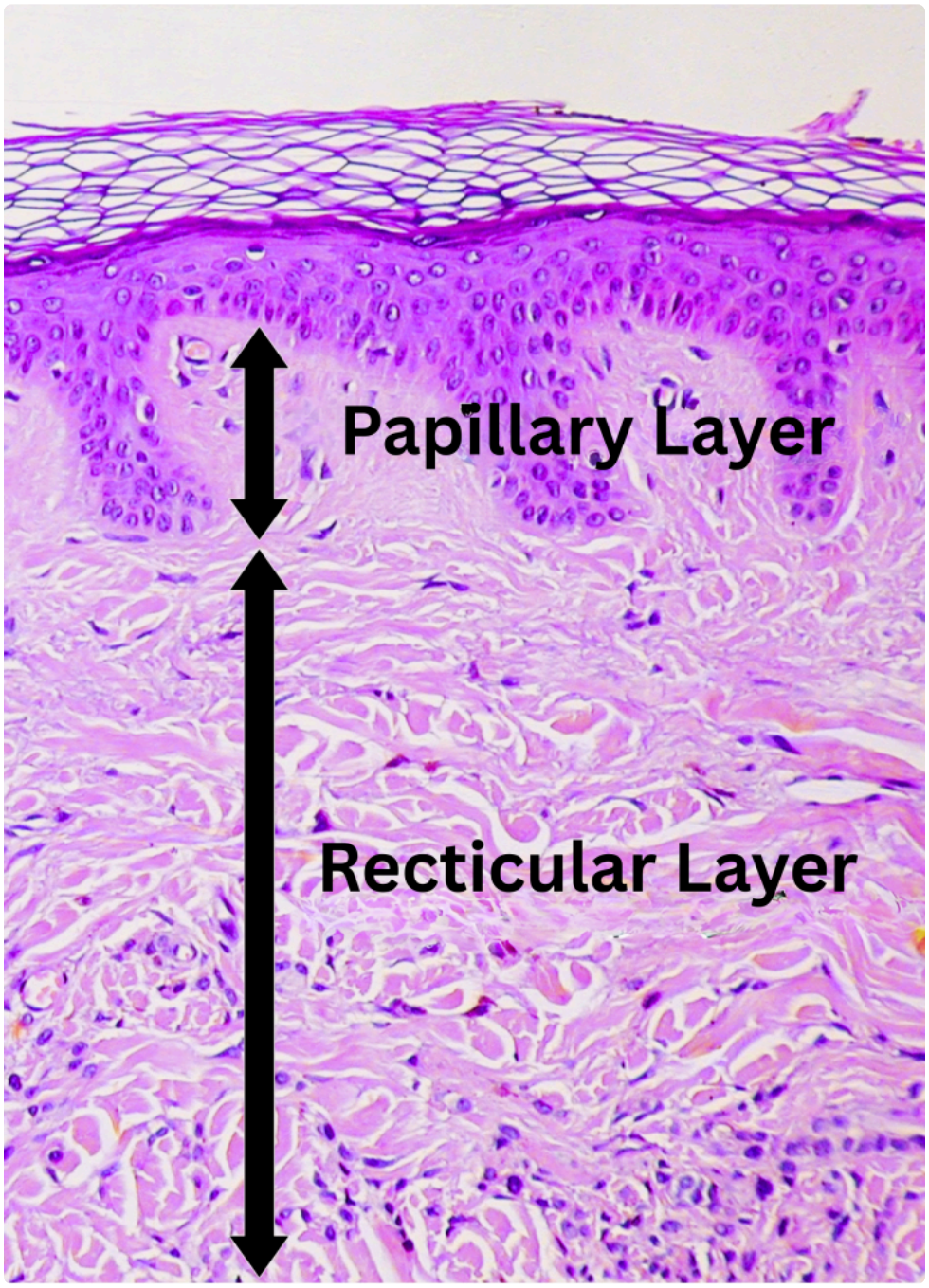


Figure 5.7 Layers of the Dermis

Papillary Layer

The **papillary layer** of the dermis is made of loose, areolar connective tissue, which means the collagen and elastin fibers of this layer form a loose mesh. This superficial layer of the dermis projects up into the stratum basale of the epidermis to form finger-like **dermal papillae**, resulting in the formation of the ridges on fingers that create

fingerprints. Fingerprints are unique to each individual and can be used for forensic analysis, as the patterns do not change with the growth and aging processes. However, the primary purpose of the dermal papillae that create fingerprints is to improve grip by increasing friction between the skin and surfaces.

Other important structures found in the papillary layer include fibroblasts, a small number of **adipocytes** (fat cells), an abundance of small blood vessels, and phagocytes to help fight bacteria or other pathogens that have invaded the skin. This layer also contains lymphatic capillaries, nerve fibers, and light touch receptors called **Meissner corpuscles**.

Reticular Layer

Deep to the papillary layer of the dermis is the much thicker **reticular layer** that is composed of dense, irregular connective tissue. This layer contains many blood vessels and has a rich nerve supply. In addition, hair follicles, sebaceous (oil) glands, and sudoriferous (sweat) glands are found in this layer.

The reticular layer appears **reticulated** (net-like) due to a tight mesh of fibers, including elastin fibers and collagen fibers. **Elastin fibers** provide some elasticity to the skin and enable movement. **Collagen fibers** provide structure and strength. Collagen also binds water to keep the skin hydrated.

Hypodermis

The **hypodermis** (also called the **subcutaneous layer** or **superficial fascia**) is located directly below the dermis. While not technically part of the skin, it connects the skin to the underlying **fascia** (fibrous tissue) of the bones and muscles. The hypodermis consists of well-vascularized, loose, areolar connective tissue and **adipose** tissue that stores fat and provides insulation and cushioning.

Accessory Structures of the Skin

The skin has a variety of structures that are essential for normal functioning and include the hair, nails, sudoriferous (sweat) glands, sebaceous (oil) glands, ceruminous glands, and sensory receptors.

Video

Watch the video "Skin Structure Explained (Dermis Overview)" below to learn more about the structure and function of the dermis.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Hair

Strands of hair originate in the dermis in a structure called the **hair follicle**. Hair is primarily made of dead, keratinized cells growing out of the epidermis. Hair grows continuously but is eventually shed and replaced by new hair. Similar to the skin, hair gets its color from the pigment melanin, and different hair colors result from differences in the type of melanin. As a person ages, the melanin production decreases, and hair tends to lose its color and become gray and/or white.

Hair has two main parts, called the hair shaft and the hair root:

- **Hair shaft**: The hair shaft is the part of the hair that protrudes from the surface of the skin.
- **Hair root**: The hair root is anchored in the follicle in the dermis. Each hair root is connected to a smooth muscle called the **arrector pili muscle**. When stimulated, these smooth muscles make the hair shaft "stand up," creating what you know as "goose bumps."

Refer to Figure 5.7[6] for an illustration of hair and the arrector pili muscle.

6. OpenStax College. (2013). *506 Hair* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:506_Hair.jpg

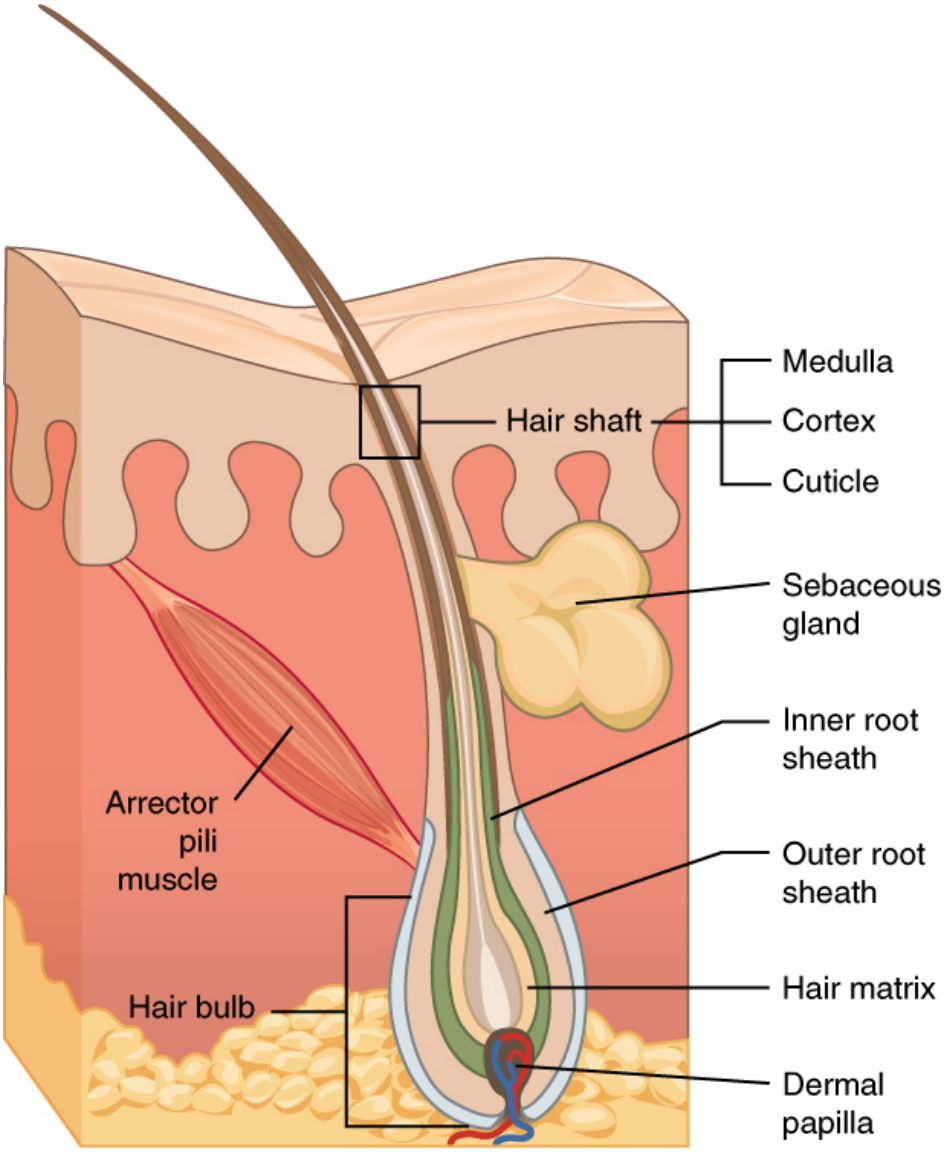


Figure 5.7 Hair Anatomy

Nails

The fingernails and toenails are made up of several structures:

- **Nail bed**: The nail bed is a specialized structure of the epidermis found at the tips of our fingers and toes. The nail bed is rich in blood vessels except at the base, where a thick layer of epithelium over the nail matrix forms a crescent-shaped region called the **lunula** (the "little moon").
- **Nail body**: The nail body is made up of densely packed dead keratinocytes formed on the nail bed. It protects the tips of our fingers and toes, and the **free edge** (the white part of the nail that extends beyond the nail bed) can also help the fingers

pick up small objects.

- **Nail root**: The nail root contains dividing cells from the stratum basale that allow the nail to grow continuously.
- **Cuticle**: The nail cuticle, also called the **eponychium**, is a small area of epidermis at the base of the nail.
- Hyponychium: The **hyponychium** is the area beneath the free edge of the nail and is made up of a thickened layer of stratum corneum.

See Figure 5.8[7] for an illustration of nail structures.

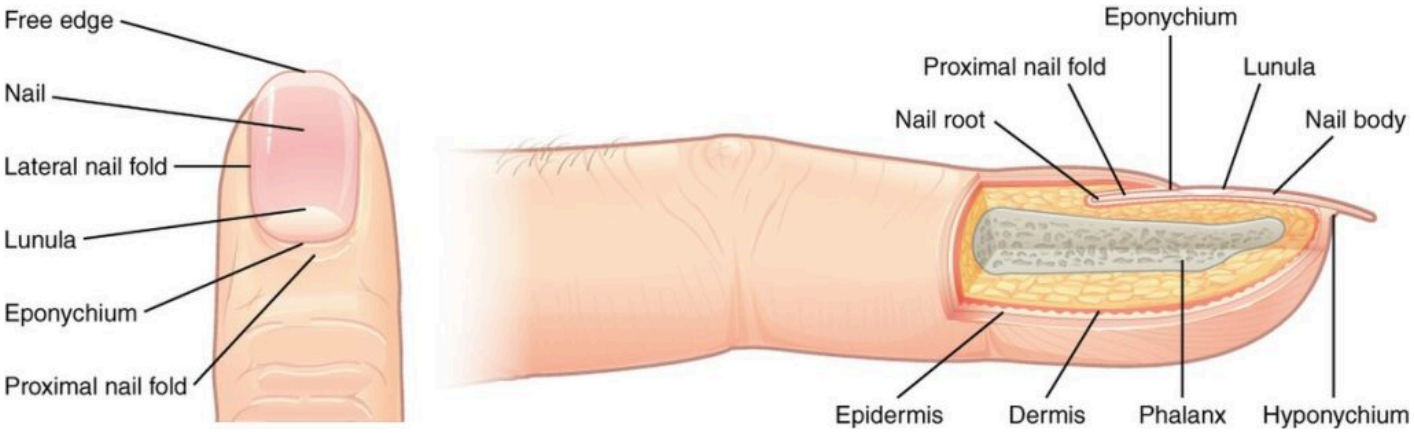


Figure 5.8 Nail Structures

Sudoriferous Glands

There are two types of sudoriferous (sweat) glands found in the human body, called eccrine sweat glands and apocrine sweat glands, each secreting slightly different products.

Eccrine Sweat Glands

An **eccrine sweat gland** produces sweat for thermoregulation to help cool the body. These glands are found all over the skin's surface but are especially abundant on the palms of the hands, the soles of the feet, and the forehead. This type of sweat is composed mostly of water and some salt. Even when the body does not appear to

7. OpenStax College. (2013). *507 Nails* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:507_Nails.jpg

be noticeably sweating, approximately 500 mL of sweat is secreted a day. If the body becomes excessively warm due to high temperature, vigorous activity, or a combination of the two, sweat glands will be stimulated to produce large amounts of sweat. Sweat is released from the gland through a pore located at the skin's surface. See Figure 5.9[8] for an illustration of an eccrine sweat gland.

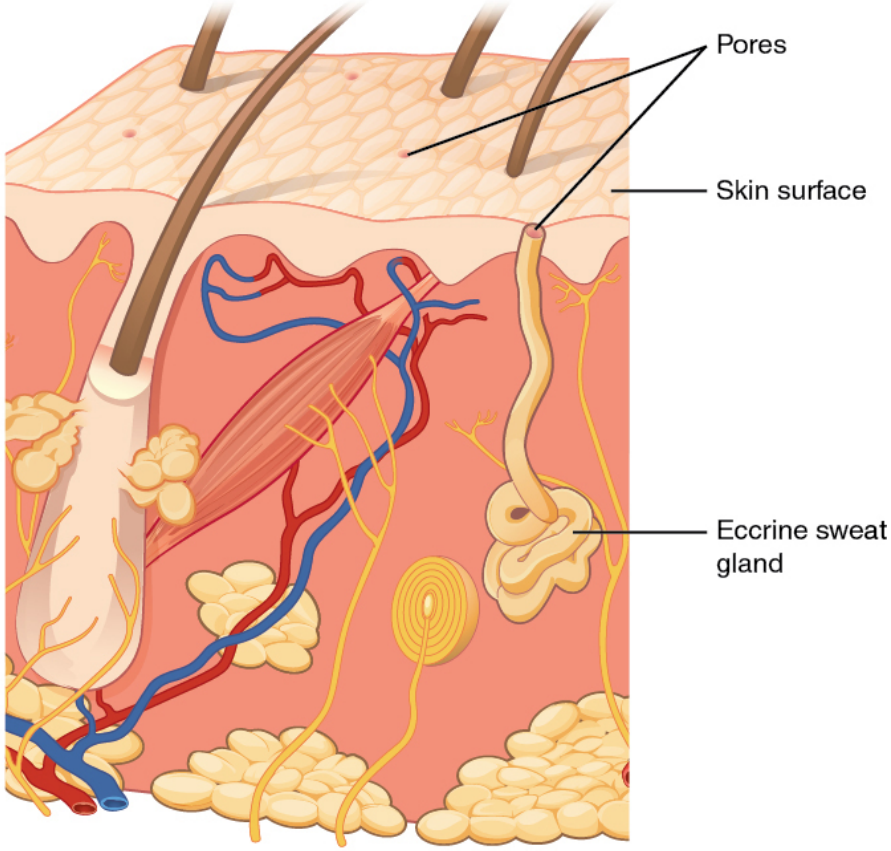


Figure 5.9 Eccrine Sweat Gland

Apocrine Sweat Glands

Apocrine sweat glands are found near hair follicles in densely hairy areas, such as the armpits and genital area. In addition to water and salt, apocrine sweat glands secrete organic compounds that make the sweat thicker and subject to bacterial decomposition, resulting in odor. The release of apocrine sweat is controlled by hormones and the nervous system. These glands aren't active until puberty.

8. OpenStax College. (2013). *508 Eccrine gland* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:508_Eccrine_gland.jpg

Sebaceous Glands

A **sebaceous (oil) gland** lubricates and waterproofs the skin and hair by producing and secreting an oily mixture called **sebum**. Most sebaceous glands are found next to hair follicles. Sebum performs the following actions:

- Provides natural lubrication
- Waterproofs the skin
- Prevents bacterial growth on the surface of the skin
- Helps prevent water loss from the body

Sebaceous glands are relatively inactive during childhood because the secretion of sebum is stimulated by hormones, many of which do not become active until puberty. Likewise, sebaceous gland activity decreases as we age due to decreased hormonal stimulation, leading to drier skin.

Ceruminous Glands

Ceruminous (wax) glands are found in the ear canal. These glands produce a waxy substance called **cerumen** that protects the ear canal from water and bacteria.

Sensory Receptors

Sensory receptors found throughout the skin help us interpret our environment and react accordingly. Receptors found in the skin include the following:

- **Meissner corpuscle**: The Meissner corpuscle (also referred to as a tactile corpuscle) detects light touch, such as an ant crawling across the skin or an eyelash on the cheek. See Figure 5.10[9] for an image of a Meissner corpuscle.
- **Pacinian corpuscle**: The Pacinian corpuscle (also referred to as a lamellated corpuscle) detects pressure and vibration.
- **Merkel cell**: Merkel cells are another type of touch receptor found scattered throughout the stratum basale.

9. OpenStax College. (2016). *514 Light micrograph of a Meissner corpuscle* [Photograph]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:514_Light_Micrograph_of_a_Meissner_Corpuscle.jpg

- **Nociceptors**: Nociceptors are found throughout the skin and detect pain.
- **Thermoreceptors**: Thermoreceptors are a special type of receptor that detects temperature.

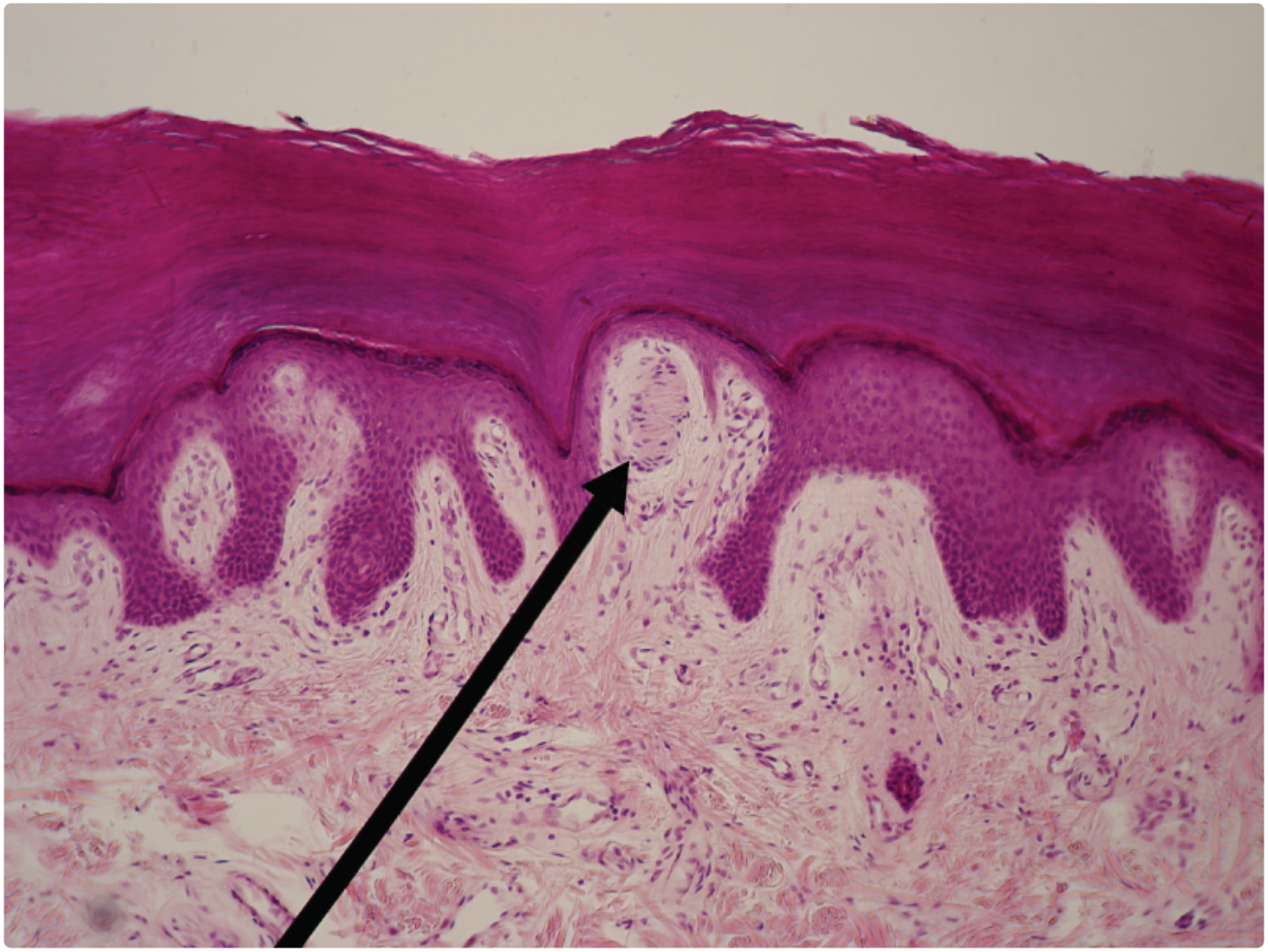


Figure 5.10 Meissner Corpuscle

Skin Pigmentation

The color of skin is influenced by a number of pigments, including hemoglobin and melanin. **Hemoglobin** can give skin a reddish hue (or "rosy" color) to light-skinned individuals.

Melanin is a brownish/black pigment that is produced by cells called melanocytes, which are found in the stratum basale layer of the epidermis. Dark-skinned individuals produce more melanin than those with pale skin, although the number of melanocytes

is relatively the same between different people. The genes you inherit from your parents determine your skin color. Exposure to the ultraviolet (UV) rays of the sun or a tanning bed causes more melanin to be produced and built up in keratinocytes, resulting in the darkening of the skin, or a tan. This increased melanin protects the DNA of skin cells from UV damage and the breakdown of folic acid, a nutrient necessary for our health. Too much melanin can interfere with the production of vitamin D, an important nutrient necessary for calcium absorption. Melanin production peaks about ten days after UV exposure, which is why pale-skinned individuals tend to sunburn more easily than dark-skinned individuals, who have more protection. See Figure 5.11[10] for an illustration of melanocytes that produce melanin.

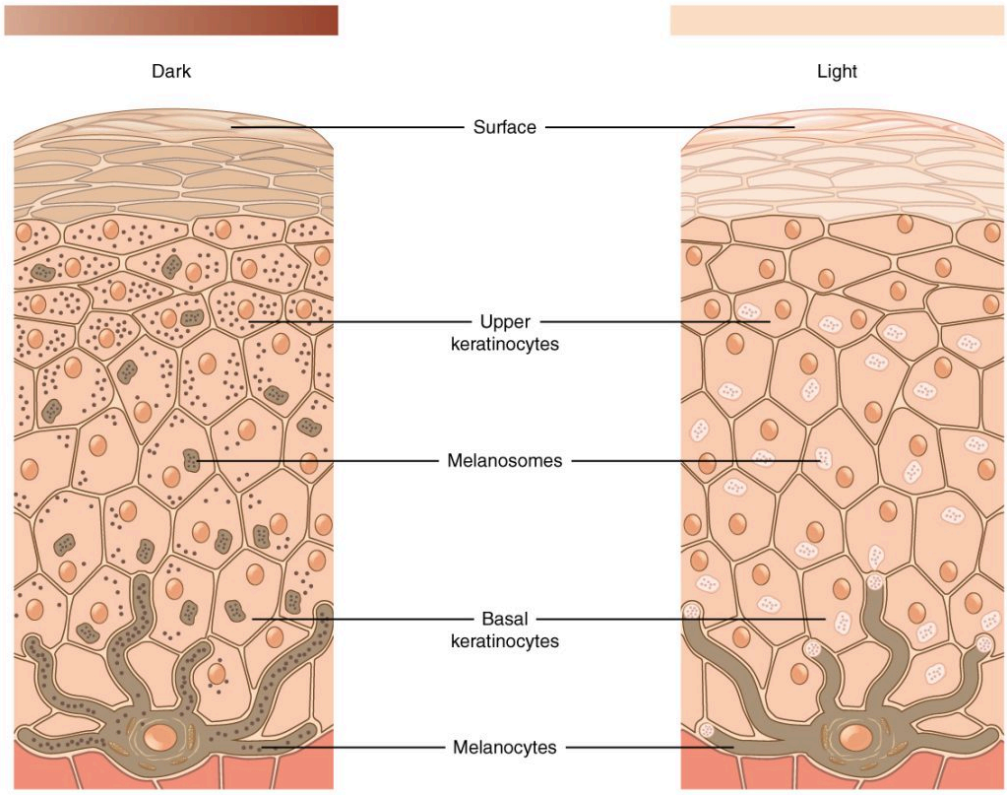


Figure 5.11 Melanocytes Produce Melanin That Influences Skin Color

Skin Color as a Diagnostic Tool

The color of the skin can provide helpful diagnostic clues, so examination of the

10. OpenStax College. (2013). *504 Melanocytes* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:504_Melanocytes.jpg

skin should be part of any thorough physical examination. Common skin color changes include the following:

- **Erythema**: Redness of the skin. Increased blood flow to the surface of the skin can give skin a red appearance, such as from a burn or injury.
- **Cyanosis**: Bluish color of the skin. With a prolonged decrease in oxygen level, the skin can appear blue, a condition referred to as cyanosis (*kyanos* is the Greek word for "blue"). This happens when the oxygen supply is restricted, as when someone is experiencing difficulty breathing because of asthma or a heart attack.
- **Jaundice**: Yellowish appearance of the skin. Liver disease or liver cancer can cause the accumulation of bile and the yellow pigment bilirubin, leading to the skin appearing yellow or jaundiced (*jaune* is the French word for "yellow"). Infants born prematurely often develop jaundice due to their immature livers, which have trouble breaking down bilirubin.
- **Pallor**: Whitish color of the skin. A sudden drop in oxygen can affect skin color, causing the skin to initially turn ashen (white).[11]

Video

Watch the video "Integumentary System" below to learn about the structure and function of the skin and its role in protection, temperature regulation, and sensation.[12]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

11. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
12. Amoeba Sisters. (2022, December 21). Integumentary system [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=t1iQHHJ0YyE

Wisc-Online Interactive Activity

*]:pointer-events-auto [content-visibility:auto] supports-[content-visibility:auto]:[contain-intrinsic-size:auto_100lvh] R6Vx5W_threadScrollVars scroll-mb-[calc(var(--scroll-root-safe-area-inset-bottom,0px)+var(--thread-response-height))] scroll-mt-[calc(var(--header-height)+min(200px,max(70px,20svh)))]" dir="auto" data-turn-id="request-69fb51b4-e5b0-832f-bc6f-69728425238f-4" data-turn-id-container="request-69fb51b4-e5b0-832f-bc6f-69728425238f-4" data-testid="conversation-turn-14" data-scroll-anchor="false" data-turn="assistant">
Complete the Wisc-Online interactive activity **“Skin and the Integumentary System”** to review the structure and functions of the skin and practice identifying key parts of the integumentary system.

5.4 Wound Healing

When skin is injured, there are four phases of wound healing that take place: hemostasis, inflammation, proliferation, and maturation. See Figure 5.12[1] for an illustration of these phases of wound healing.

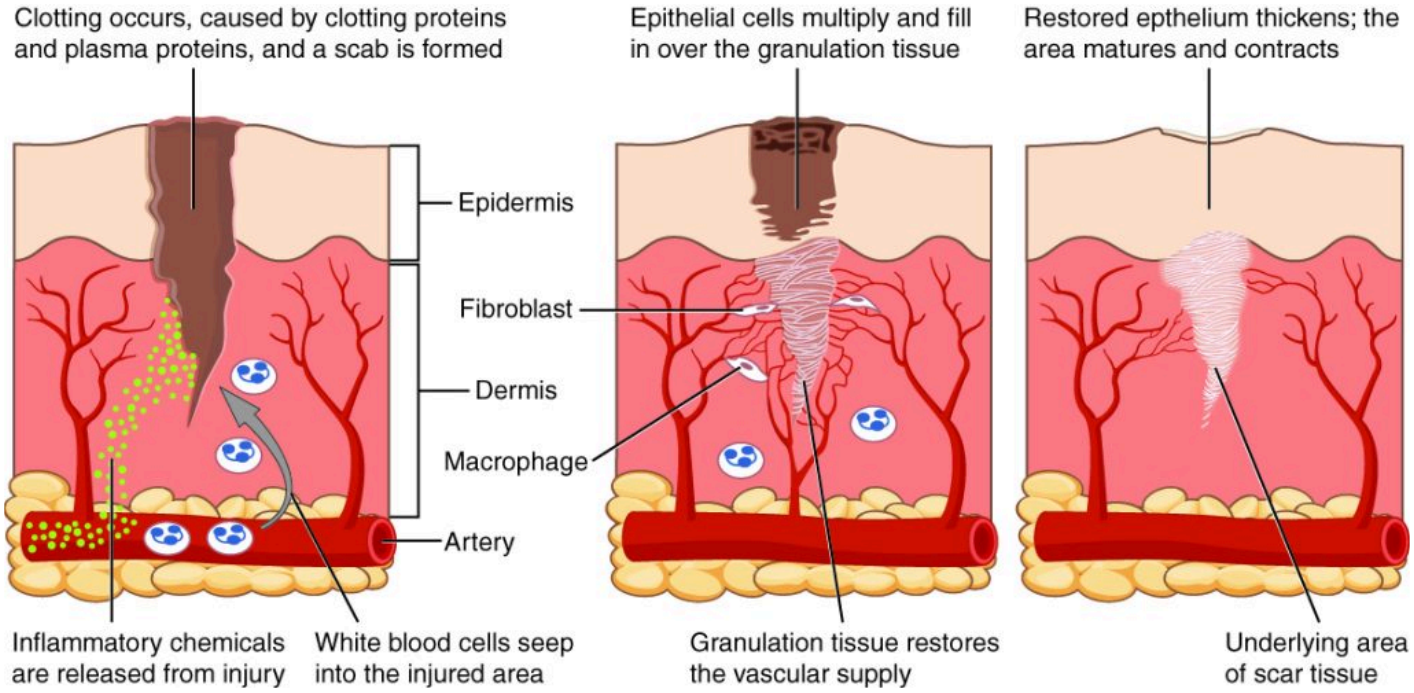


Figure 5.12 Wound Healing

To illustrate the phases of wound healing, imagine that you accidentally cut your finger with a knife as you were slicing an apple. Immediately after the injury occurs, blood vessels constrict, and clotting factors are activated. This is referred to as the **hemostasis phase**. Clotting factors form clots that stop the bleeding and act as a barrier to prevent bacterial contamination. Platelets release growth factors that alert various cells to start the repair process at the wound location. The hemostasis phase lasts up to 60 minutes, depending on the severity of the injury.

After the hemostasis phase, the **inflammatory phase** begins. Vasodilation occurs so that white blood cells in the bloodstream can move into the wound to start cleaning the

1. OpenStax College. (2013). *417 Tissue repair* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:417_Tissue_Repair.jpg

wound bed. The inflammatory process appears to the observer as swelling, redness, and drainage.

The **proliferative phase** begins within a few days after the injury and includes four important processes: epithelialization, angiogenesis, collagen formation, and contraction. **Epithelialization** refers to the development of new epidermis and granulation tissue. **Granulation tissue** is new connective tissue with new, fragile, thin-walled capillaries. Collagen is formed to provide strength and integrity to the wound. At the end of the proliferation phase, the wound begins to contract in size

Capillaries begin to develop within the wound 24 hours after injury during a process called **angiogenesis**. These capillaries bring more oxygen and nutrients to the wound for healing. When performing dressing changes, it is essential for the nurse to protect this granulation tissue and the associated new capillaries. Healthy granulation tissue appears pink due to the new capillary formation. It is also moist, painless to the touch, and may appear "bumpy." Conversely, unhealthy granulation tissue is dark red and painful. It bleeds easily with minimal contact and may be covered by shiny white or yellow fibrous tissue referred to as a biofilm that must be removed because it impedes healing.

During the **maturation phase**, collagen continues to be created to strengthen the wound. Collagen contributes strength to the wound to prevent it from reopening. A wound typically heals within four to five weeks and often leaves behind a scar. The scar tissue is initially firm, red, and slightly raised from the excess collagen deposition. Over time, the scar begins to soften, flatten, and become pale in about nine months.[2]

Video

Watch the video "Wound Healing Explained (Stages of Skin Repair)" below to learn more about the stages of wound healing and tissue repair.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

5.5 Skin Disorders

Acne

Acne is a skin condition that typically occurs on the face and back, which are areas rich in sebaceous (oil) glands. It is most common at the onset of puberty due to hormonal changes, but can also occur in infants and continue into adulthood. See Figure 5.13[1] for an illustration of acne.

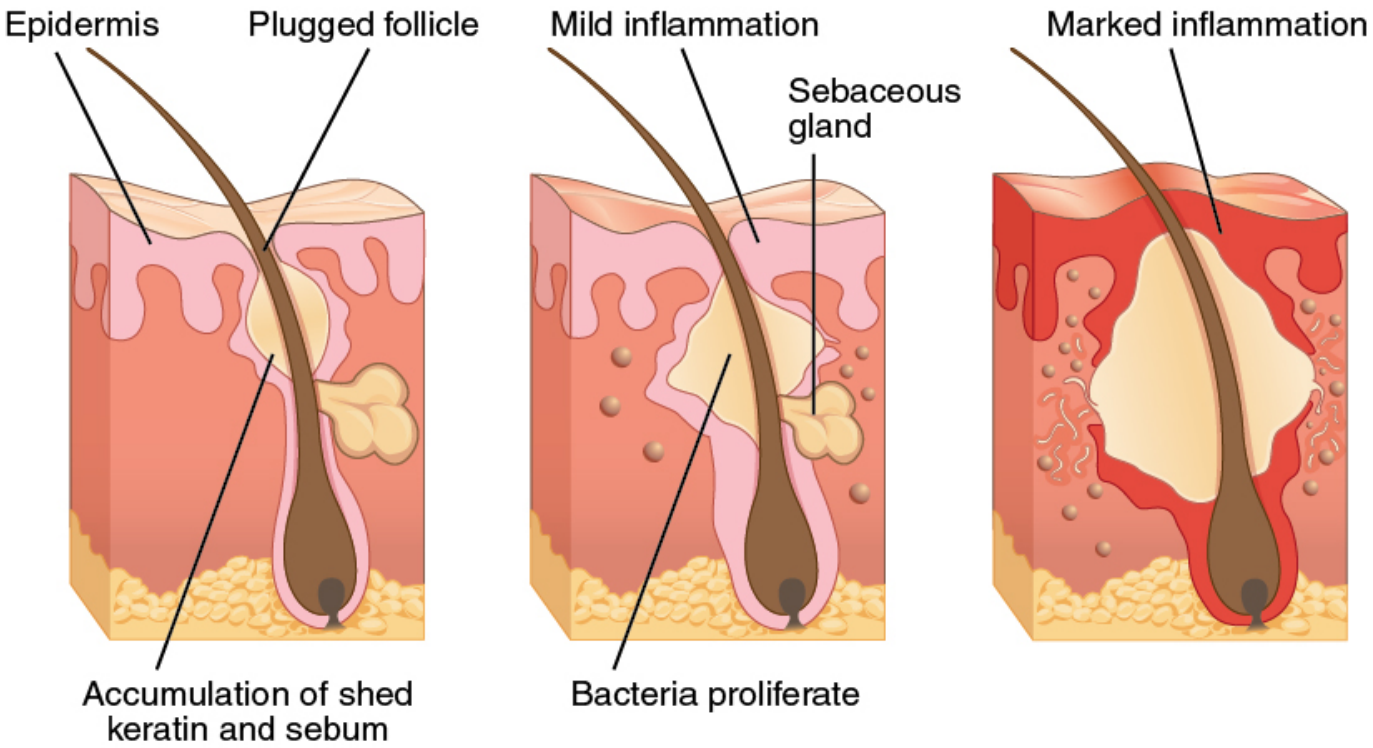


Figure 5.13 Acne

1. OpenStax College. (2013). *515 Acne formation* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:515_Acne_formation.jpg

Albinism

Albinism is a genetic disorder that completely or partially affects the color of the skin, hair, and eyes due to the inability of melanocytes to produce melanin. This lack of melanin causes skin and hair to appear white or very pale. Individuals with albinism need more protection from ultraviolet (UV) radiation, as they are more prone to sunburns and skin cancer. They also tend to be more sensitive to light and may have vision problems due to the lack of pigmentation in the retina. Treatment of this disorder usually involves limiting UV exposure to the skin and eyes. See Figure 5.14[2] for an image of an infant with albinism.



Figure 5.14 Infant with Albinism

2. João Pedro. (2014). *Albino newborn* [Photograph]. Flickr. CC BY-SA 2.0. https://www.flickr.com/photos/felipefdesign/12135299916

Alopecia

Alopecia is the medical term for hair loss in areas where hair normally grows. See Figure 5.15[3] for an image of alopecia.



Figure 5.15 Alopecia

Burns

A **burn** is skin damage caused by intense heat, radiation, electricity, or chemicals.

3. Thirunavukkarasye-Raveendran. (2017). *Alopecia areata 1* [Photograph]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Alopecia_areata_1.jpg

Burns can result in the death of skin cells, and large burns result in massive fluid loss that can result in dehydration, infection, electrolyte imbalance, and renal and circulatory failure that can be fatal.

Patients with severe burns are treated with intravenous fluids to offset dehydration, as well as intravenous nutrients that enable the body to repair tissues and replace lost proteins. Another serious threat to burn patients is infection. Burned skin is extremely susceptible to bacteria and other pathogens due to the loss of protection by intact layers of skin.

Burns can be measured in terms of the total surface area affected. This is referred to as the "rule of nines," which gives specific anatomical areas a percentage that is a factor of nine. See Figure 5.16[4] for an illustration of the rule of nines.

4. OpenStax College. (2013). *513 Degree of burns* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:513_Degree_of_burns.jpg

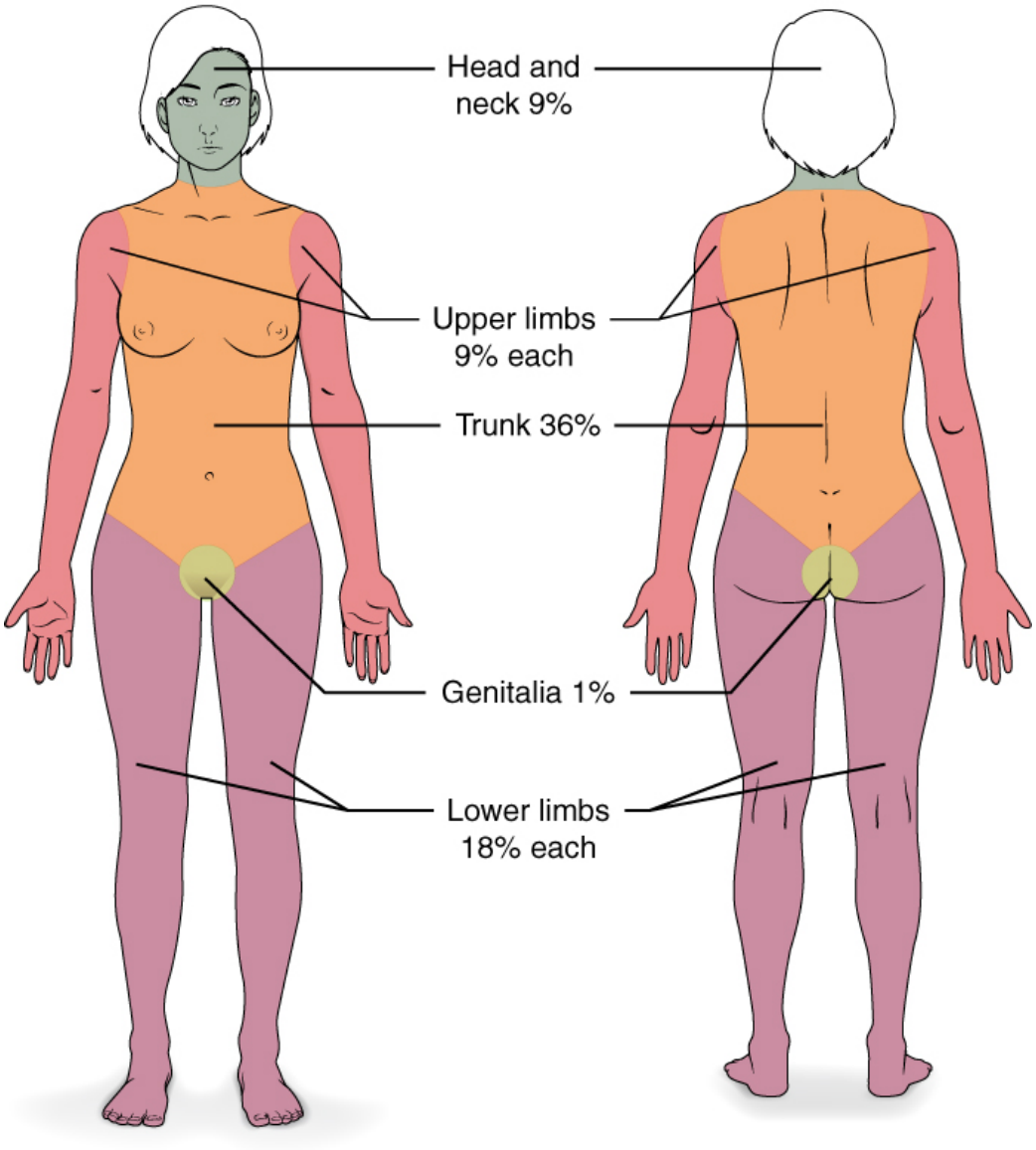


Figure 5.16 Rule of Nines

Burns are also classified by the degree of their severity using the guidelines described in the following subsections. See Figure 5.17[5] for illustrations of first-degree, second-degree, and third-degree burns.

5. Persian Poet Gal. (2006). *Burn degree diagram* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Burn_Degree_Diagram.png

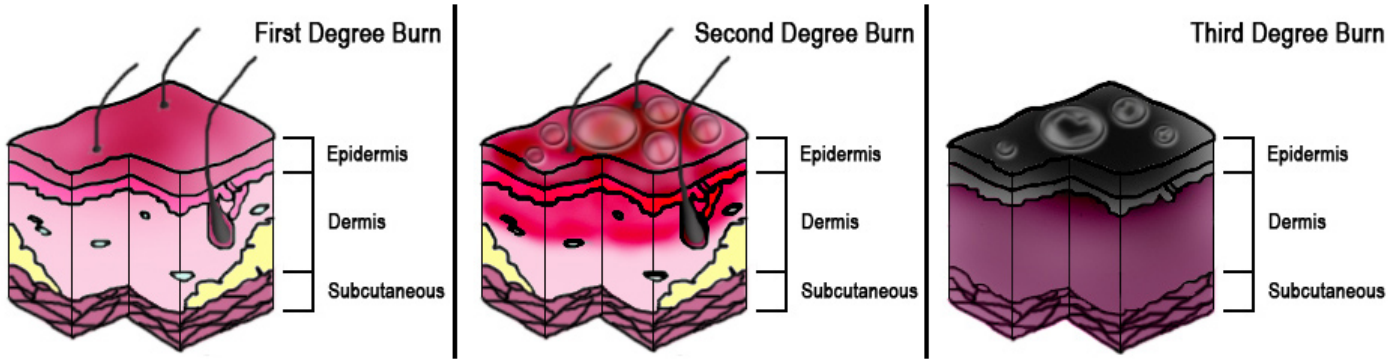


Figure 5.17 First-, Second-, and Third-Degree Burns

First-Degree Burn

A **first-degree burn** is a superficial burn that affects only the epidermis. Although the skin may be red, painful, and swollen, these burns typically heal on their own within a few days. A mild sunburn is an example of a first-degree burn. See Figure 5.18[6] for an image of a first-degree burn.

6. Bejinhan. (2010). *First-degree burn* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:First-degree_burn.jpg



Figure 5.18 First-Degree Burn

Second-Degree Burn

A **second-degree burn**, referred to as a partial thickness burn, affects both the epidermis and a portion of the dermis. These burns result in redness, swelling, and a painful blistering of the skin. It is important to keep the burn site clean to prevent infection. Second-degree burns will usually heal within several weeks. See Figure 5.19[7] for an image of a second-degree burn.

7. Kronoman. (2008). *Hand2ndburn* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Hand2ndburn.jpg



Figure 5.19 Second-Degree Burn

Third-Degree and Fourth-Degree Burns

Third-degree burns are referred to as **full-thickness burns** and extend fully into the epidermis, dermis, and hypodermis, destroying the tissue and affecting the nerve endings and sensory function. These are serious burns requiring medical attention that may appear white, red, or black. They are usually not as painful as second-degree burns because the nerve endings are damaged. See Figure 5.20[8] for an image of a third-degree burn. A **fourth-degree burn** is even more severe, affecting the underlying muscle and bone. Full-thickness burns cannot be repaired by the body because the local tissues used for repair are damaged. They often require debridement, or amputation in severe cases, followed by grafting of the skin from an unaffected part of the body or from skin grown in tissue culture.

8. Craig0927. (2009). *8 day old 3rd degree burn* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:8-day-old-3rd-degree-burn.jpg



Figure 5.20 Third-Degree Burn

Callus

A **callus** is a thickened area of the epidermis due to constant rubbing or abrasion. The stem cells in the stratum basale are stimulated to increase the thickness of the skin to protect it from further damage. See Figure 5.21[9] for an image of calluses on a person's plantar surface of the right foot and the medial surface of the left foot.

9. Jmarchn. (n.d.). *Calluses* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Calluses.jpg



Figure 5.21 Callus

A **corn** is a specialized form of a callus formed by abrasions on the skin that result from an elliptical-type motion. They're usually found on the feet.

Dandruff

Dandruff is a condition of flakes of dead skin from the scalp. See Figure 5.22[10] for an image of dandruff.

10. BestShah. (2022). *Dandruff with hair* [Photograph]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Dandruff_with_Hair.jpg

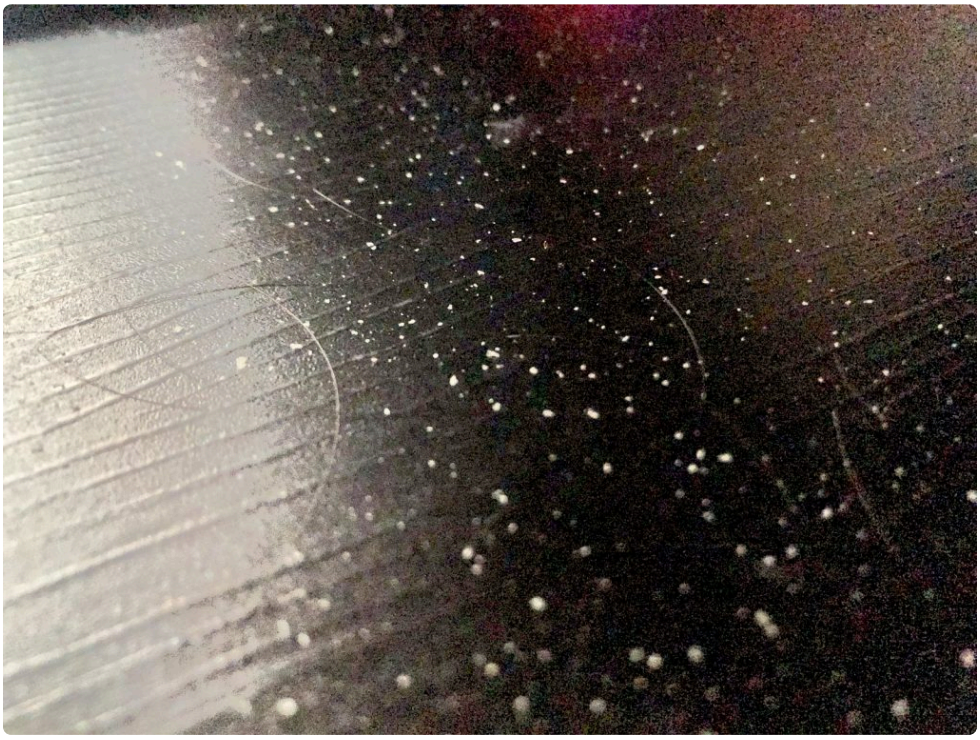


Figure 5.22 Dandruff

Eczema

Eczema (atopic dermatitis) is an allergic reaction that appears as dry, itchy patches of skin resembling rashes. Eczema may be accompanied by swelling of the skin, flaking, and, in severe cases, bleeding. See Figure 5.23[11] for an illustration of eczema.

11. Jambula. (2006). *Eczema-arms* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Eczema-arms.jpg. NIAID. (2017). *Child with eczema* [Photograph]. Wikimedia Commons. CC BY 2.0.https://commons.wikimedia.org/wiki/File:Child_with_Eczema_(34034003933).jpg



Figure 5.23 Eczema

Freckles

Freckles are patches of melanin determined by genetics. See Figure 5.24[12] for an image of an individual with freckles.

12. Loyna. (2005). *Vesnuschki* [Photograph]. Wikimedia Commons. CC BY-SA 2.5. https://commons.wikimedia.org/wiki/File:Vesnuschki.jpg



Figure 5.24 Freckles

Fungal Infections

Tinea is the name of a group of skin diseases caused by a fungus. Types of tinea include ringworm, athlete's foot, and jock itch. These infections are usually not serious, but they can be uncomfortable because of the symptoms of itching and burning. They can be transmitted by touching infected people, damp surfaces such as shower floors, or even from pets. Ringworm (tinea corporis) is a type of rash that forms on the body, typically looking like a red ring with a clear center, although a worm doesn't cause it. Scalp ringworm (tinea capitis) causes itchy, red patches on the head that can leave bald spots. Athlete's foot (tinea pedis) causes itching, burning, and cracked skin between the toes. Jock itch (tinea cruris) causes an itchy, burning rash in the groin area. Fungal infections are often treated successfully with over-the-counter creams and powders, but some require prescription medicine such as nystatin. See Figure 5.25[13] for an image of tinea pedis (athlete's foot).

13. ProjectManhattan. (2014). *Athlete's foot* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Athlete%27s_foot.jpg



Figure 5.25 Tinea Pedis

Hirsutism

Hirsutism is the medical term for excessive hair growth in areas where hair is usually minimal or absent. See Figure 5.26[14] for an image of hirsutism in a female.

14. Gacaferri Lumezi B, Goci A, Lokaj V, Latifi H, Karahoda N, Minci G, Telaku D, Gercari A, Kocinaj A. (2014). *Severe hirsutism in a 17 year old female* [Photograph]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:PMC4103002_ircmj-16-9410-g001.png



Figure 5.26 Hirsutism

Hives

Hives (also known as **urticaria**) are circular, fluid-filled, itchy, raised lesions, often due to an allergic reaction. See Figure 5.27[15] for an image of hives.

15. Enochlau. (2004). *Rash* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Rash.jpg



Figure 5.27 Hives

Hyperhidrosis

Hyperhidrosis is a medical condition of excessive sweating that is not related to heat or exercise. It is treated with medications, Botox injections, or surgery. See Figure 5.28[16] for an image depicting hyperhidrosis.

16. Amnaijaz23. (2015). *Hyperhidrosis* [Photograph]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Hyperhidrosis.jpg



Figure 5.28 Hyperhidrosis

Keloid

A **keloid** is a raised bump due to an overproduction of scar tissue. See Figure 5.29[17] for an image of post-surgical keloids.

17. Htirgan. (2014). *Keloid, post surgical* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Keloid,_Post_Surgical.JPG



Figure 5.29 Keloid

Laceration

A **laceration** is an irregular tear or cut of the skin that may require suturing or another type of surgical repair. See Figure 5.30[18] for an image of a laceration before and after it was sutured.

18. Jeanne Oostdyk. (2005). *Suture, before and after, RMO* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Suture,_before_and_after,_RMO.jpg



Figure 5.30 Laceration

Moles

Moles (or **nevi**) are large masses of melanocytes that are usually benign but should

be monitored for changes that could indicate the presence of skin cancer. See Figure 5.31[19] for an image of a normal-appearing mole.



Figure 5.31 Mole

Pressure Injuries

Pressure injuries (also known as pressure ulcers, decubitus ulcers, and bedsores) are caused by constant pressure on bony areas that reduce blood flow and lead to tissue injury and **necrosis** (tissue death). See Figure 5.32[20] for an image of a pressure injury.

19. National Cancer Institute. (1988) *Normal mole with no color differences* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Normal_mole_with_no_color_differences.jpg

20. AfroBrazilian. (2014). *Decubitus 01* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Decubitus_01.JPG

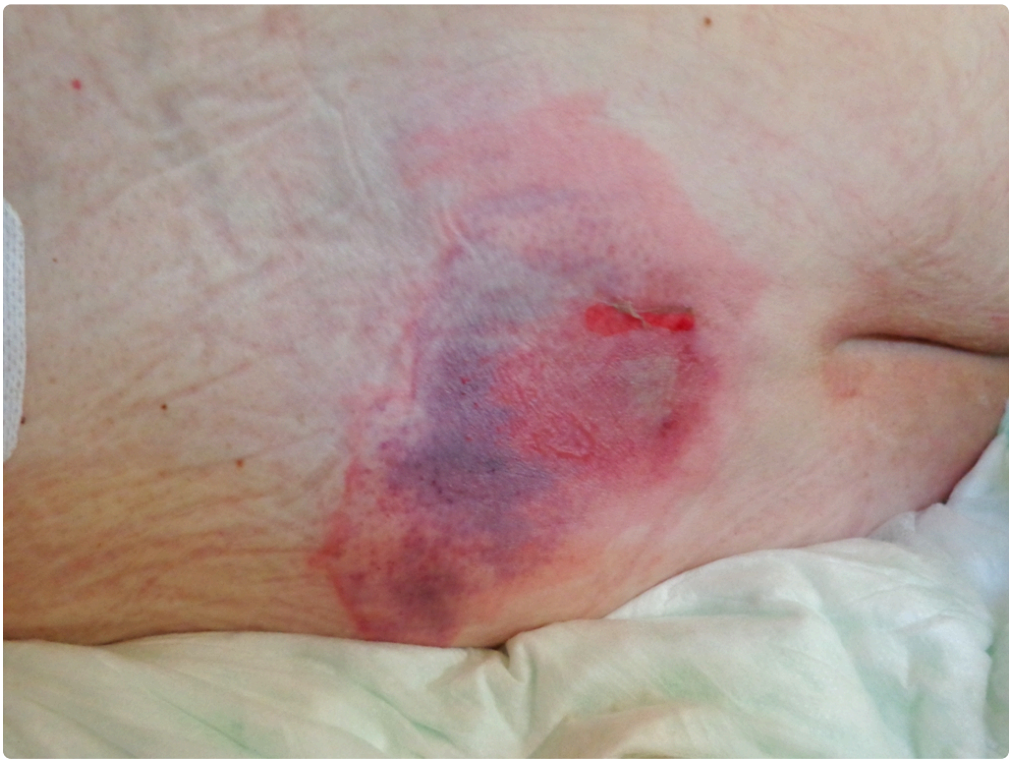


Figure 5.32 Pressure Injury

Psoriasis

Psoriasis is a skin condition in which keratinocytes in the epidermis divide and move too quickly to the surface, resulting in patchy, scaly build-ups on the skin. See Figure 5.33[21] for an image of psoriasis on an individual's arm.

21. Jacopo188. (2013). *Psoriasis 002* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Psoriasis_002.jpg



Figure 5.33 Psoriasis

Shingles

Shingles is a painful rash that occurs along nerves and is caused by reactivation of the varicella-zoster virus. Chicken pox is a disease caused by the first exposure to the virus, and shingles is a reactivation of the same virus. See Figure 5.34[22] for an image of shingles.

22. Preston Hunt. (2007). *Shingles on the chest* [Photograph]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Shingles_on_the_chest.jpg



Figure 5.34 Shingles

Skin Cancer

The Skin Cancer Foundation reports that one in five Americans will experience some type of skin cancer in their lifetime. Too much sun exposure can lead to wrinkling of the skin due to the destruction of the cellular structure and, in severe cases, can cause enough DNA damage to result in skin cancer. One of the contributing factors to the increase in the number of skin cancer cases is the breakdown of the ozone layer of the atmosphere, which has resulted in increased exposure to UV radiation. Other risk factors for skin cancer include older age, family history, fair skin, and immunosuppression.

Skin cancers fall into three main types: basal cell carcinoma, squamous cell carcinoma, and malignant melanoma.

Basal Cell Carcinoma

Basal cell carcinoma is a form of skin cancer that affects the stem cells in the stratum basale layer of the epidermis. It is the most common type of skin cancer in the United States and is frequently found on the head, neck, arms, and back, which are the areas most susceptible to long-term sun exposure.

Although UV radiation is the main cause of basal cell carcinoma, exposure to other agents, such as arsenic and radiation medical therapy, can also lead to basal cell carcinoma.

Basal cell carcinomas start in the stratum basale and usually spread along this boundary. At some point, they begin to grow toward the surface and become an uneven patch, bump, growth, or scar on the skin surface. Like most cancers, basal cell carcinomas respond best to treatment when caught early. Treatment options include surgery, freezing (cryosurgery), and topical ointments.

See Figure 5.35[23] for an image of basal cell carcinoma.



Figure 5.35 Basal Cell Carcinoma

23. John Hendrix. (2006). *Basal cell carcinoma* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Basal_cell_carcinoma.jpg

Squamous Cell Carcinoma

Squamous cell carcinoma is the second most common skin cancer. The American Cancer Society reports that two out of every ten skin cancers are squamous cell carcinomas. It is more aggressive than basal cell carcinoma. Squamous cell carcinoma affects the keratinocytes of the stratum spinosum and usually appears as lesions on the scalp, ears, and hands. If not removed, these carcinomas can **metastasize** or spread to other areas of the body. Surgery and radiation are used to treat squamous cell carcinoma. See Figure 5.36[24] for an image of squamous cell carcinoma.



Figure 5.36 Squamous Cell Carcinoma

Melanoma

A **melanoma** is a cancer characterized by the uncontrolled growth of melanocytes, the melanin-producing cells in the epidermis. Typically, a melanoma develops from a mole. It is the most fatal of all skin cancers, as it is highly metastatic and can be difficult to detect before it has spread to other organs. Melanomas usually appear as

24. Unknown photographer. (n.d.). *Squamous cell carcinoma* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Squamous_Cell_Carcinoma.jpg

asymmetrical brown and black patches with uneven borders and a raised surface. Treatment typically involves surgical excision and immunotherapy. See Figure 5.37[25] for an image of melanoma.



Figure 5.37 Melanoma

Patients are taught the following ABCDE mnemonic to help notice signs of early-stage melanoma. If you observe a mole on your body displaying these signs, consult your health care provider:

- Asymmetry: the two sides are not symmetrical or don't match
- Borders: the edges are irregular in shape
- Color: the color is varied shades of brown, black, or other colors
- Diameter: it is larger than 6 mm (0.24 in), the size of a pencil eraser
- Evolving: its shape has changed, or it is growing

25. Unknown photographer. (1985). *Melanoma* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Melanoma.jpg

Some specialists cite the following additional signs for serious forms of nodular melanoma:

- Elevated: it is raised on the skin surface
- Firm: it feels hard to the touch
- Growing: it is getting larger

Striae

Striae, commonly called stretch marks, result when the dermis is stretched beyond its limits of elasticity, often due to rapid weight gain during puberty and pregnancy. They often appear on the hips and abdomen and initially have a reddish color but lighten over time. See Figure 5.38[26] for an image of striae.



Figure 5.38 Striae

26. Medicalpal. (2018). *Striae alba – stretch mark* [Photograph]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Striae_Alba_-_Stretch_Mark.jpg

Vitiligo

Vitiligo is a skin condition in which melanocytes in some areas lose their ability to produce melanin, resulting in lighter patches of skin. See Figure 5.39[27] for an image of vitiligo on a person with darker-pigmented skin.



Figure 5.39 Vitiligo

27. Grook Da Oger. (2009). *Vitiligo* [Photograph]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Vitiligo.jpg

Wart

A **wart** is an uncontrolled growth of epidermal cells caused by the papilloma virus. See Figure 5.40[28] for an image of a wart on a toe.[29]



Figure 5.40 Wart

28. Mndno. (2011). *Verruca vulgaris on the first toe* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Verruca_vulgaris_on_the_first_toe.jpg

29. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

5.6 Career Connections Related to the Integumentary System

Dermatology is the study of the integumentary system. The integumentary system includes the skin, hair, nails, glands, and related structures. Because this system protects the body from injury, infection, dehydration, and environmental hazards, many different professionals help people maintain healthy skin, hair, and nails. Careers related to the integumentary system can include aestheticians, estheticians, cosmetologists, nail technicians, and medical assistants.

Aesthetician

An **aesthetician** is a licensed professional who may provide skin care services that support skin health, healing, or recovery. Aestheticians may work with clients who have skin concerns related to scars, injuries, aging, acne, or other conditions affecting the skin. Their specific duties and services vary based on training, workplace, and state regulations.

Esthetician

An **esthetician** is a skin care professional who typically works in salon, spa, or personal care settings. Estheticians focus on cosmetic skin care services such as facials, skin cleansing, exfoliation, hair removal, chemical peels, and product recommendations. They do not diagnose or treat medical skin conditions, but may encourage clients to seek care from a health care provider when needed.

Cosmetologist

A **cosmetologist** is a state-licensed beauty professional who provides personal care services related to hair, skin, and nails. Cosmetologists may offer services such as haircutting, hairstyling, coloring, manicures, pedicures, makeup application, and basic

skin care, depending on state regulations. They use knowledge of the integumentary system while following safety and sanitation practices to protect clients from injury and infection.

Nail Technician

A nail technician is a beauty professional who provides services related to the fingernails, toenails, and surrounding skin. Nail technicians may perform manicures, pedicures, nail shaping, polishing, and artificial nail services. They use knowledge of nail structure, skin care, sanitation, and infection prevention to help protect the health and safety of clients.

Medical Assistant

A medical assistant is a health care professional who supports patient care and office procedures in clinics and other medical settings. In dermatology or primary care settings, medical assistants may help room patients, collect health information, prepare patients for examinations, assist with minor procedures, support documentation, and provide basic patient education. Some medical assistants may also help with wound care or changing dressings under the direction of a licensed provider.

Take a Closer Look

Explore careers related to the human body's integumentary system on these websites.

- Skincare specialists from the U.S. Bureau of Labor Statistics
- Aesthetician and esthetician careers from O*NET OnLine
- Cosmetology from the U.S. Bureau of Labor Statistics
- Cosmetology careers from the American Association of Career Schools
- Medical assisting from the American Association of Medical Assistants

5.7 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

5.8 Glossary

Acne: A skin condition that typically occurs on the face and back, which are areas rich in sebaceous (oil) glands. (**Chapter 5.5**)

Adipocytes: Fat-storing cells found in the hypodermis. (**Chapter 5.3**)

Adipose: A type of tissue that stores fat for energy and insulation. (**Chapter 5.3**)

Aesthetician: A skin care professional who provides cosmetic treatments such as facials and skin exfoliation. (**Chapter 5.6**)

Albinism: A genetic disorder that completely or partially affects the color of the skin, hair, and eyes due to the inability of melanocytes to produce melanin. (**Chapter 5.5**)

Alopecia: The medical term for hair loss in areas where hair normally grows. (**Chapter 5.5**)

Angiogenesis: The formation of new blood vessels, essential for wound healing. (**Chapter 5.4**)

Apocrine sweat gland: A sweat gland found in the armpits and groin, producing a thicker secretion. (**Chapter 5.3**)

Arrector pili muscle: A small muscle attached to hair follicles that causes hair to stand upright when contracted. (**Chapter 5.3**)

Avascular: Lacking blood vessels, as seen in the epidermis. (**Chapter 5.3**)

Basal cell: A type of cell in the stratum basale that continuously divides to form new skin cells. (**Chapter 5.3**)

Basal cell carcinoma: A form of skin cancer that affects the stem cells in the stratum basale layer of the epidermis. (**Chapter 5.5**)

Burn: Skin damage caused by intense heat, radiation, electricity, or chemicals. (**Chapter 5.5**)

Callus: A thickened area of the epidermis due to constant rubbing or abrasion. (**Chapter 5.5**)

Cerumen: Waxy substance; earwax. (**Chapter 5.3**)

Ceruminous (wax) glands: Glands in the ear that produce earwax. (**Chapter 5.3**)

Collagen fibers: Strong, fibrous proteins that provide structural support in connective tissues. (**Chapter 5.3**)

Convection: The transfer of heat through the movement of air or liquid around the skin. (**Chapter 5.2**)

Corn: A specialized form of a callus formed by abrasions on the skin that result from an elliptical-type motion. (**Chapter 5.5**)

Cornification: The process by which keratinocytes harden to form the stratum corneum. (**Chapter 5.3**)

Cosmetologist: A professional trained in beauty treatments, including hair, skin, and nail care. (**Chapter 5.6**)

Cuticle: The thin layer of skin at the base of the nail. (**Chapter 5.3**)

Cyanosis: A bluish discoloration of the skin caused by poor oxygenation. (**Chapter 5.3**)

Dandruff: A condition of flakes of dead skin from the scalp. (**Chapter 5.5**)

Dehydration: A condition in which the body loses more water than it takes in, affecting skin elasticity. (**Chapter 5.2**)

Dermal papillae: Finger-like projections in the dermis that increase surface area for nutrient exchange with the epidermis. (**Chapter 5.3**)

Dermatologist: A medical doctor specializing in dermatology. (**Chapter 5.6**)

Dermatology: The medical specialty focused on diagnosing and treating skin, hair, and nail disorders. (**Chapter 5.6**)

Dermis: The thick layer of skin beneath the epidermis, containing nerves, blood vessels, and connective tissue. (**Chapter 5.3**)

Eccrine sweat gland: A gland that produces sweat for temperature regulation. (**Chapter 5.3**)

Eczema: An allergic reaction that appears as dry, itchy patches of skin resembling rashes. (**Chapter 5.5**)

Elastin fibers: Protein fibers in the dermis that provide skin elasticity. (**Chapter 5.3**)

Epidermis: The outermost layer of the skin, providing a protective barrier. (**Chapter 5.3**

Epithelialization: The process by which new skin cells cover a wound. (**Chapter 5.4**)

Eponychium: Another term for the cuticle, protecting the nail matrix. (**Chapter 5.3**)

Erythema: Redness of the skin due to increased blood flow. (Chapter 5.3)

Esthetician: Another term for an aesthetician, primarily focused on non-medical skin care treatments. (Chapter 5.6)

Fascia: A fibrous tissue that encloses muscles and organs. (Chapter 5.3)

First-degree burn: A superficial burn that affects only the epidermis. (Chapter 5.5)

Fourth-degree burn: A burn affecting the underlying muscle and bone. (Chapter 5.5)

Freckles: Patches of melanin determined by genetics. (Chapter 5.5)

Free edge: The white part of the nail that extends beyond the nail bed. (Chapter 5.3)

Full-thickness burns: Burns that extend fully into the epidermis, dermis, and hypodermis, destroying the tissue and affecting the nerve endings and sensory function. (Chapter 5.5)

Granulation tissue: New connective tissue and tiny blood vessels that form during wound healing. (Chapter 5.4)

Hair follicle: The structure in the skin that produces hair. (Chapter 5.3)

Hair root: The part of the hair embedded in the follicle. (Chapter 5.3)

Hair shaft: The visible part of the hair above the skin surface. (Chapter 5.3)

Hemoglobin: A protein in red blood cells that carries oxygen and contributes to skin color. (Chapter 5.3)

Hemostasis phase: The initial phase of wound healing, where clotting occurs to stop bleeding. (Chapter 5.4)

Hirsutism: The medical term for excessive hair growth in areas where hair is usually minimal or absent. (Chapter 5.5)

Hives: Circular, fluid-filled, itchy, raised lesions often due to an allergic reaction. (Chapter 5.5)

Hyperhidrosis: A medical condition of excessive sweating that is not related to heat or exercise. (Chapter 5.5)

Hypodermis: The layer beneath the dermis that contains fat and connective tissue. (Chapter 5.3)

Hyponychium: The skin under the free edge of the nail that provides a seal against infections. (Chapter 5.3)

Inflammatory phase: The second phase of wound healing, where the body fights infection and clears debris. (**Chapter 5.4**)

Integumentary system: The organ system that includes the skin, hair, nails, and associated glands, serving as a protective barrier for the body. (**Chapter 5.1**)

Jaundice: Yellowing of the skin and eyes due to excess bilirubin. (**Chapter 5.3**)

Keloid: A raised bump due to an overproduction of scar tissue. (**Chapter 5.5**)

Keratin: A tough, fibrous protein that strengthens hair, skin, and nails. (**Chapter 5.3**)

Keratinocyte: The primary cell type in the epidermis that produces keratin. (**Chapter 5.3**)

Laceration: An irregular tear or cut of the skin that may require suturing or another type of surgical repair. (**Chapter 5.5**)

Langerhans cells: Immune cells in the epidermis that help fight infection. (**Chapter 5.3**)

Lunula: A thick crescent-shaped layer of epithelium over the nail matrix. (**Chapter 5.3**)

Maturation phase: The final phase of wound healing, where collagen strengthens and scars form. (**Chapter 5.4**)

Meissner corpuscles: Sensory receptors in the skin that detect light touch. (**Chapter 5.3**)

Melanin: A pigment that provides color to the skin and protects against UV radiation. (**Chapter 5.3**)

Melanocytes: Cells in the epidermis that produce melanin. (**Chapter 5.3**)

Melanoma: Cancer characterized by the uncontrolled growth of melanocytes, the melanin-producing cells in the epidermis. (**Chapter 5.5**)

Merkel cells: Sensory cells in the stratum basale that detect touch. (**Chapter 5.3**)

Metastasize: Spread to other areas of the body. (**Chapter 5.5**)

Moles: Large masses of melanocytes that are usually benign but should be monitored for changes that could indicate the presence of skin cancer; also known as nevi. (**Chapter 5.5**)

Nail bed: The area of skin beneath the nail that supplies nutrients and support. (**Chapter 5.3**)

Nail body: The hard, visible part of the nail. (**Chapter 5.3**)

Nail root: The part of the nail beneath the skin where new nail growth occurs. (Chapter 5.3)

Necrosis: Tissue death. (Chapter 5.5)

Nevi: Large masses of melanocytes that are usually benign but should be monitored for changes that could indicate the presence of skin cancer; also known as moles. (Chapter 5.5)

Nociceptors: Pain receptors in the skin. (Chapter 5.3)

Pacinian corpuscle: A sensory receptor that detects deep pressure and vibration. (Chapter 5.3)

Pallor: Unusual paleness of the skin due to reduced blood flow. (Chapter 5.3)

Papillary layer: The upper layer of the dermis with loose connective tissue and dermal papillae. (Chapter 5.3)

Pressure injuries: Caused by constant pressure on bony areas that reduce blood flow and lead to tissue injury; also known as pressure ulcers, decubitus ulcers, and bedsores. (Chapter 5.5)

Proliferative phase: The third phase of wound healing, where new tissue forms to replace the wound. (Chapter 5.4)

Psoriasis: A skin condition in which keratinocytes in the epidermis divide and move too quickly to the surface, resulting in patchy, scaly build-ups on the skin. (Chapter 5.5)

Reticular layer: The deeper layer of the dermis, composed of dense connective tissue. (Chapter 5.3)

Reticulated: Arranged in a net-like pattern, as seen in the collagen fibers of the reticular layer. (Chapter 5.3)

Sebaceous (oil) gland: A gland that secretes sebum to lubricate and protect the skin. (Chapter 5.3)

Sebum: An oily substance produced by sebaceous glands to keep skin moisturized. (Chapter 5.3)

Second-degree burn: Referred to as a partial thickness burn; it affects both the epidermis and a portion of the dermis. (Chapter 5.5)

Shingles: A painful rash that occurs along nerves and is caused by reactivation of the varicella-zoster virus. (Chapter 5.5)

Squamous cell carcinoma: The second most common skin cancer, affecting the

keratinocytes of the stratum spinosum and usually appearing as lesions on the scalp, ears, and hands. (Chapter 5.5)

Stratum basale: The deepest layer of the epidermis, where new skin cells are produced. (Chapter 5.3)

Stratum corneum: The outermost layer of the epidermis, composed of dead, keratinized cells. (Chapter 5.3)

Stratum granulosum: A layer of the epidermis where keratinocytes begin to die and accumulate keratohyalin granules. (Chapter 5.3)

Stratum lucidum: A thin, translucent layer of the epidermis found only in thick skin. (Chapter 5.3)

Stratum spinosum: A layer of the epidermis that provides structural integrity and contains Langerhans cells. (Chapter 5.3)

Striae: When the dermis is stretched beyond its limits of elasticity, often due to rapid weight gain during puberty and pregnancy. They often appear on the hips and abdomen and initially have a reddish color but lighten over time. Commonly called stretch marks. (Chapter 5.5)

Subcutaneous layer: Another name for the hypodermis. (Chapter 5.3)

Superficial fascia: The connective tissue layer that separates skin from underlying muscles and bones. (Chapter 5.3)

Thermoreceptors: Sensory receptors that detect temperature changes. (Chapter 5.3)

Thick skin: Skin found on the palms and soles, with extra layers for protection. (Chapter 5.3)

Thin skin: Skin that covers most of the body and has fewer epidermal layers. (Chapter 5.3)

Third-degree burns: Referred to as full-thickness burns that extend fully into the epidermis, dermis, and hypodermis, destroying the tissue and affecting the nerve endings and sensory function. (Chapter 5.5)

Tinea: A group of skin diseases caused by a fungus; types include ringworm, athlete's foot, and jock itch. (Chapter 5.5)

Translucent: Allowing light to pass through but not detailed images, as seen in the stratum lucidum. (Chapter 5.3)

Urticaria: Circular, fluid-filled, itchy, raised lesions often due to an allergic reaction. (**Chapter 5.5**)

Vitiligo: A skin condition in which melanocytes in some areas lose their ability to produce melanin, resulting in lighter patches of skin. (**Chapter 5.5**)

Wart: An uncontrolled growth of epidermal cells caused by the papilloma virus. (**Chapter 5.5**)

PART VI

CHAPTER 6 SKELETAL SYSTEM

6.1 Introduction to the Skeletal System

Chapter Competency

Analyze how components of the skeletal system function in the body.

Learning Objectives

- Identify gross and microscopic structural components of the skeletal system.
- Correlate the structural components of the skeletal system with their functions.
- Identify the major chemical components of the skeletal system.
- Illustrate the relationships among the components of the skeletal system.
- Summarize the functions of the skeletal system.
- Correlate joint structure with joint movement.

Imagine you are working as a physical therapy assistant helping a patient recover after a fracture, joint injury, or surgery. As the patient begins rehabilitation, you observe how bones, joints, ligaments, tendons, cartilage, and muscles work together to support posture and produce movement. To help the patient regain strength, mobility, and function, you must understand how the skeletal system is structured and how its components support, protect, and move the body.

The skeletal system consists of bones, cartilage, ligaments, and tendons that form the strong internal framework of the human body. Bones support body weight, protect internal organs, store minerals, assist with movement, and contain tissue that produces blood cells. Bone is also a living tissue that can change in strength and thickness in response to activity, body weight, nutrition, and periods of reduced use. **Cartilage**

provides flexible support and cushioning, **ligaments** connect bones to other bones, and **tendons** attach muscles to bones so that muscle contractions can produce movement.

In this chapter, you will explore the structure and function of the skeletal system. You will learn about the major functions of bones, the microscopic and gross anatomy of bone tissue, and the chemical components that give bone both strength and flexibility. You will also study the organization of the axial and appendicular skeletons, identify major bones and landmarks, and examine how joints are classified according to their structure and movement. Finally, you will learn about common skeletal system disorders and how changes in bone and joint structure can affect function.

By mastering these concepts, you will gain a deeper understanding of how the skeletal system supports the body, protects vital organs, enables movement, stores minerals, and contributes to blood cell production. This foundation will help you connect skeletal structure to movement, injury prevention, rehabilitation, and disorders affecting bones and joints.

See Figure 6.1[1] for an illustration comparing ligaments and tendons.

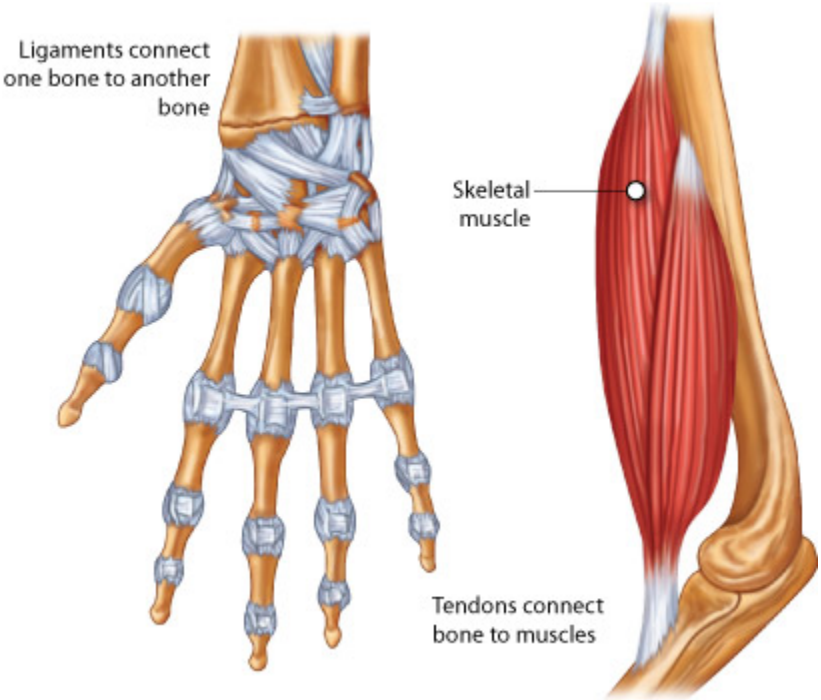


Figure 6.1 Ligaments and Tendons

1. CCCOnline. (n.d.). *Tendon-lig* [Diagram]. Colorado Community College System. CC BY-NC-SA 4.0. https://pressbooks.ccconline.org/bio106/chapter/skeletal-structures-and-functions/

Video

Watch the video "Skeletal System" below to learn about the structure and function of bones and how the skeletal system supports the body, protects organs, and enables movement.[2]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

2. Amoeba Sisters. (2023, June 7). Skeletal system [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=m26gr04HIVE

6.2 Major Functions of the Skeletal System

The skeletal system performs five important functions for the human body, including support, protection, movement, storage, and blood cell production.

Support

Just as the steel beams of a building provide a scaffold to support its weight, the bones, ligaments, and cartilage of the skeletal system form a framework to support the weight of the body. Bones also give shape to the body, such as the face. Without the skeletal system, the body would not have any structure.

Protection

Bones protect internal organs from injury by covering or surrounding them. For example, the ribs protect the lungs and heart, the bones of the vertebral column (spine) protect the spinal cord, and the cranium (skull) protects the brain. See Figure 6.2[1] for an illustration of how the cranium completely surrounds and protects the brain from injury.

1. OpenStax College. (2013). *618 Bones protect brain* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:618_Bones_Protect_Brain.jpg

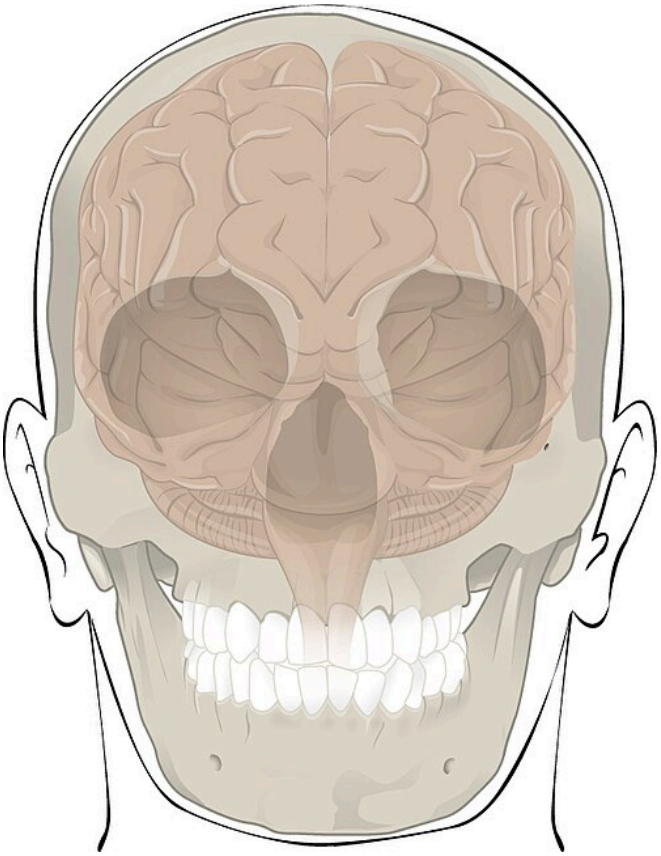


Figure 6.2 Protection of the Brain by the Skull

Movement

Bones facilitate movement by serving as attachment points for muscles. Some bones only serve as a support for the muscles; others also transmit the forces produced when your muscles contract. From a mechanical point of view, bones act as levers and joints serve as fulcrums. See Figure 6.3[2] for an image depicting how bones facilitate movement.

2. bozdoz. (2009). *Leg press* [Photograph]. Wikimedia Commons. CC BY 2.0. https://commons.wikimedia.org/wiki/File:Leg_press.jpg



Figure 6.3 Bones Facilitate Movement

Storage

Bone stores a number of important minerals, such as calcium and phosphorus. These minerals can be stored or released back into the bloodstream to maintain normal levels.

Bone also serves as a site for fat storage. The softer connective tissue that fills the inside of most bones is referred to as bone marrow. There are two types of bone marrow: yellow marrow and red marrow. **Yellow bone marrow** contains adipose tissue and stores triglycerides that can be used for energy. **Red bone marrow** produces blood cells, as described in the following subsection. See Figure 6.4[3] for an image of red and yellow bone marrow.

3. OpenStax College. (2013). *619 Red and yellow bone marrow* [Photograph]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:619_Red_and_Yellow_Bone_Marrow.jpg

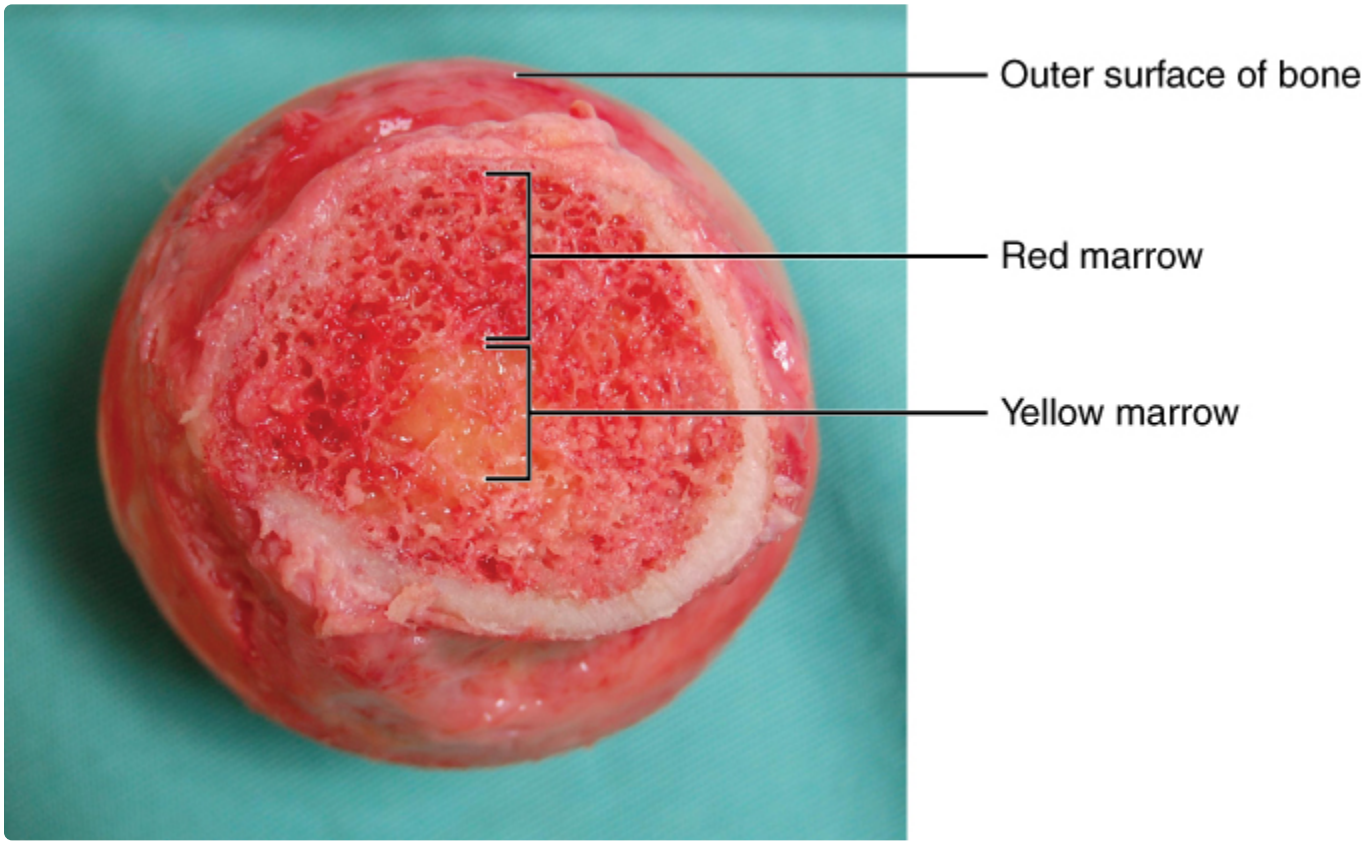


Figure 6.4 Head of Femur Showing Red and Yellow Marrow

Blood Cell Production

Bone is also a site for blood cell production. Red bone marrow is where **hemopoiesis** (the production of blood cells) takes place. Red blood cells, white blood cells, and platelets are all produced in the red bone marrow.[4] Blood cell production is further discussed in **Chapter 10**.

Video

Watch the video "Skeletal System Explained (Bone Structure and Function)" below to learn more about the structure and function of the skeletal system.

4. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.



6.3 Anatomy of the Skeletal System

Shapes of Bones

At birth, a baby has 270–300 bones, some of which are made entirely of cartilage. These bones eventually **fuse** (grow together) to form 206 adult bones. Bones stop growing in length between the ages of 18 and 21, but the total amount of bone tissue a person has (called **bone density**) continues to increase slowly until the late 20s.

Bone tissue, also called osseous tissue, is different from other tissues in the body. Bone is hard, and many of its functions depend on that hardness characteristic.

The 206 bones that compose the adult skeleton are divided into five categories based on their shapes. Each bone shape has a distinct function:

- Long Bones: A **long bone** is cylindrical in shape and is longer than it is wide. Long bones are found in the upper extremities (i.e., humerus, ulna, and radius) and lower extremities (i.e., femur, tibia, fibula), as well as in the fingers (i.e., metacarpals and phalanges) and toes (i.e., metatarsals and phalanges). Long bones function as levers that move when muscles contract.
- Short Bones: A **short bone** is cube-like in shape and about the same size in length, width, and thickness. The only short bones in humans are the carpals of the wrists and the tarsals of the ankles. Short bones provide stability and support, as well as some limited motion.
- Flat Bones: A **flat bone** is typically thin, but it is also often curved. Examples of flat bones include the cranial (skull) bones, the scapulae (shoulder blades), the sternum (breastbone), and the ribs. Flat bones serve as points of attachment for muscles and often protect internal organs.
- Irregular Bones: An **irregular bone** has a complex shape, such as the vertebrae that protect the spinal cord. It does not have an easily described shape and, therefore, does not fit any other classification. For example, many facial bones are classified as irregular bones.
- Sesamoid Bones: A **sesamoid bone** is a small, round bone that is shaped like a sesame seed. These bones form in tendons and help to protect them. Sesamoid

bones vary in number and placement from person to person, but are typically found in tendons associated with the feet, hands, and knees. The patellae (singular = patella) are the largest sesamoid bones found in humans.

See Figure 6.5[1] for an illustration of the classification of bones.

1. OpenStax College. (2013). *601 Bone classification* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:601_Bone_Classification.jpg

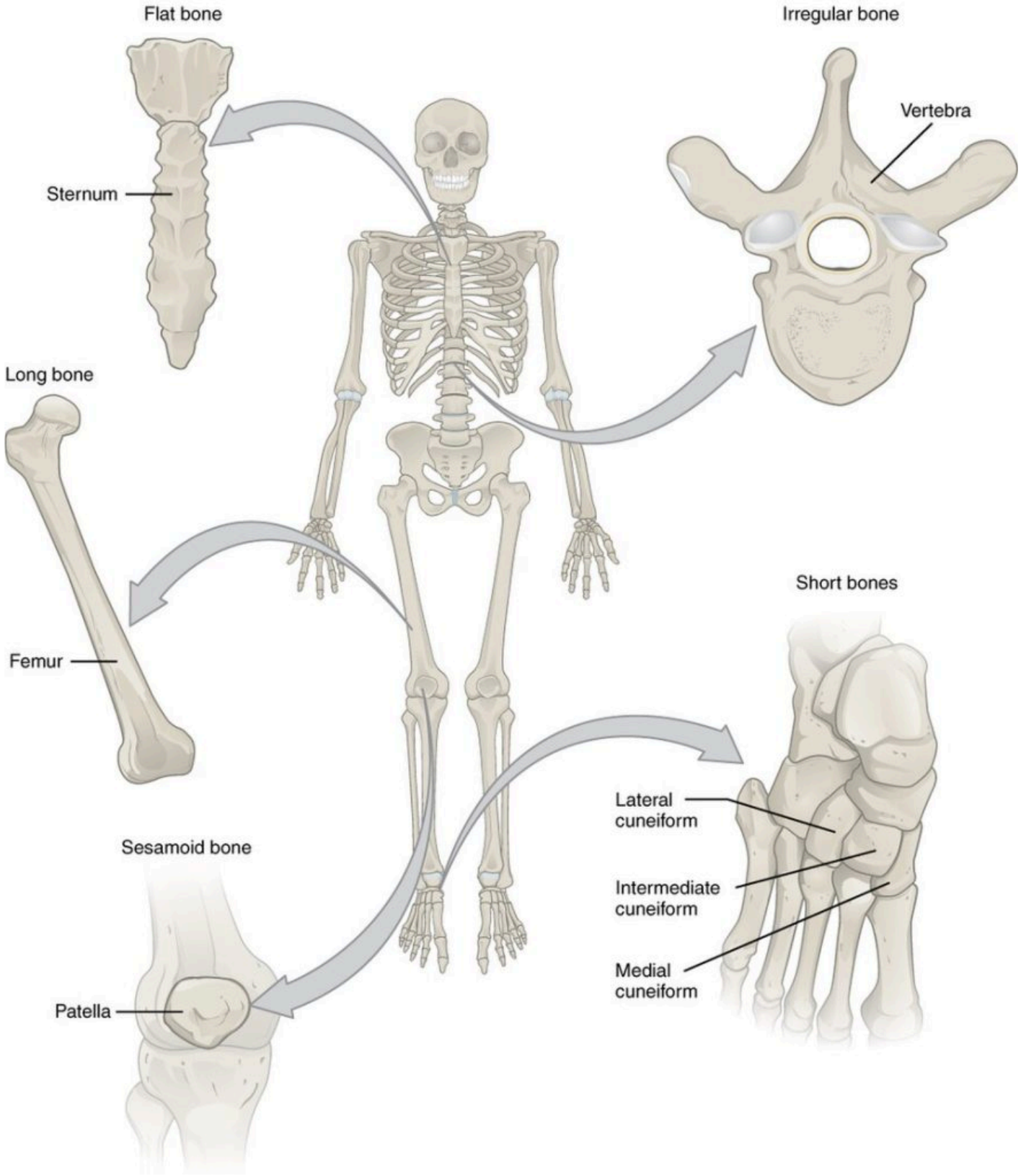


Figure 6.5 Classifications of Bones

Table 6.3a reviews bone classifications with their associated features, functions, and examples.

Table 6.3a. Bone Classifications[2]

Bone Classification	Features	Function(s)	Examples
Long	Cylinder-like shape; longer than it is wide	Leverage	Femur, tibia, fibula, metatarsals, humerus, ulna, radius, metacarpals, phalanges
Short	Cube-like shape approximately equal in length, width, and thickness	Provide stability and support while allowing for some motion	Carpals, tarsals
Flat	Thin and curved	Points of attachment for muscles; protectors of internal organs	Sternum, ribs, scapulae, cranial bones
Irregular	Complex shape	Protect internal organs	Vertebrae, facial bones
Sesamoid	Small and round; embedded in tendons	Protect tendons from compressive forces; muscle leverage	Patellae

Anatomy of a Long Bone

The structure of a long bone allows for the best visualization of all parts of a bone. See

2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Figure 6.6[3] for an illustration of the anatomy of a long bone. Major parts of a long bone include the following:

- Diaphysis: The **diaphysis** is the shaft that runs between the proximal and distal ends of the bone. It is composed of compact or cortical bone tissue.
- Epiphysis: The **epiphysis** (plural = epiphyses) is the wider end of the bone and is made of spongy or cancellous bone tissue. Red marrow fills the spaces in the spongy bone.
- Metaphysis: The epiphyses meet the diaphysis at the narrow area called the **metaphysis**. The metaphysis contains the epiphyseal plate (commonly referred to as the growth plate), a layer of hyaline cartilage in a growing bone. When the bone stops growing in early adulthood (at approximately 18–21 years of age), the hyaline cartilage is replaced by bone tissue, and the epiphyseal plate becomes an **epiphyseal line**.
- Articular cartilage: The epiphyses are covered with **articular cartilage**, a thin layer of hyaline cartilage that reduces friction in joints and acts as a shock absorber.
- Periosteum: The outer surface of the bone is covered with a fibrous membrane called the **periosteum** (*peri-* = "around" or "surrounding" and *oste-* = "bone"). The periosteum contains blood vessels, nerves, and lymphatic vessels that nourish compact bone. Tendons and ligaments also attach to bones at the periosteum. The periosteum covers the entire outer surface of the bone, except where the epiphyses meet other bones to form joints. See Figure 6.7[4] for an illustration of the periosteum.
- Medullary (or marrow) cavity: The hollow region in the diaphysis is called the **medullary cavity**, which is filled with red marrow in children and yellow marrow in adults.
- Endosteum: The **endosteum** (*end-* = "inside" and *oste-* = "bone") is a delicate, membranous lining of the medullary cavity, where bone growth, repair, and remodeling occur. See Figure 6.7 for an illustration of the endosteum.

3. OpenStax College. (2013). *603 Anatomy of long bone* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:603_Anatomy_of_Long_Bone.jpg
4. OpenStax College. (2013). *607 Periosteum and endosteum* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:607_Periosteum_and_Endosteum.jpg

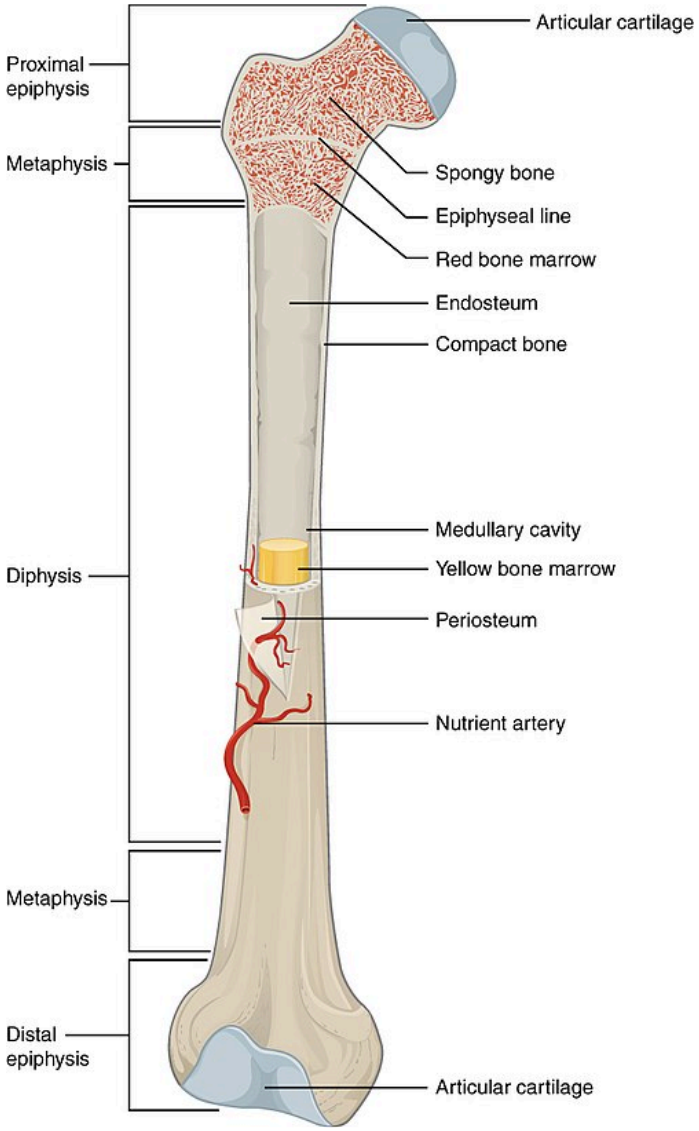


Figure 6.6 Anatomy of a Long Bone

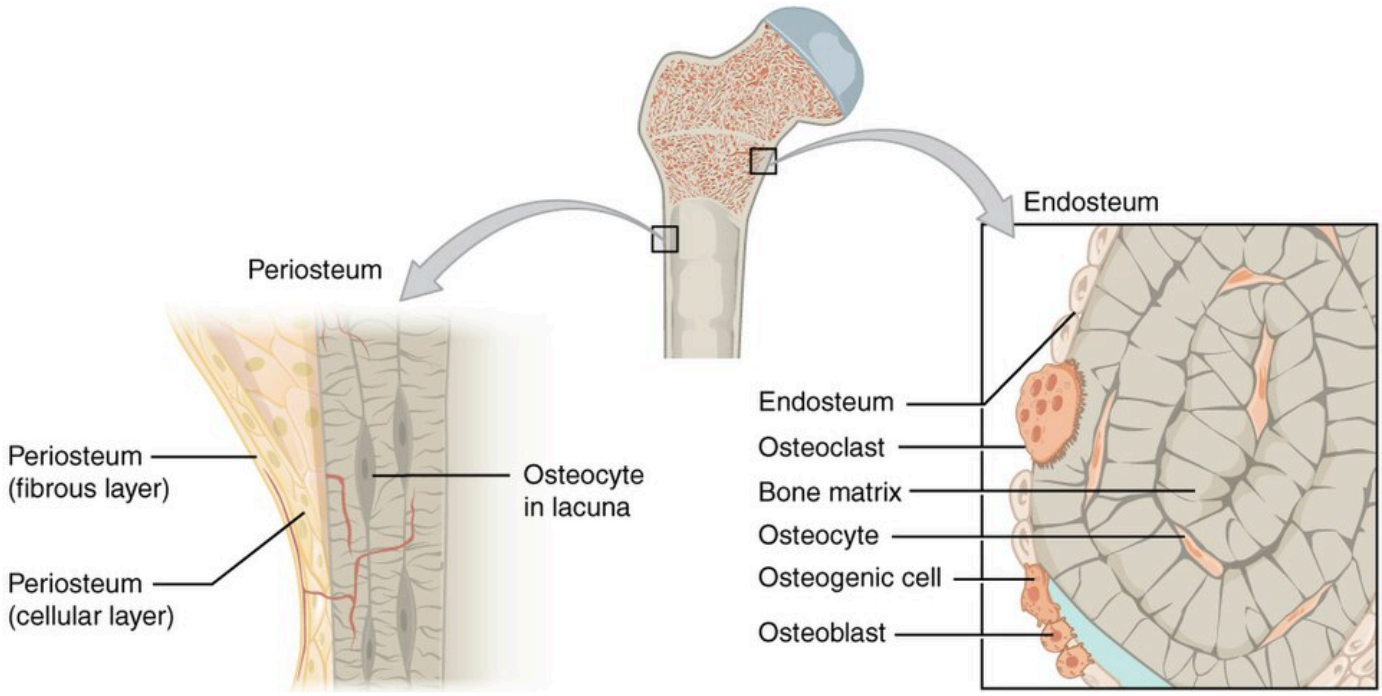


Figure 6.7 Periosteum and Endosteum

Anatomy of a Flat Bone

Flat bones, such as those of the skull, consist of an internal layer of spongy bone that is covered on either side by a layer of compact bone. The two layers of compact bone and the interior spongy bone work together to protect the internal organs. If the outer layer of a cranial bone fractures, the brain is still protected by the intact inner layer. Spongy and compact bone is further described below under the "Bone Tissue" subsection. See Figure 6.8[5] for an illustration of flat bones of the skull.

5. OpenStax College. (2013). *621 Anatomy of a flat bone* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:621_Anatomy_of_a_Flat_Bone.jpg

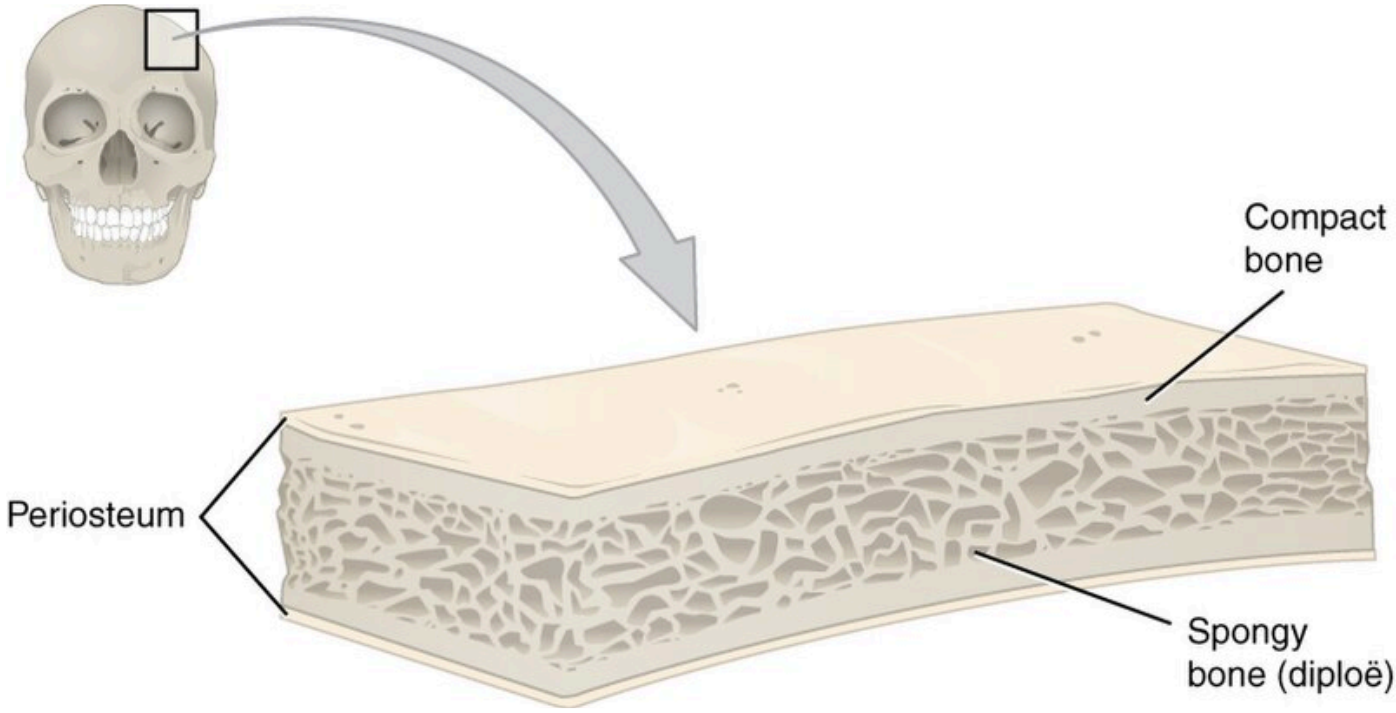


Figure 6.8 Flat Bone

Bone Cells

Types of Bone Cells

Although bone cells make up a small amount of the bone volume, they are important to the function of bones. Four types of cells are found within bone tissue and include the following:

- Osteogenic cells: **Osteogenic cells** are stem cells with high mitotic activity, meaning they are the only bone cells that divide. Osteogenic cells are found in the deep layers of the periosteum and the marrow. Osteogenic cells differentiate and develop into osteoblasts.
- Osteoblasts: **Osteoblasts** continuously form new bone and are found primarily in the periosteum and endosteum. They make and secrete the collagen matrix of bone tissue. Calcium salts are deposited into this matrix to mineralize (harden) the bone. Osteoblasts do not divide.
- Osteocytes: An **osteocyte** is a mature bone cell responsible for maintaining bone tissue. It is the most common type of bone cell. Each osteocyte is located in a space called a lacuna (plural = lacunae). Like osteoblasts, osteocytes lack mitotic activity.

They communicate with each other and receive nutrients through **canaliculi** (singular = canaliculus), tiny channels within the bone matrix.

- Osteoclasts: **Osteoclasts** are responsible for bone resorption, or breakdown. They contain enzymes that dissolve bone. They are found on bone surfaces and are produced by bone marrow. The ongoing balance between osteoblasts and osteoclasts is responsible for the constant but subtle reshaping of bone.

See Figure 6.9[6] for an illustration of bone cells.

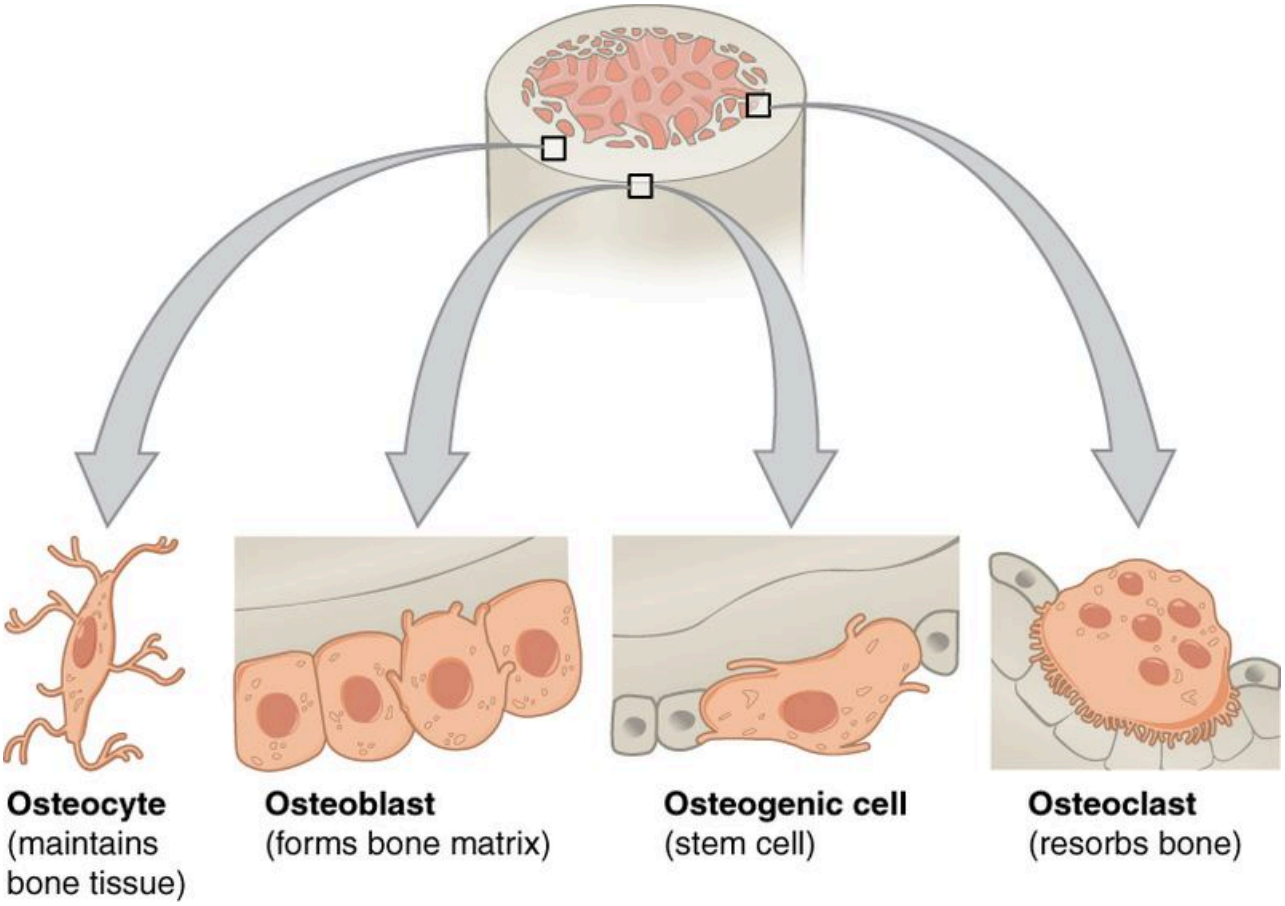


Figure 6.9 Bone Cells

Table 6.3b summarizes the functions and locations of bone cells.

Table 6.3b. Functions and Locations of Bone Cells[7]

6. OpenStax College. (2013). *604_Bone_cells* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:604_Bone_cells.jpg

7. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Type of Bone Cell	Function	Location
Osteogenic Cells	Develop into osteoblasts	Deep layers of the periosteum and the marrow
Osteoblasts	Bone formation	Periosteum and endosteum
Osteocytes	Maintain bone tissue	Sit in lacunae within the matrix
Osteoclasts	Bone resorption	Periosteum and endosteum

Bone Tissue

The difference between compact and spongy bone is best explored through their histology (tissues). Most bones contain both compact and spongy bone tissue, but their amounts vary based on the bone's function. Compact bone is dense so that it can withstand weight and force, while spongy (cancellous) bone has open spaces and supports shifts in weight distribution.

Compact Bone

Compact bone is the denser, stronger of the two types of bone tissue. It can be found deep to the periosteum and in the diaphyses (shafts) of long bones, where it provides support and protection. See Figure 6.10[8] for an illustration of compact bone.

8. (a) OpenStax College. (2013). *624_Diagram_of_Compact_Bone-new* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:624_Diagram_of_Compact_Bone-new.jpg and (b)Berkshire Community College Bioscience Image Library. (2018). *Connective_Tissue_Compact_Bone* [Photograph]. Wikimedia Commons. CC0 Public Domain. https://commons.wikimedia.org/wiki/File:Connective_Tissue_Compact_Bone_(41068142774).jpg

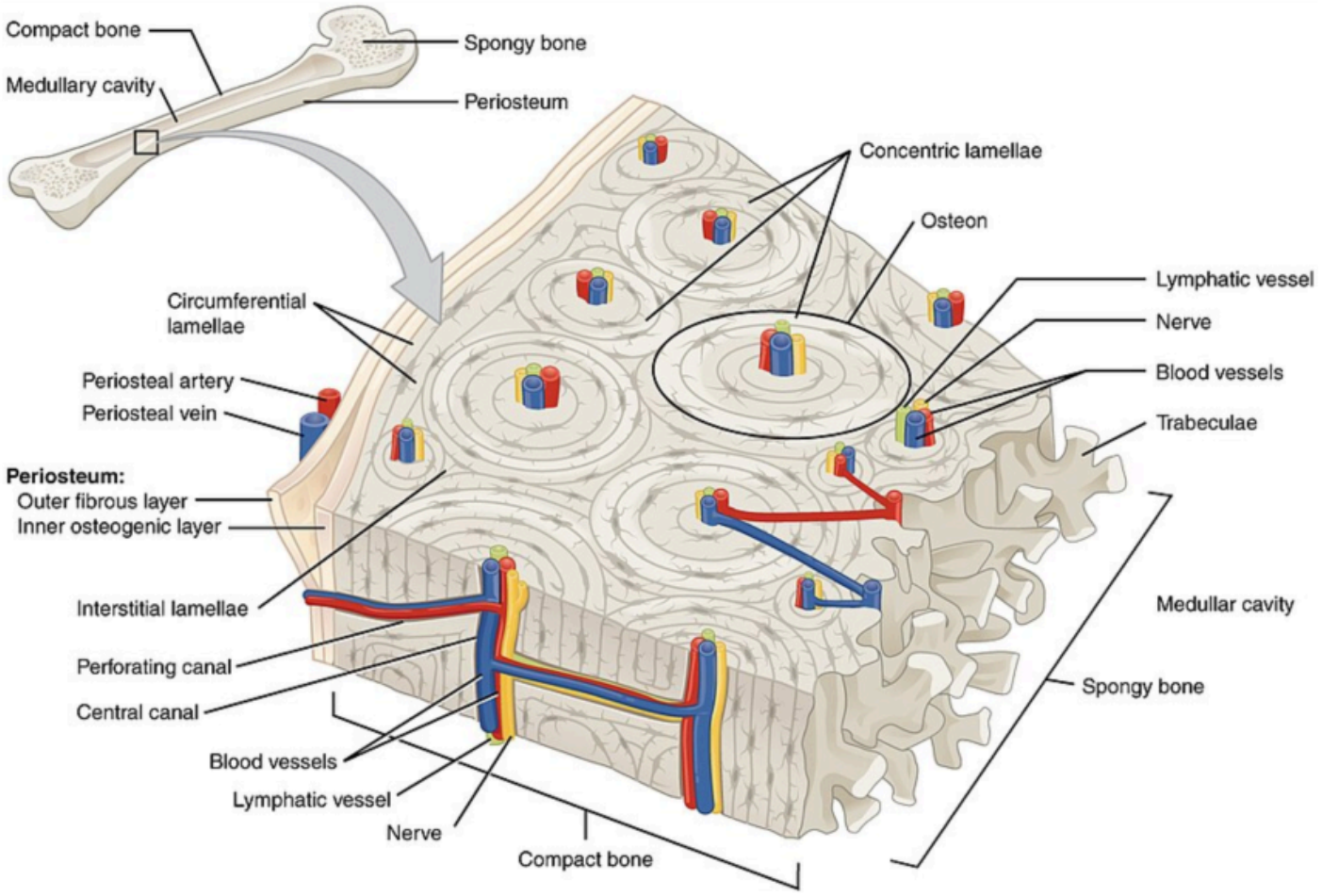


Figure 6.10 Compact Bone: (a) Osteon, (b) Concentric Lamellae and Central Canals in an Image of an Osteon

Osteon

The basic structural unit of compact bone is called an **osteon**, also called the Haversian system. Each osteon is composed of the following:

- Lamellae: **Lamellae** (singular = lamella) are circular/concentric rings of calcified matrix.
- Central Canal: The **central canal** (also called Haversian canal) is found in the center of each osteon. It contains blood vessels, nerves, and lymphatic vessels. These vessels and nerves branch off at right angles through a **perforating canal** (also called Volkmann's canal) to extend to the periosteum and endosteum.
- Lacunae: **Lacunae** (singular = lacuna) are spaces that hold the osteocytes.
- Canaliculi: **Canaliculi** are tiny canals that connect lacunae with the central canal. The canaliculi transport nutrients from the central canal to the osteocytes and wastes from the osteocytes to the central canal.

Spongy Bone

Like compact bone, **spongy bone** (also known as **cancellous bone**), contains osteocytes in lacunae, but they are not arranged in osteons. Instead, the lacunae and osteocytes are found in a lattice-like network of matrix called **trabeculae** (singular = trabecula). Each trabecula forms along lines of stress to provide strength to the bone. The spaces make bones lighter so muscles can move them easily. In addition, the spaces in spongy bone contain red marrow where blood cell formation occurs. See Figure 6.11[9] for an illustration of spongy bone.

9. OpenStax College. (2013). *606_Spongy_Bone* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:606_Spongy_Bone.jpg

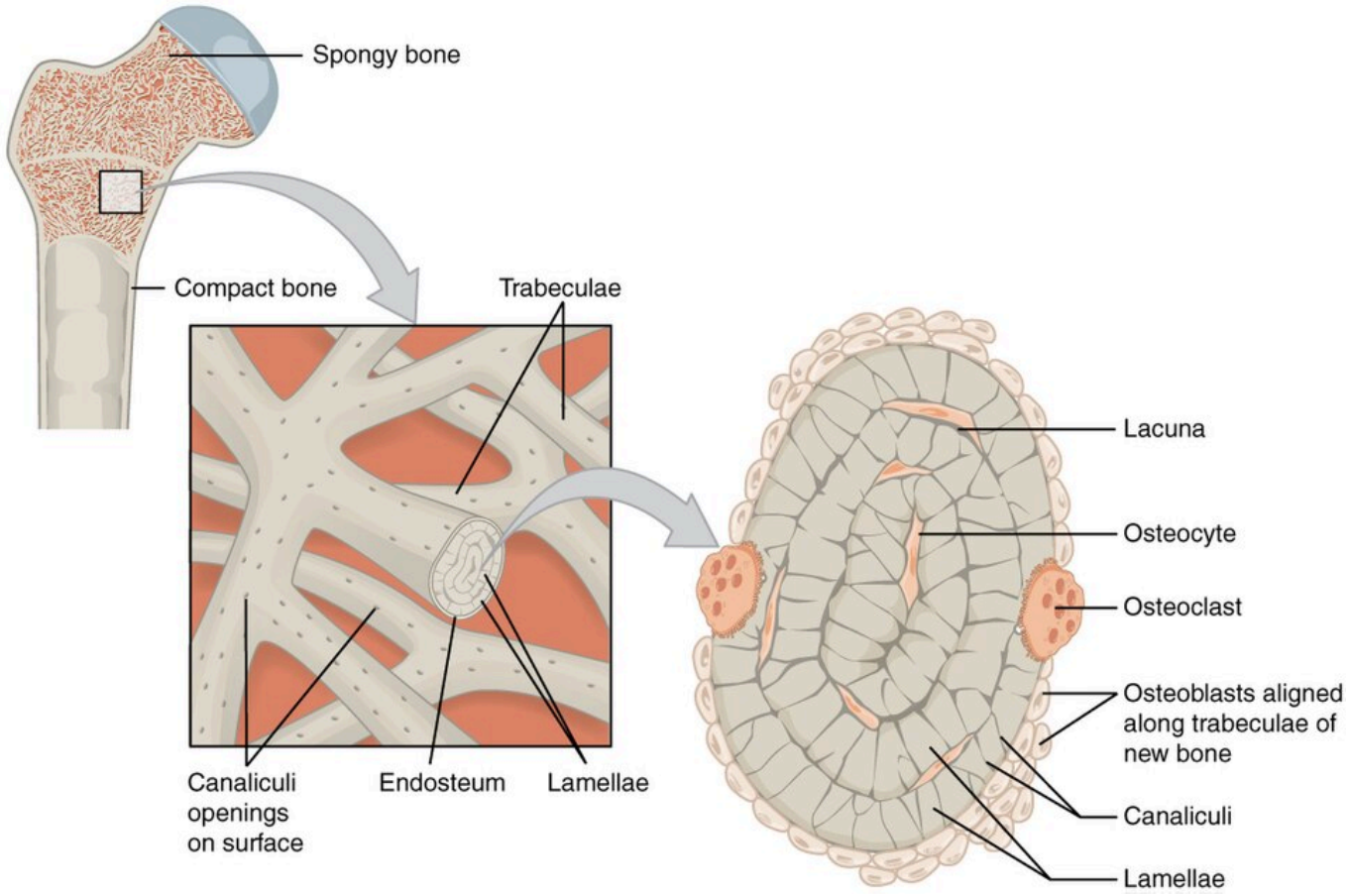


Figure 6.11 Spongy Bone

Bone Formation

In the early stages of embryonic development, the embryo's skeleton is made up of fibrous membranes and hyaline cartilage. By the sixth or seventh week of embryonic life, the process of actual bone development called **ossification** (or osteogenesis) begins. There are two bone development pathways called intramembranous ossification and endochondral ossification.

Intramembranous Ossification

During **intramembranous ossification**, compact and spongy bone develop directly from sheets of mesenchymal (undifferentiated) connective tissue. Examples of bones formed by intramembranous ossification are the flat bones of the face, most of the cranial bones, and the clavicles.

There are four steps in intramembranous ossification that include the following:

1. Mesenchymal (undifferentiated) cells in the embryonic skeleton clump together and begin to differentiate into specialized cells. Some cells differentiate into capillaries, while others become osteogenic cells that turn into osteoblasts.
2. The osteoblasts secrete **osteoid**, an uncalcified bone matrix, which calcifies (hardens) within a few days as mineral salts are deposited in it. The calcified matrix traps osteoblasts within it. Once trapped, the osteoblasts become osteocytes.
3. Osteoid is secreted around the capillaries and forms spongy bone trabeculae, while mesenchymal cells on the surface of the spongy bone form the periosteum.
4. The periosteum forms a protective layer of compact bone around the trabecular bone. Blood vessels in the spongy bone condense to form red marrow.

See Figure 6.12[10] for an illustration of these steps of intramembranous ossification.

10. OpenStax College. (2013). *611 Intramembraneous Ossification* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:611_Intramembraneous_Ossification.jpg

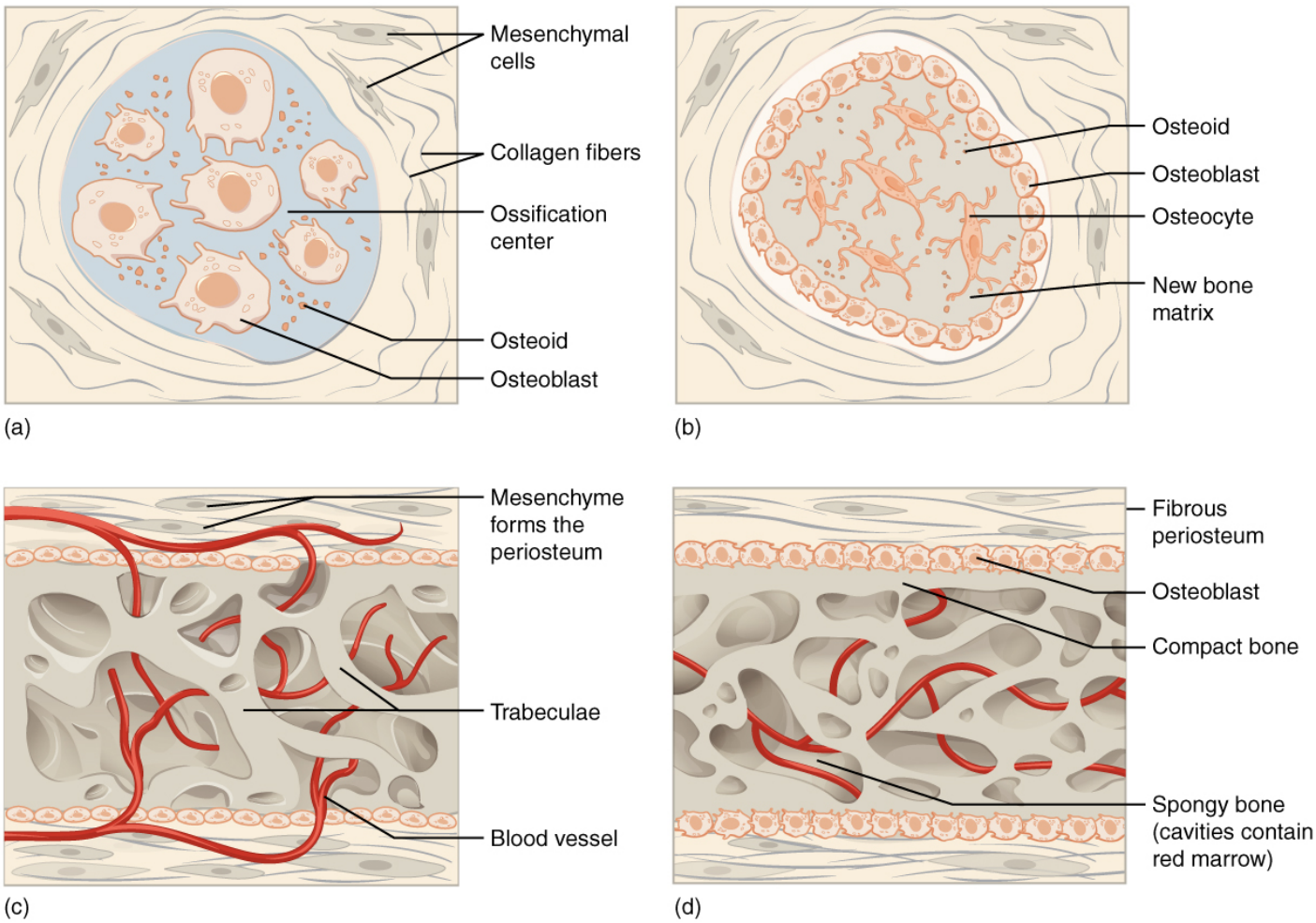


Figure 6.12 Intramembranous Ossification: (a) Mesenchymal Cells Group into Clusters, and Ossification Centers Form; (b) Secreted Osteoid Traps Osteoblasts, Which Then Become Osteocytes; (c) Trabecular Matrix and Periosteum Form; and (d) Compact Bone Develops Around the Trabecular Bone, and Crowded Blood Vessels Condense into Red Marrow

Intramembranous ossification begins during fetal development in the uterus and continues into adolescence. At birth, the skull and clavicles are not fully ossified yet. This allows the skull and shoulders to deform during passage through the birth canal. The last bones to ossify by intramembranous ossification are the flat bones of the face, which reach their adult size at the end of the adolescent growth spurt, and the clavicles, which fully ossify around 22 to 25 years of age.

Endochondral Ossification

During **endochondral ossification**, (*endo-* = within; *chondr-* = cartilage) bone develops by replacing hyaline cartilage. The cartilage serves as a template that will be

completely replaced by new bone. Endochondral ossification takes much longer than intramembranous ossification. Most bones of the body are formed by endochondral ossification.

Steps of endochondral ossification include the following:

1. Mesenchymal cells differentiate into **chondroblasts** (cartilage-forming cells). Chondroblasts form a hyaline cartilage model in the shape of the future bone. The **perichondrium**, a membrane that surrounds the cartilage model, also forms.
2. The cartilage calcifies.
3. Blood vessels grow into the calcified cartilage of the diaphysis that stimulates osteoblasts to form spongy bone in the **primary ossification center** (first place bone develops). The perichondrium becomes the periosteum at this point.
4. A medullary cavity is formed. Eventually, the spongy bone of the diaphysis will be turned into compact bone.
5. Around birth, the **secondary ossification centers** (second place bone is formed) develop in the epiphyses of the bone. The process is similar, where an artery grows into the calcified cartilage and stimulates osteoblasts to form spongy bone. Unlike the diaphysis, the epiphyses will remain spongy bone, and no medullary cavity is formed.
6. Cartilage remains in the epiphyseal (growth) plate and on the epiphysis surface as articular (joint) cartilage.

See Figure 6.13[11] for an illustration of endochondral ossification.

11. OpenStax College. (2013). *608_Endochrondal_Ossification* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:608_Endochrondal_Ossification.jpg

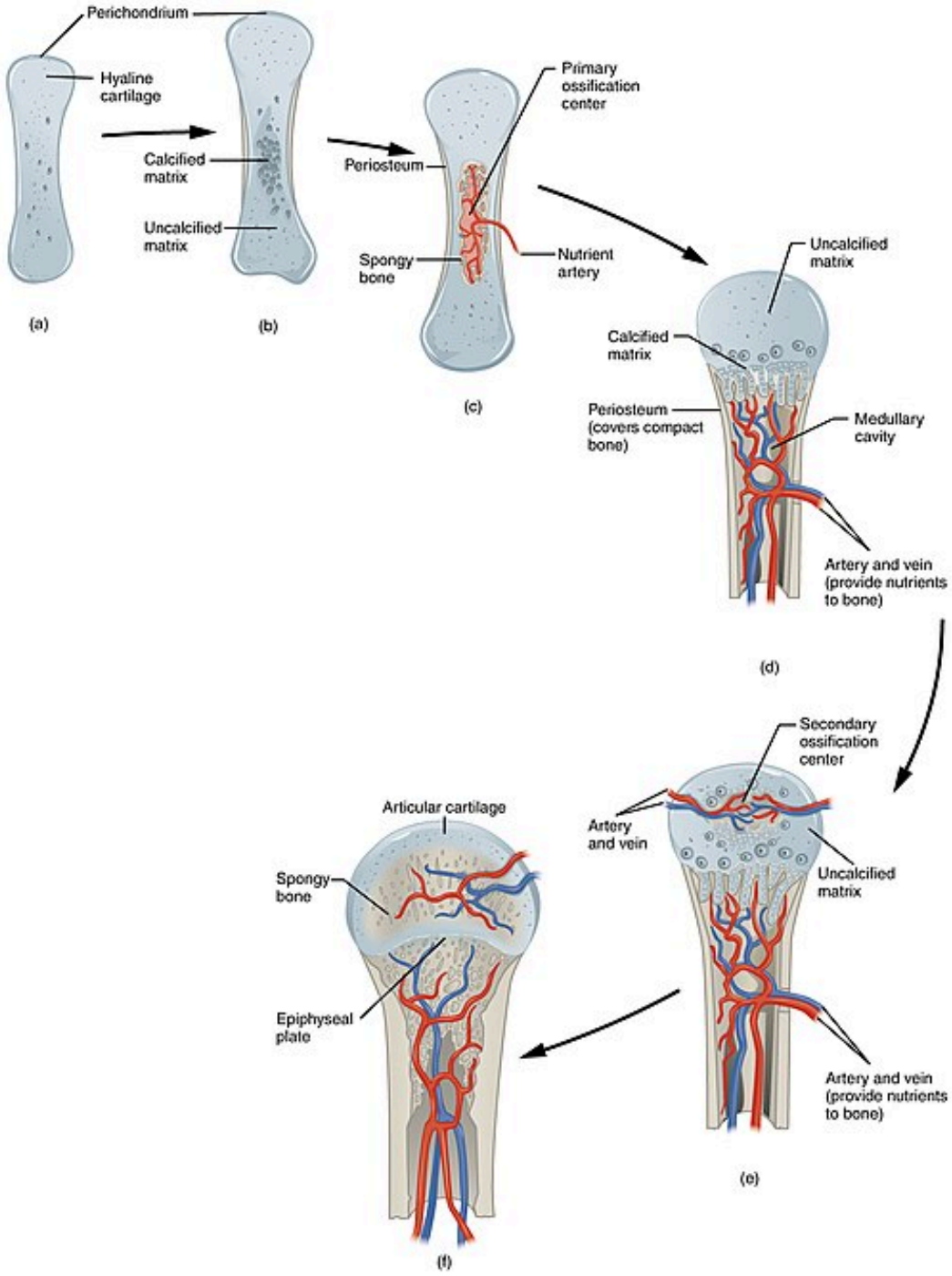


Figure 6.13 Endochondral Ossification

Bone Growth and Remodeling

Bones grow and repair themselves through interstitial growth, appositional growth, and bone remodeling.

Interstitial Growth

Interstitial growth refers to longitudinal bone growth (lengthening of the bone). The epiphyseal plate (growth plate) is an area of hyaline cartilage where growth occurs in immature long bones until early adulthood. During interstitial growth, the epiphyseal (end) side of the epiphyseal plate forms cartilage, and on the diaphyseal side, the cartilage is ossified, causing the diaphysis (shaft) to grow in length.

The epiphyseal plate has four zones of cells and activity, including the following:

1. The **reserve zone** is the region closest to the epiphyseal end of the plate and contains small chondrocytes (cartilage cells) within the matrix. These chondrocytes do not participate in bone growth but attach the epiphyseal plate to the epiphysis.
2. The **proliferative zone** is the next layer and contains stacks of slightly larger chondrocytes. It makes new chondrocytes via mitosis to replace those that die at the diaphyseal end of the plate.
3. Chondrocytes in the next layer, the **zone of maturation and hypertrophy**, are older and larger than those in the proliferative zone. The more mature cells are located closer to the diaphyseal end of the plate. The longitudinal growth of bone is a result of cell division in the proliferative zone and the maturation of cells in the zone of maturation and hypertrophy that will be converted to bone.
4. Most of the chondrocytes in the **zone of calcified matrix**, the zone closest to the diaphysis, are dead because the matrix around them has calcified. Capillaries and osteoblasts from the diaphysis enter this zone, and the osteoblasts secrete bone matrix in the remaining calcified cartilage. Thus, the zone of calcified matrix connects the epiphyseal plate to the diaphysis. A bone grows in length when bone tissue is added to the diaphysis.

   See Figure 6.14[12] for an illustration of long bone growth by interstitial growth.

12. OpenStax College. (2013). *622_Longitudinal_Bone_Growth* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:622_Longitudinal_Bone_Growth.jpg

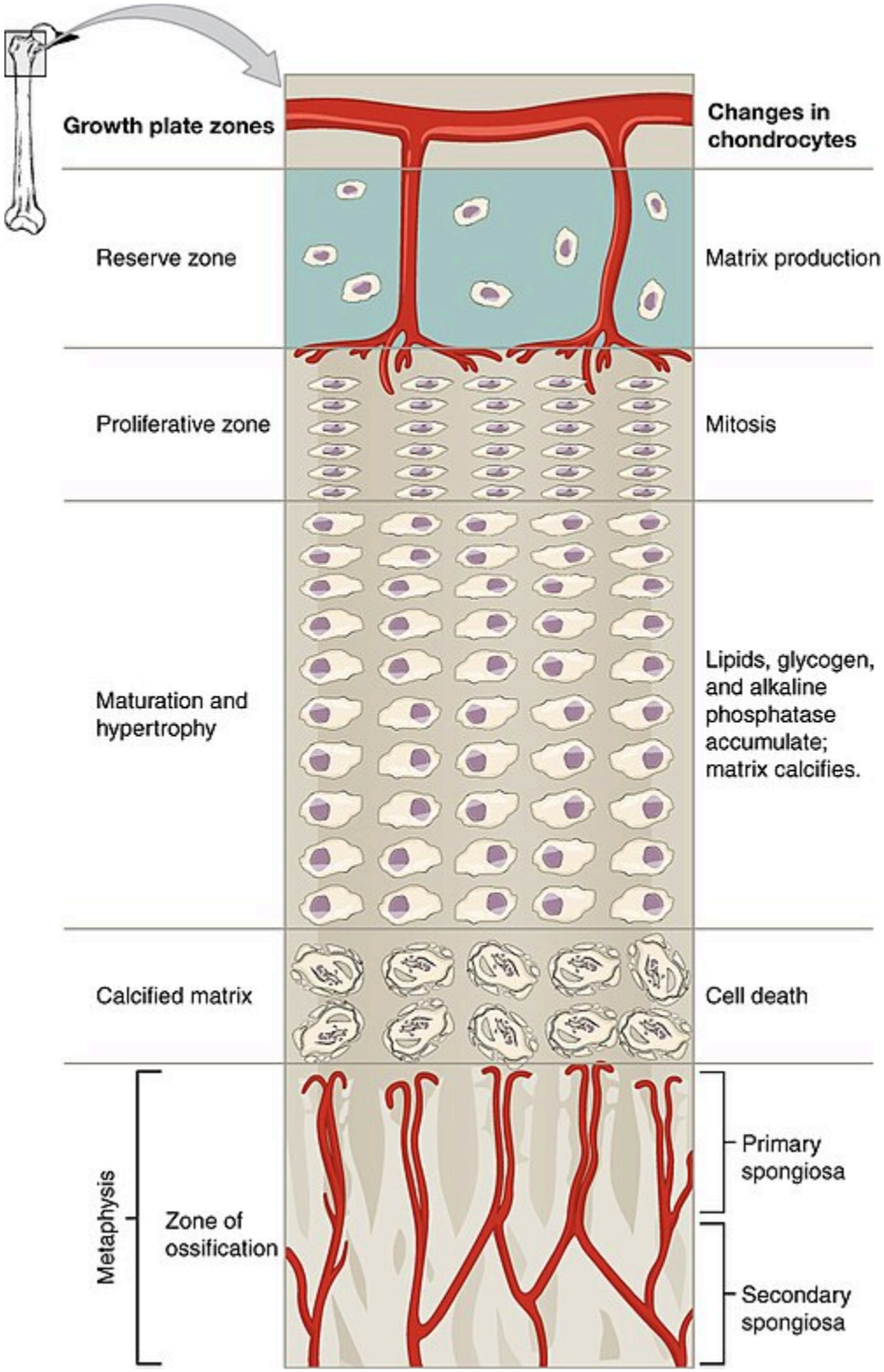


Figure 6.14 Growth Plate Zones During Interstitial Growth

Bones continue to grow in length until early adulthood. The rate of growth is controlled by hormones. When the chondrocytes in the epiphyseal plate stop dividing

and bone replaces the cartilage, longitudinal growth stops. All that remains of the epiphyseal plate is the **epiphyseal line**. See Figure 6.15[13] for an illustration of progression from the epiphyseal plate to the epiphyseal line.

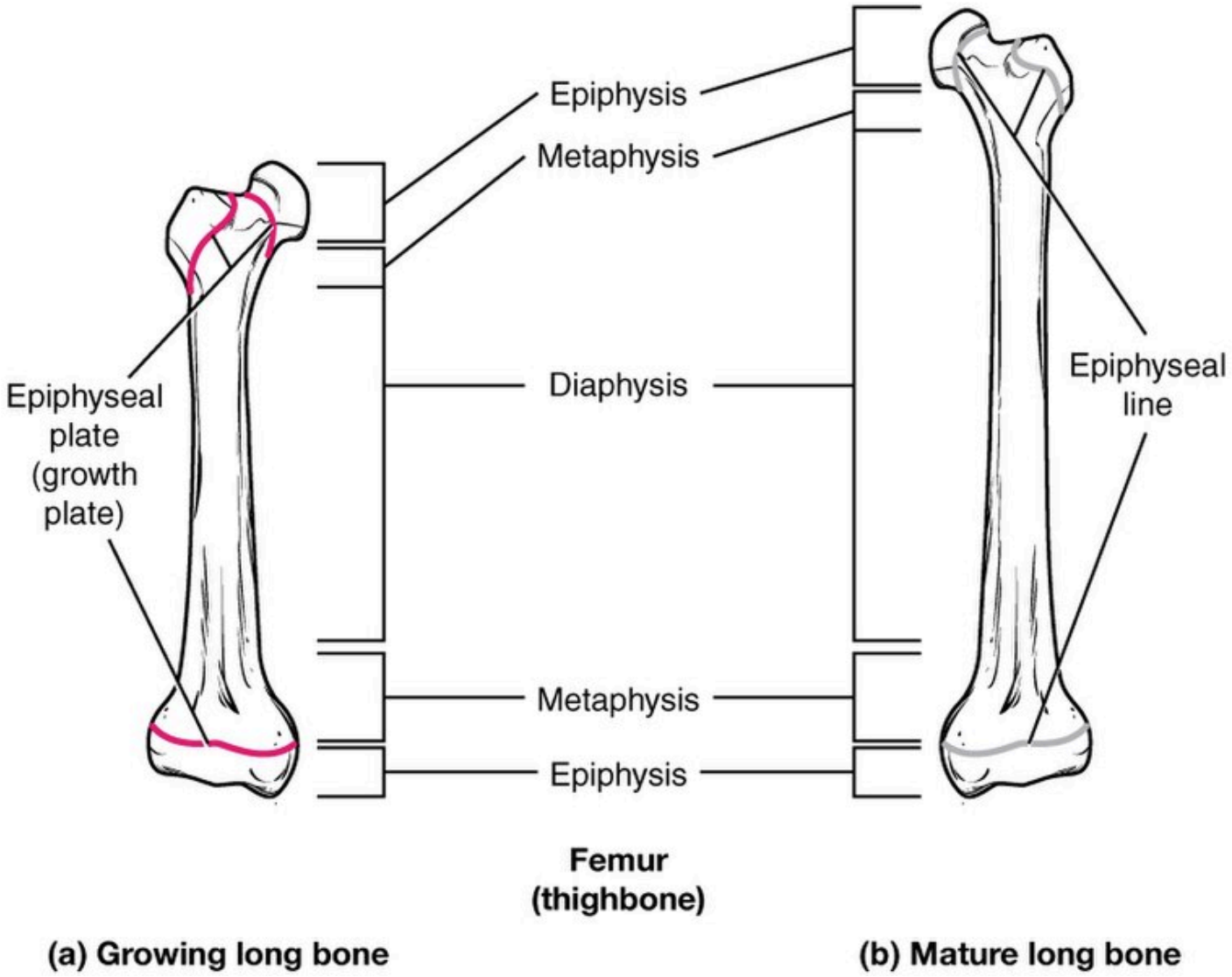


Figure 6.15 Progression of Interstitial Bone Growth: (a) Epiphyseal Plates in Growing Long Bone and (b) Epiphyseal Lines in Mature Bone

See Figure 6.16[14] for a radiographic image of bone plates.

13. OpenStax College. (2013). *623_Epiphyseal_Plate-Line* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:623_Epiphyseal_Plate-Line.jpg

14. Gilo1969. (2009). *Tib_fib_growth_plates* [Photograph]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Tib_fib_growth_plates.jpg



Figure 6.16 Bone Plates

Video

Watch the video “The Secret Behind Long Bone Growth – The Human Body:

Secrets of Your Life Revealed – Grow – BBC" below to learn how long bones grow and develop during the human lifespan.[15]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Appositional Growth

While bones are increasing in length, they are also increasing in diameter, called **appositional growth**. Growth in diameter can continue even after longitudinal growth stops. Osteoclasts resorb old bone that lines the medullary cavity, while osteoblasts produce new bone tissue deep to the periosteum. The erosion of old bone along the medullary cavity and the deposition of new bone beneath the periosteum increase the diameter of the diaphysis and also increase the diameter of the medullary cavity. This process is called **modeling**.

Bone Remodeling

Bone remodeling is the resorption of old or damaged bone while osteoblasts lay new bone to replace it. Injury, exercise, and other activities lead to remodeling, but even without injury or exercise, about 5 to 10% of the skeleton is remodeled annually just by destroying old bone and replacing it with fresh bone. **Wolff's Law** states that bone remodels in response to the stresses placed upon it. Increased mechanical stress strengthens bone, while decreased stress leads to bone loss. For example, weight-

15. BBC. (2017, October 5). *The secret behind long bone growth – The human body: Secrets of your life revealed – Grow – BBC* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=r1wyy_3_4mk

bearing exercise increases bone density, whereas prolonged bed rest can lead to bone thinning.

Fractures and Fracture Repair

A **fracture** is a broken bone. While some fractures are minor, others can be severe and result in complications. For example, a fractured diaphysis of the femur has the potential to release fat globules into the bloodstream. These can become lodged in the capillary beds of the lungs, leading to respiratory distress and, if not treated quickly, result in death.

There are four stages of fracture repair that include the following:

1. Formation of a fracture hematoma: When a bone breaks, bleeding occurs from vessels torn by the fracture. These vessels can be in the periosteum, osteons, and/or medullary cavity. The blood begins to clot, and about six to eight hours after the fracture, the clotted blood forms a **fracture hematoma**. The interruption of blood flow to the bone results in the death of bone cells around the fracture.
2. Formation of a fibrocartilaginous (soft) callus. Over the next two to three weeks, chondrocytes from the endosteum form fibrocartilage between the two ends of the broken bone.
3. Formation of a bony (hard) callus. Over the next three to four months, osteoclasts resorb the dead bone. Osteogenic cells become active, divide, and differentiate into osteoblasts. The cartilage in the callus is replaced by spongy bone formed by endochondral ossification.
4. Remodeling. Compact bone replaces the spongy bone at the outer margins of the fracture, and healing is complete. A slight swelling may remain on the surface of the bone, which may be visible on an X-ray, but typically, there is no external evidence of the fracture.

See Figure 6.17[16] for an illustration of the stages of fracture repair.

16. Laboratoires Servier. (2019). *Fracture_repair_–_Smart-Servier_(cropped)* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Fracture_repair_–_Smart-Servier_(cropped).jpg

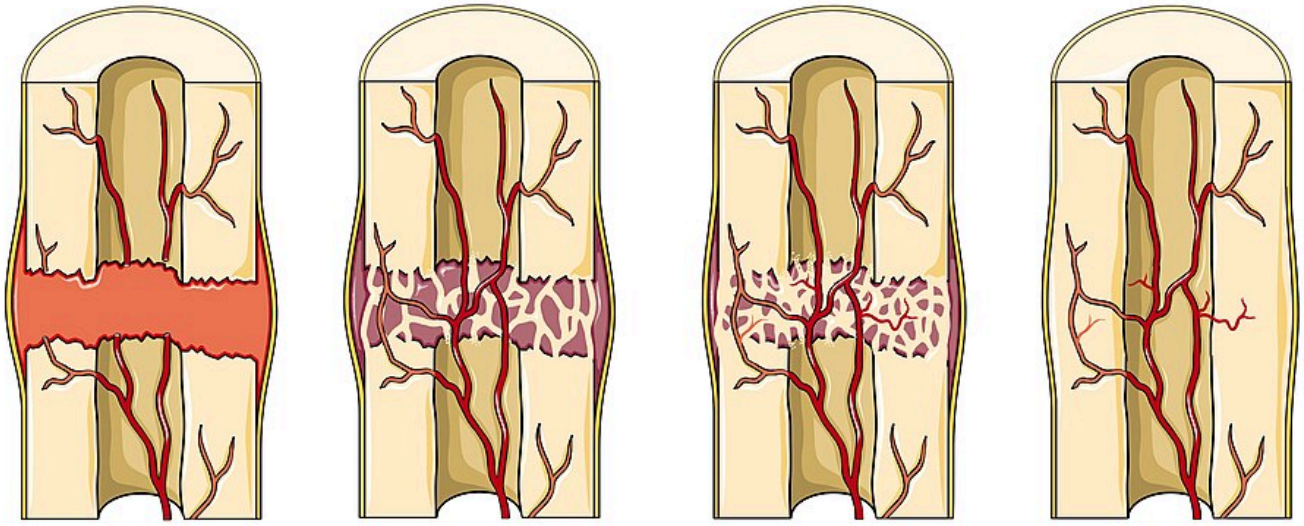


Figure 6.17 Stages of Fracture Repair: (a) Formation of Fracture Hematoma; (b) Formation of Fibrocartilaginous (Soft) Callus; (c) Formation of Bony (Hard) Callus; and (d) Remodeling

Types of Fractures

Fractures can be classified in many ways, including by their complexity and location. See Figure 6.18[17] for an illustration of types of fractures.

17. OpenStax College. (2013). *612_Types_of_Fractures* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:612_Types_of_Fractures.jpg

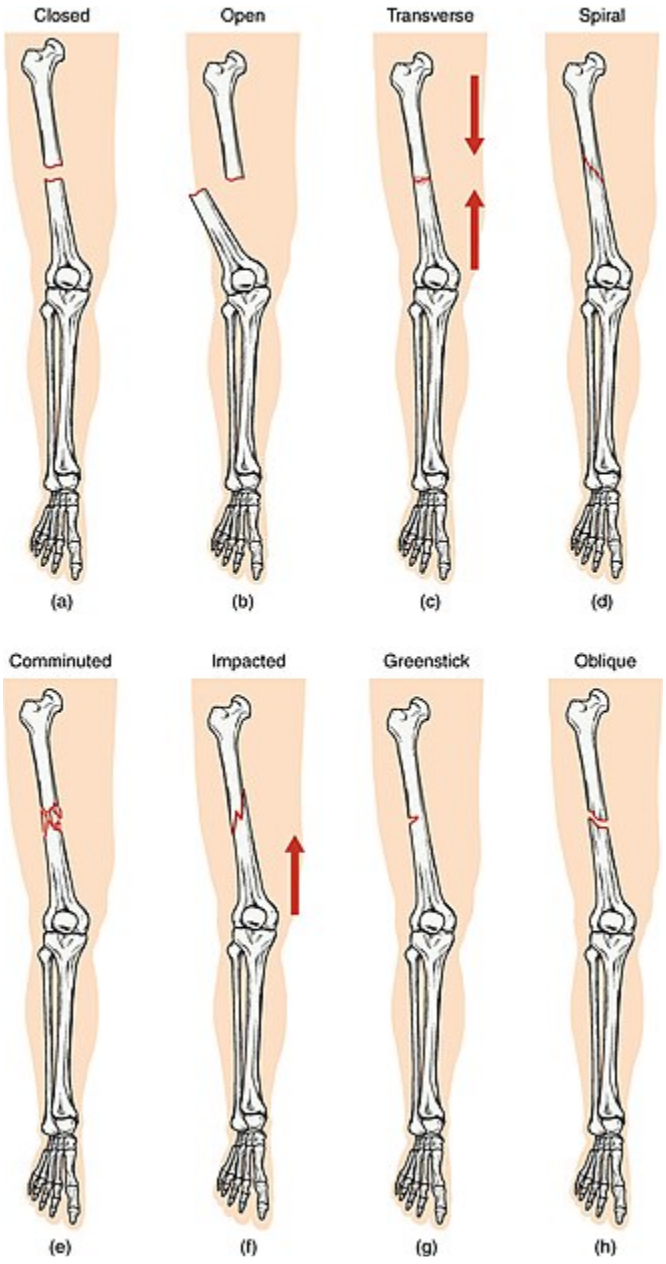


Figure 6.18 Types of Fractures: (a) Closed Fracture, (b) Open Fracture, (c) Transverse Fracture, (d) Spiral Fracture, (e) Comminuted Fracture, (f) Impacted Fracture, (g) Greenstick Fracture, and (h) Oblique Fracture

Table 6.3c outlines common types of fractures. A fracture may be described by using more than one term because it may have the features of more than one type. For example, an open transverse fracture refers to a fracture that occurs across the axis of a long bone where at least one end of the bone is also protruding from the skin.

Table 6.3c. Types of Fractures[18]

Type of Fracture	Description
Transverse	Occurs straight across the long axis of the bone
Oblique	Occurs at an angle that is not 90 degrees
Spiral	Bone segments are pulled apart as a result of a twisting motion
Comminuted	Several breaks result in many small pieces between two large segments
Impacted	One fragment is driven into the other, usually as a result of compression
Greenstick	A partial fracture in which only one side of the bone is broken; common in children
Open (or compound)	A fracture in which at least one end of the broken bone tears through the skin; carries a high risk of infection
Closed (or simple)	A fracture that does not break the skin

Hormones of the Skeletal System

Bones contain more calcium than any other organ. When blood calcium levels decrease below normal levels, calcium is released from the bones by the osteoclasts so there is an adequate supply for the body's physiological needs. In contrast, when blood calcium levels are increased, excess calcium is stored in bone by the osteoblasts. This dynamic process of releasing and storing calcium goes on continuously.

Two hormones that maintain calcium homeostasis are parathyroid hormone (PTH) and calcitonin.

- Parathyroid Hormone (PTH): PTH is secreted by the parathyroid glands to stimulate

18. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

osteoclast activity. As a result, bone is broken down, and calcium is released from the bones into the blood, thus increasing the blood calcium level.

- Calcitonin: Calcitonin is secreted by the thyroid gland to inhibit osteoclast activity and stimulate calcium storage in the bones, thus lowering blood calcium levels.

Because of their opposing functions in maintaining calcium homeostasis, PTH and calcitonin are generally not secreted at the same time. See Figure 6.19[19] for an illustration of how the body regulates calcium homeostasis. Table 6.3d summarizes other hormones that also influence the skeletal system.

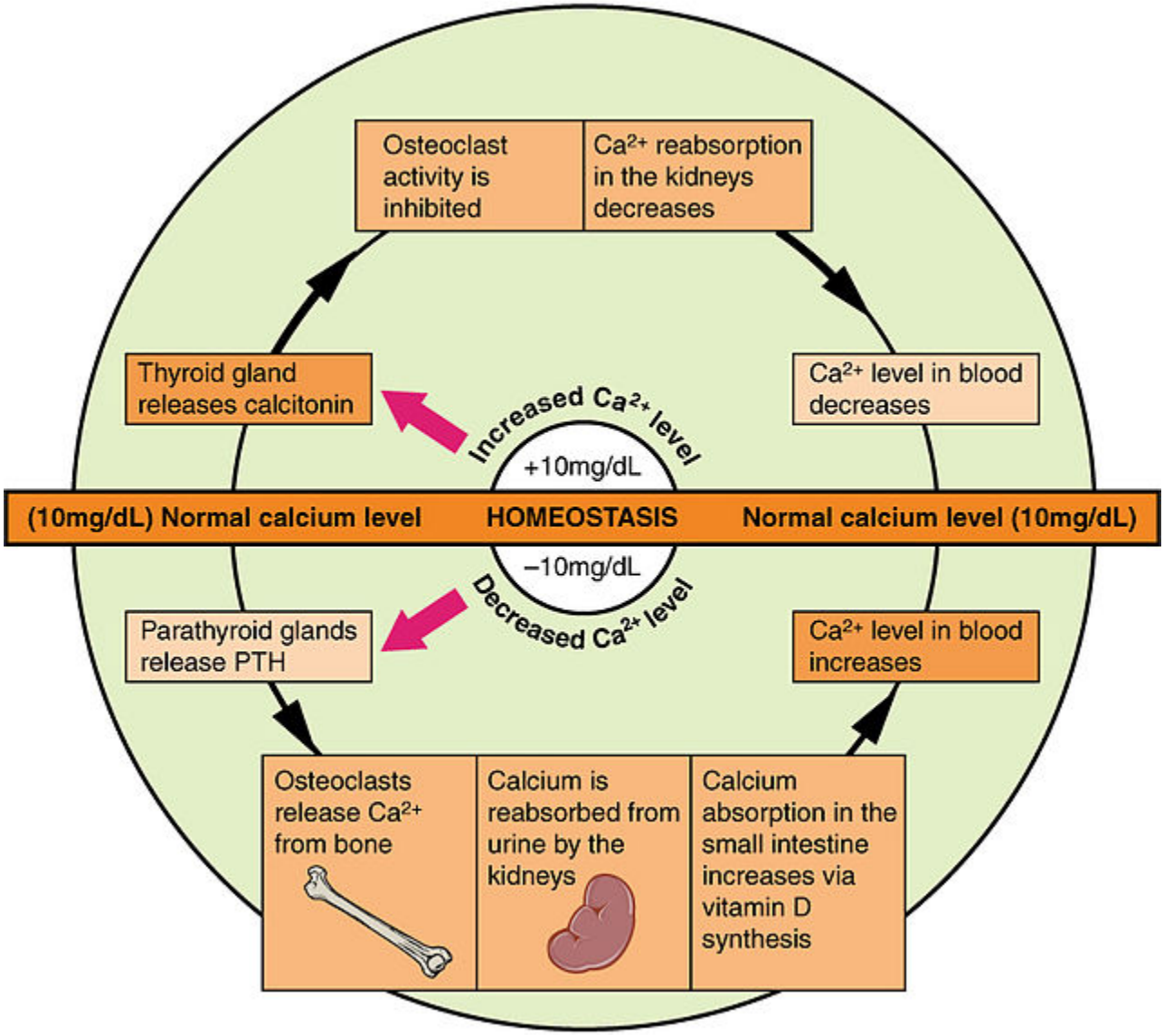


Figure 6.19 Calcium Homeostasis

19. OpenStax College. (2013). *Calcium homeostasis* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:625_Calcium_Homeostasis.jpg

Table 6.3d. Hormones That Affect the Skeletal System[20]

Hormone	Role
Human Growth Hormone and Insulin-like Growth Factors (IGF)	Increases the length of long bones (interstitial growth), enhances mineralization, and improves bone density
Thyroxine	Stimulates bone growth and promotes the production of bone matrix
Sex Hormones (Estrogen and Testosterone)	Promote osteoblastic activity and production of bone matrix; responsible for adolescent growth spurt; close the epiphyseal plate (growth plate) at the end of adolescence
Calcitriol (Vitamin D)	Stimulates absorption of calcium and phosphate from the digestive tract
Parathyroid Hormone	Stimulates osteoclast activity to release calcium from the bones to increase the blood calcium level
Calcitonin	Inhibits osteoclast activity and stimulates calcium storage by bones to lower the blood calcium level

Bone Markings

The surface features of bones vary considerably, depending on the function and location in the body. There are several classes of bone markings, including the following:

- Projections: A **projection** is an area of a bone that projects above the surface of the bone. These are the attachment points for tendons and ligaments.
- Holes: A **hole** is an opening or groove in the bone that allows blood vessels and nerves to enter the bone. As with the other markings, their size and shape reflect the size of the vessels and nerves that penetrate the bone at these points.

20. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Table 6.3e describes various bone markings, which are also illustrated in Figure 6.20.[21]

Table 6.3e. Bone Markings[22]

21. OpenStax College. (2013). *602_Bone_Markings* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:602_Bone_Markings.jpg

22. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Marking	Description	Example
Head	Prominent rounded surface	Head of femur
Facet	Flat surface	Vertebrae
Condyle	Rounded surface	Occipital condyles
Protuberance	Protruding	Chin
Process	Prominence feature	Transverse process of a vertebra
Spine	Sharp process	Ischial spine
Tubercle	Small, rounded process	Tubercle of the humerus
Tuberosity	Rough surface	Deltoid tuberosity
Line	Slight, elongated ridge	Temporal lines of the parietal bones
Crest	Ridge	Iliac crest
Fossa	Elongated basin	Mandibular fossa
Fovea	Small pit	Fovea capitis on the head of the femur
Sulcus	Groove	Sigmoid sulcus of the temporal bones
Canal	Passage in bone	Auditory canal
Fissure	Slit through bone	Auricular fissure
Foramen	Hole in bone	Foramen magnum in the occipital bone
Meatus	Opening into the canal	External auditory meatus

Sinus	Air-filled space in bone	Nasal sinus

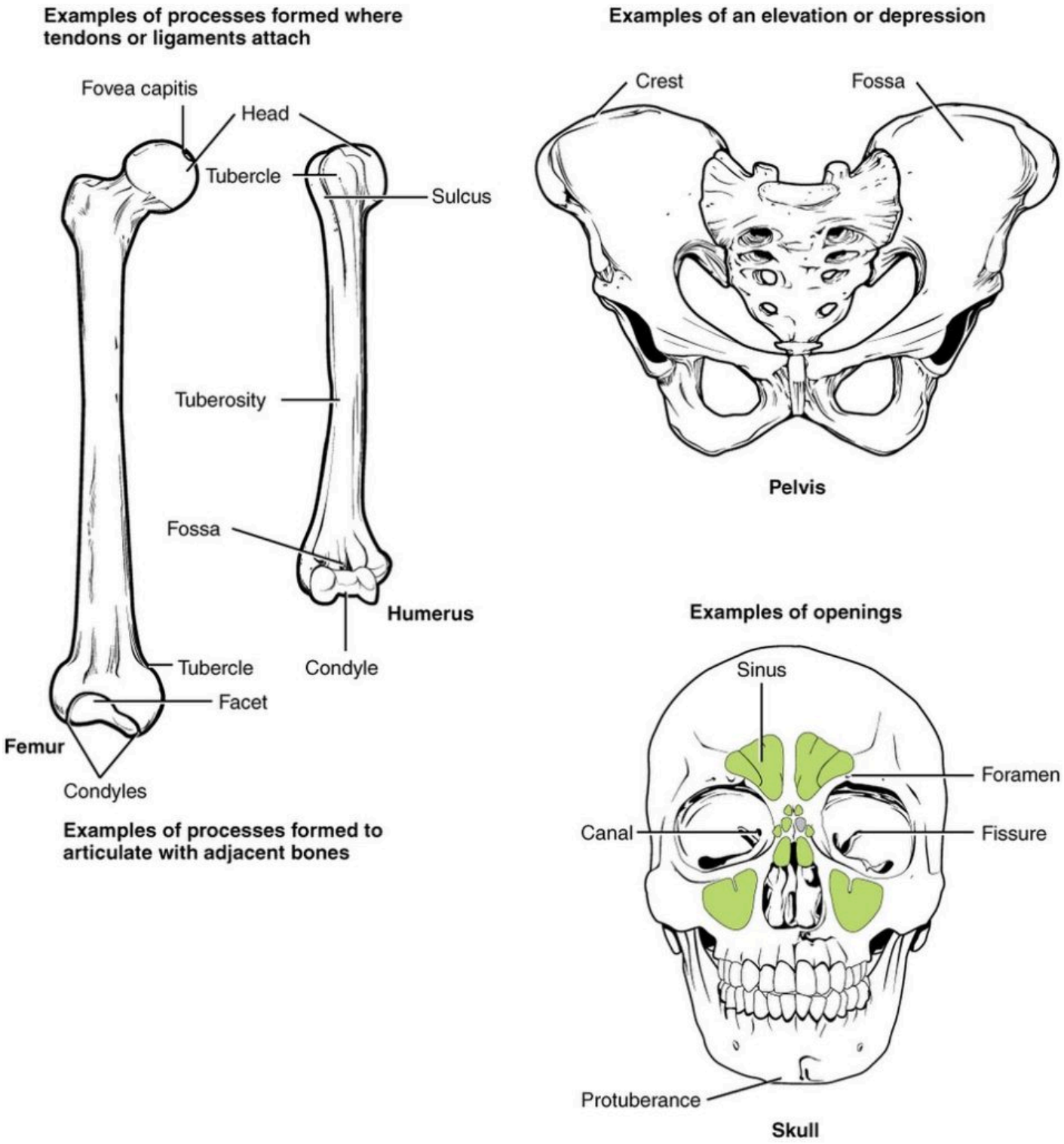


Figure 6.20 Bone Features

Divisions of the Skeletal System

The skeleton is subdivided into two major divisions called the axial skeleton and appendicular skeleton. The **axial skeleton** serves to protect the brain, spinal cord, heart, and lungs, and also serves as the attachment site for muscles that move the head, neck, and back. It consists of 80 bones, including all bones of the skull, the vertebral column, and the thoracic cage (chest):

- The skull is formed by 22 bones. Also associated with the skull are an additional seven bones, including the hyoid bone and the ear ossicles (three small bones found in each middle ear).
- The vertebral column consists of 24 bones, each called a vertebra, plus the sacrum and coccyx.
- The thoracic cage includes the 12 pairs of ribs and the sternum (the flattened bone of the anterior chest).

The **appendicular skeleton** includes all bones of the upper and lower limbs, plus the bones that attach each limb to the axial skeleton. There are 126 bones in the appendicular skeleton of an adult.[23]

See Figure 6.21[24] for an illustration of the axial and appendicular skeleton.

23. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e.* Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/

24. OpenStax College. (2013). *701_Axial_Skeleton-01* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:701_Axial_Skeleton-01.jpg

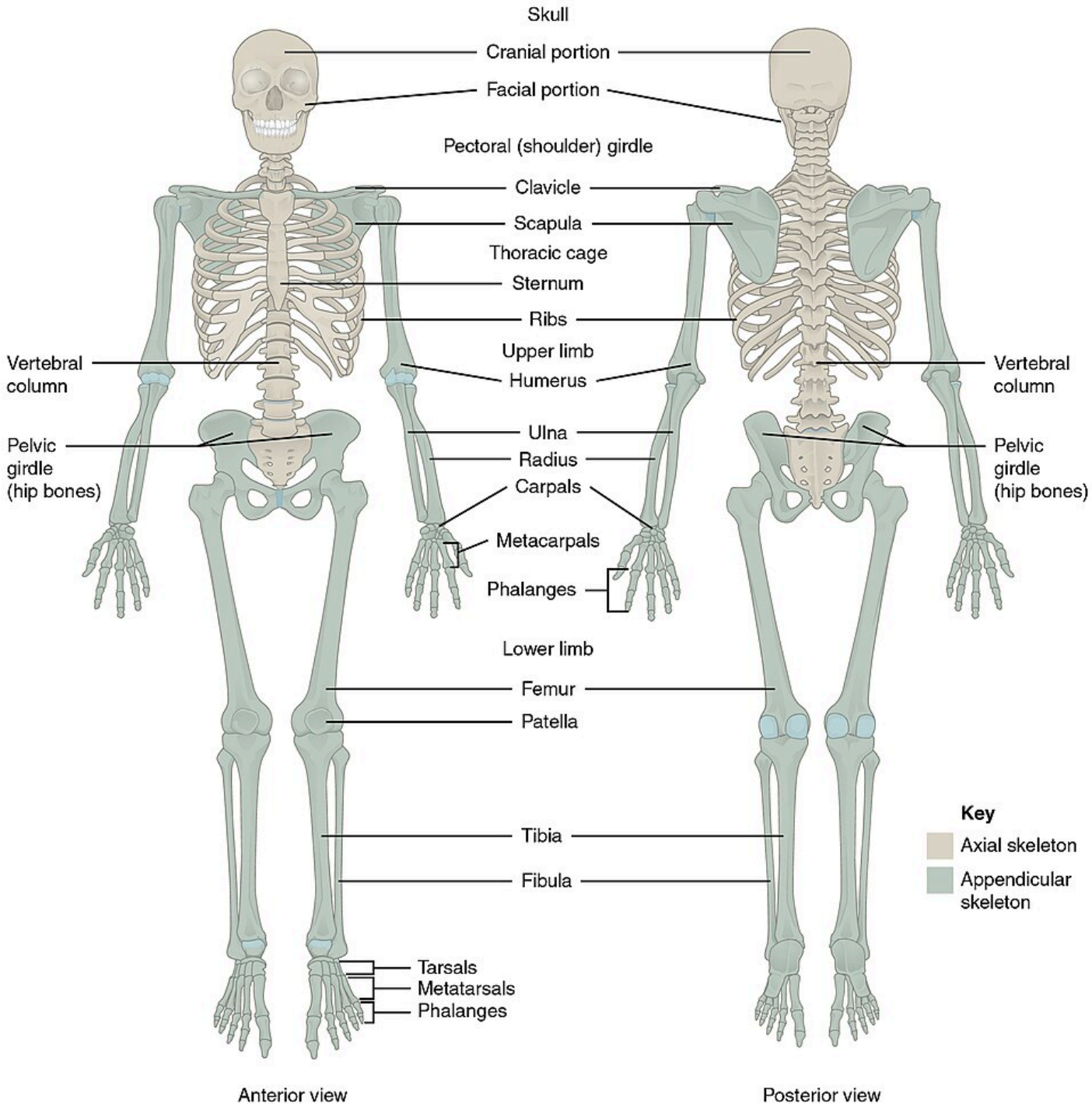


Figure 6.21 Axial and Appendicular Skeleton

The following sections will discuss the bones of the axial skeleton and the appendicular skeleton in greater detail.

6.4 Bones of the Axial Skeleton

The axial skeleton includes the skull, the hyoid bone, the vertebral column, and the bones of the thoracic cage.

Skull

The skull is subdivided into the cranium (which surrounds and protects the brain) and the facial bones.

Cranium

The cranium consists of eight bones, including the paired parietal and temporal bones and the unpaired frontal, occipital, sphenoid, and ethmoid bones. See Figure 6.22[1] for an anterior view of the cranial and facial bones.

1. OpenStax College. (2013). *704_Skull-01* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:704_Skull-01.jpg

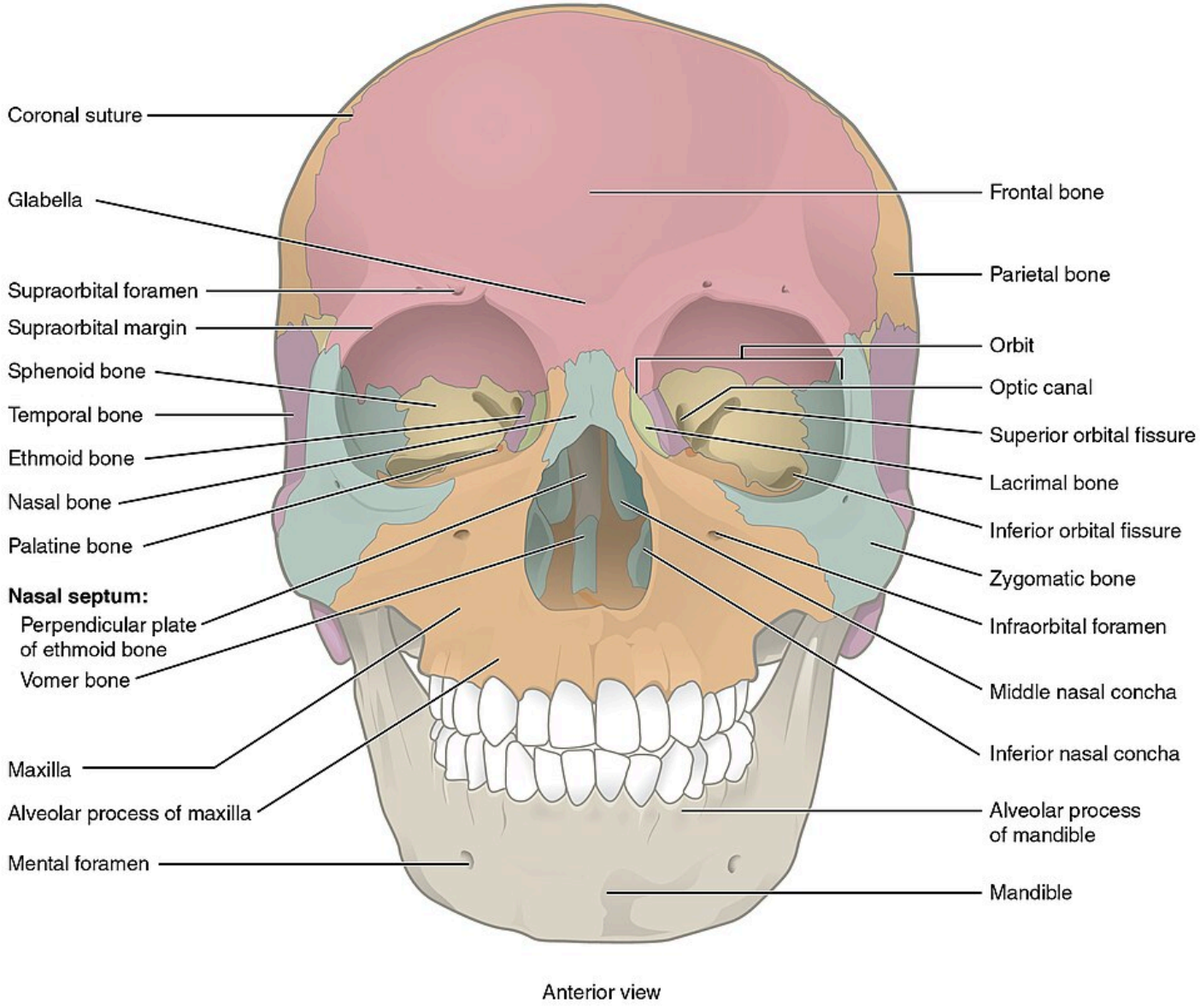


Figure 6.22 Anterior Skull and Facial Bones

The Cranial Bones

- **Frontal Bone**: A single bone superior to the eye orbits; the "forehead" bone.
- **Parietal Bones**: A pair of bones (left and right) on the upper sides of the skull above the ears.
- **Temporal Bones**: Two bones (left and right) on the lower sides of the skull surrounding the ears.
  - **External Auditory Canal (or External Auditory Meatus)**: Paired openings (left and right) in the temporal bones; the "ear canal."

- **Mastoid Process(es)**: A protrusion projecting down (inferiorly) off the temporal bone directly behind the external auditory meatus on the left and right sides. You can feel this bump if you reach behind the lower part of your ear.
- **Styloid Process(es)**: A long, slender protrusion off of the temporal bone below the ear on the left and right side of the skull. It's pointy and slender like a stylus.
- **Zygomatic Process(es)**: A long, slender protrusion off of the temporal bone that forms part of the cheek.

- **Occipital Bone:** A single bone forming the posterior side and base of the skull. See Figure 6.23[2] for an illustration of the occipital bone.
  - **Foramen Magnum**: A large hole in the base of the occipital bone where the spinal cord joins the brain. See Figure 6.24[3] for an illustration showing the foramen magnum.
- **Sphenoid Bone**: A large single complex bone of the central skull forming the posterior side of the eye sockets and part of the base of the skull. The sphenoid bone serves as a "keystone" bone because it joins with almost every other bone of the skull. It has wings like a butterfly or a bat. See Figure 6.23 for an illustration showing the sphenoid bone.
  - **Sella Turcica**: A bony landmark in the sphenoid bone and also known as "Turkish saddle" due to its resemblance to a horse's saddle. The pituitary gland sits in the sella turcica. See Figure 6.23 for an illustration containing the sella turcica.
- **Ethmoid Bone**: A single, irregularly shaped bone forming part of the nose, medial side of the eye orbits, and base of the skull. See Figure 6.25[4] for an illustration of the ethmoid bone.

2. Anatomography. (2012). *Occipital_bone_lateral* [Diagram]. Wikimedia Commons. CC BY-SA 2.1 Japan. https://commons.wikimedia.org/wiki/File:Occipital_bone_lateral.png
3. OpenStax College. (2013). *707_Superior-Inferior_View_of_Skull_Base-01* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:707_Superior-Inferior_View_of_Skull_Base-01.jpg
4. OpenStax College. (2013). *710_Ethmoid_Bone* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:710_Ethmoid_Bone.jpg

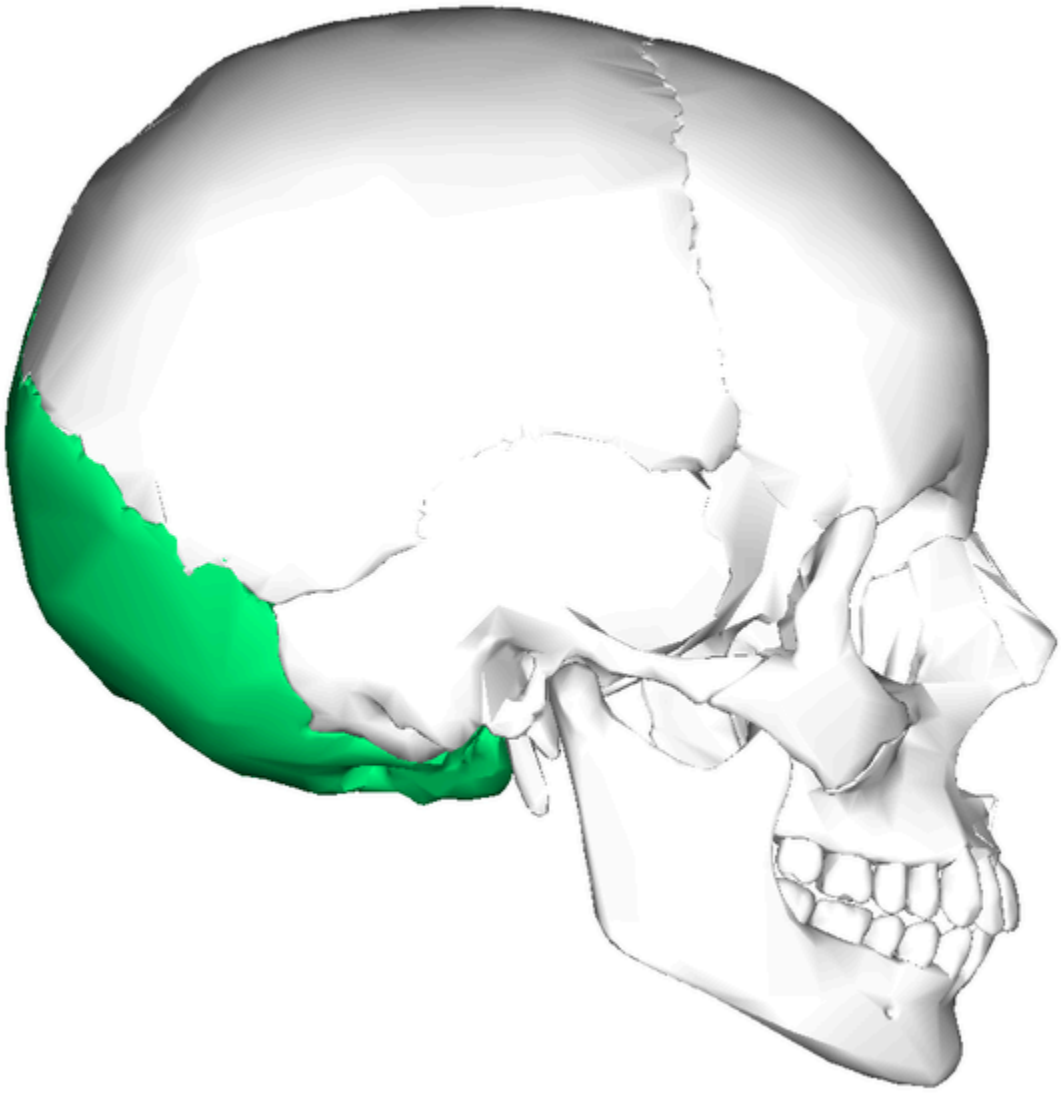
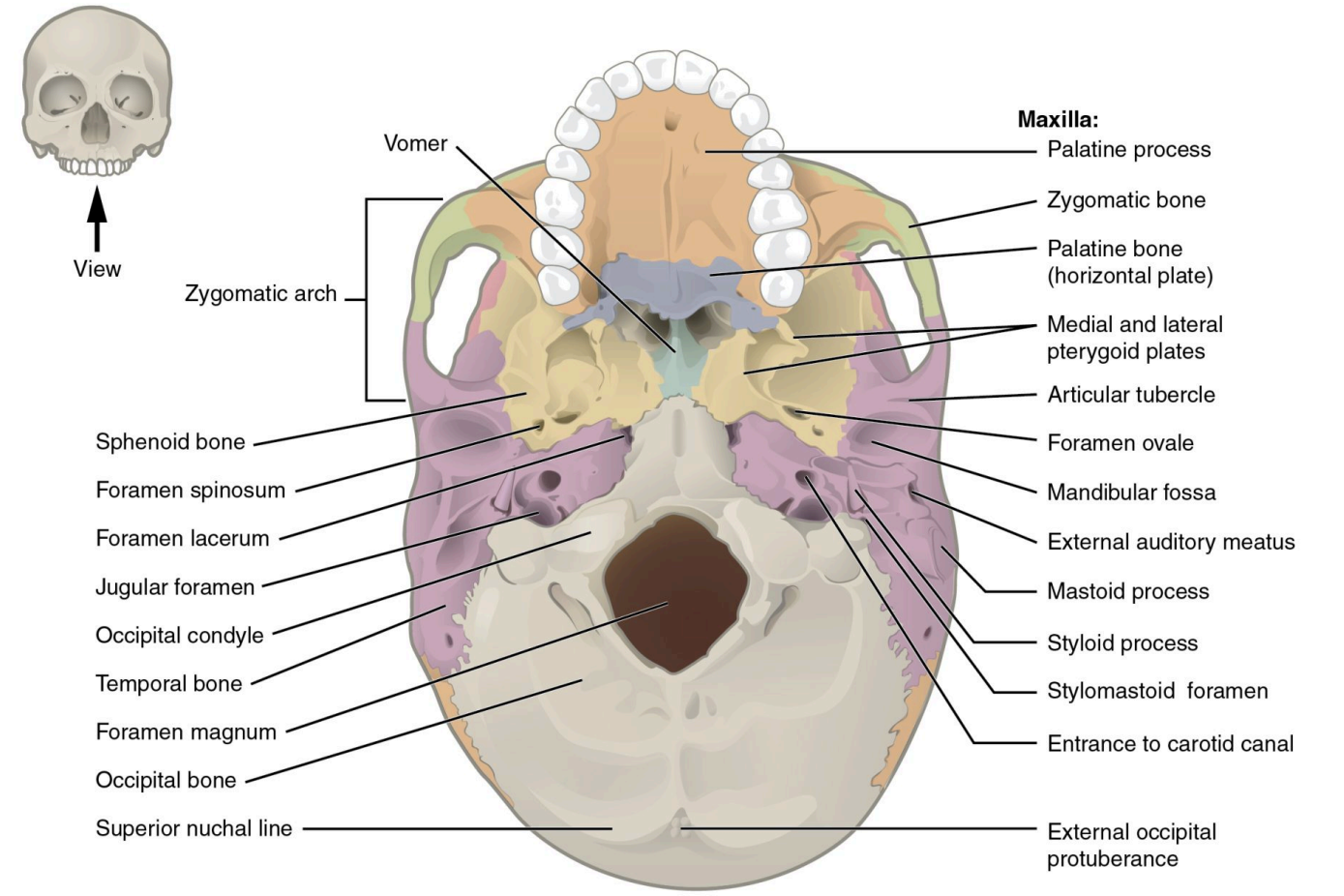
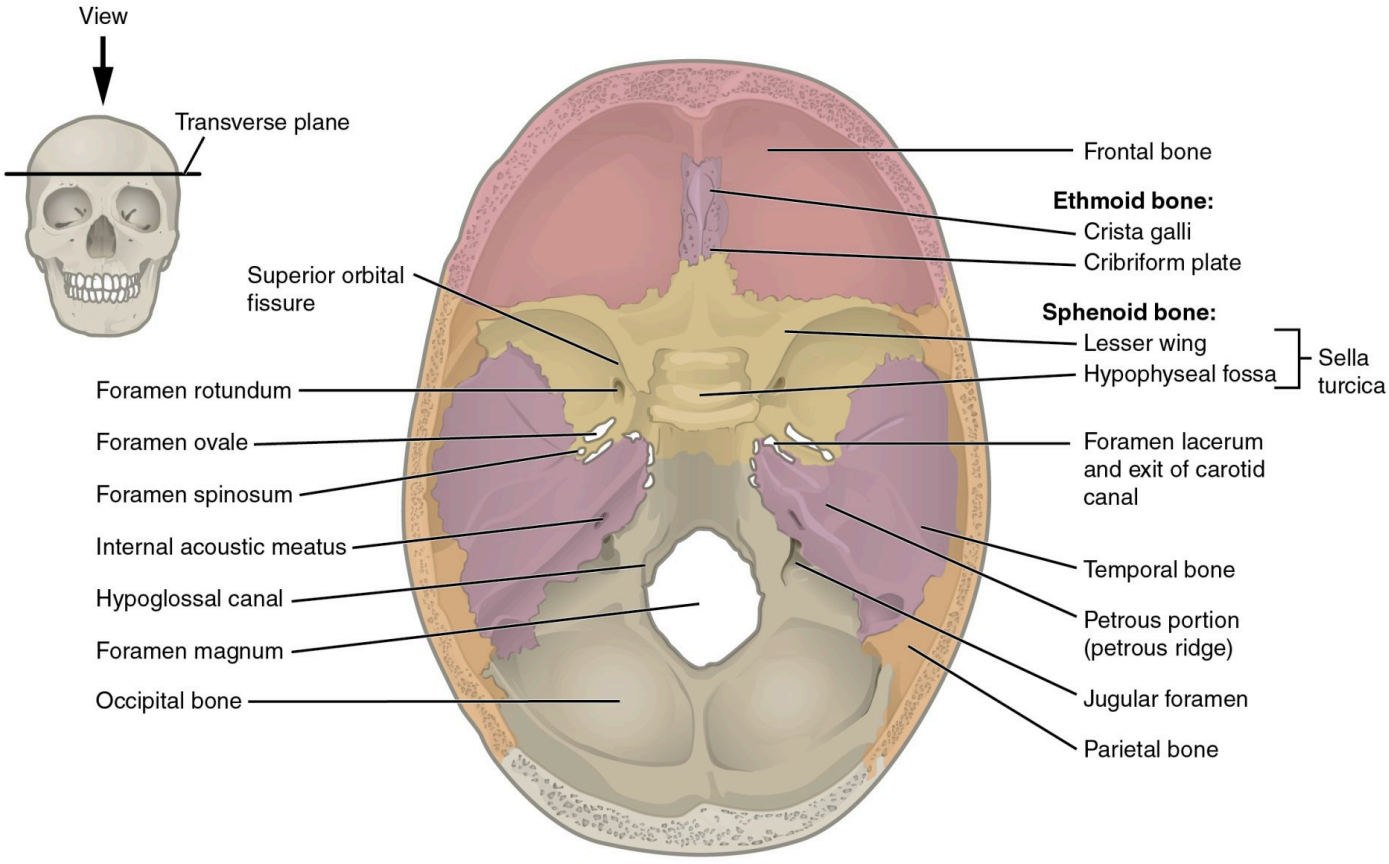


Figure 6.23 Occipital Bone



(a) Inferior view



(b) Superior view

Figure 6.24 External and Internal Views of Base of Skull

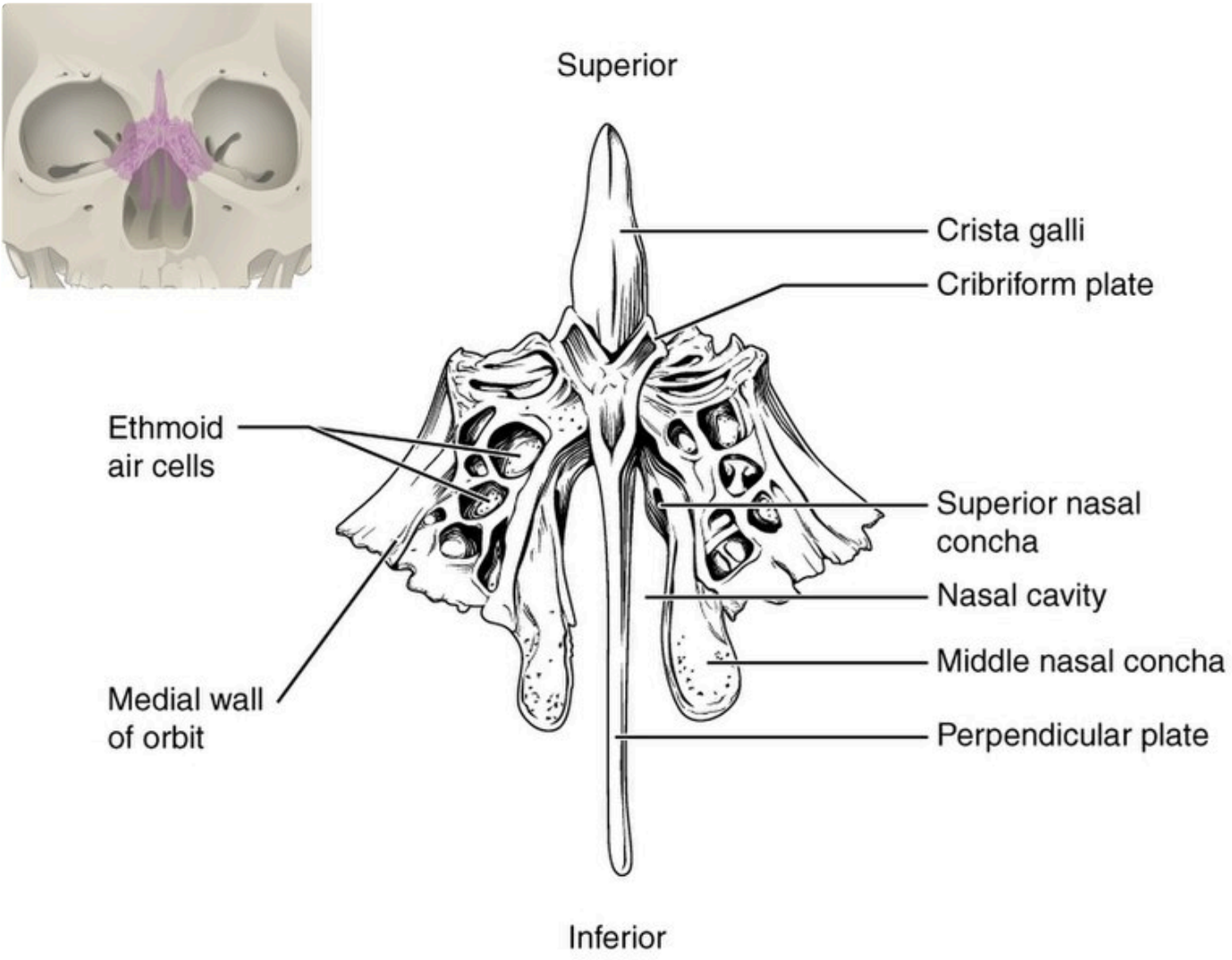


Figure 6.25 Ethmoid bone

Fontanelles

As the bones grow in the fetal skull, they remain separated from each other by large areas of dense connective tissue membranes called **fontanelles**, commonly called “soft

spots" on an infant's head. See Figure 6.26[5] for an illustration of fontanelles. There are two major fontanelles called the anterior fontanelle and the posterior fontanelle. The **anterior fontanelle** is the larger fontanelle and is located on the top of the head, at the junction of the frontal and parietal bones. The **posterior fontanelle** is a smaller fontanelle and is located on the posterior side of the skull between the parietal and occipital bones. Fontanelles are important during childbirth because they allow the infant's skull to compress and change shape as it squeezes through the birth canal. After birth, the fontanelles allow for continued growth and expansion of the skull as the brain enlarges. The fontanelles decrease in size and disappear by age 2. However, the skull bones remain separated from each other at the sutures that contain dense fibrous connective tissue, which allows for continued growth as the brain enlarges during childhood.

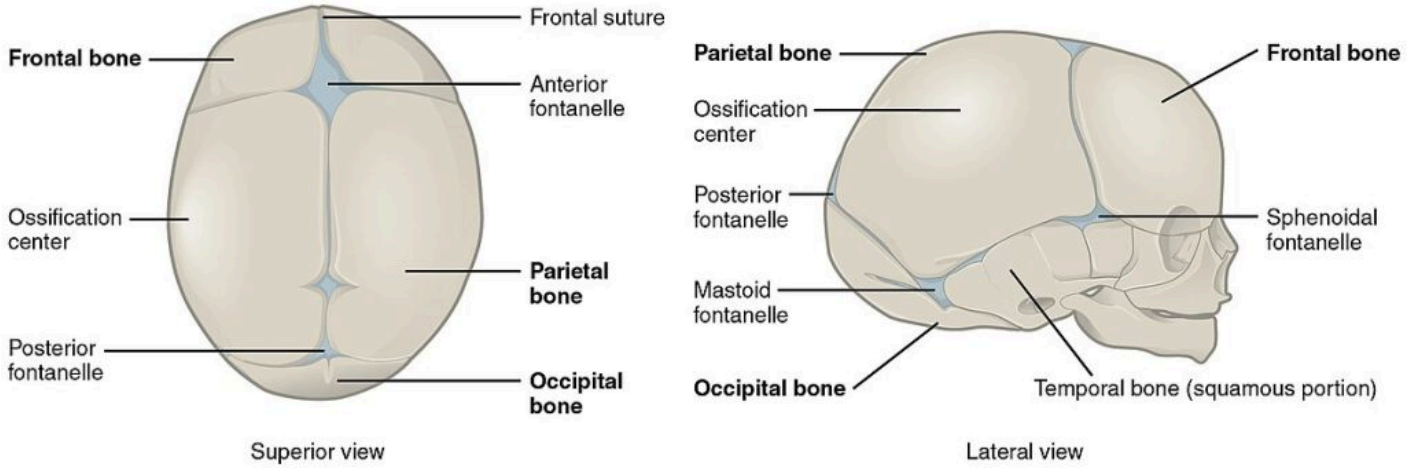


Figure 6.26 Fontanelles

Sutures of the Skull

A **suture** is a fixed (immobile) joint between bones of the skull. The narrow gap between the bones is filled with dense, fibrous connective tissue that unites the bones. The sutures are not straight, but instead follow irregular, tightly twisting paths. These twisting lines tightly lock the bones together, adding strength to the skull for brain protection.

The five sutures of the skull are as follows:

- **Coronal suture**. The coronal suture runs from side to side across the top of the skull

5. OpenStax College. (2013). *702_Newborn_Skull-01* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:702_Newborn_Skull-01.jpg

and joins the frontal bone to the parietal bones. See Figure 6.27[6] for an illustration of the lateral view of the skull depicting the coronal suture.

- **Sagittal suture**. The sagittal suture extends posteriorly from the coronal suture, along the midline at the top of the skull. See Figure 6.28 of an illustration of the posterior view of the skull to view the sagittal suture. It unites the right and left parietal bones. On the posterior skull, the sagittal suture ends by joining the lambdoid suture.
- **Lambdoid suture**. The lambdoid suture extends downward and laterally to either side from its junction with the sagittal suture. The lambdoid suture joins the occipital bone to the right and left parietal and temporal bones. This suture is named for its upside-down "V" shape, which resembles the capital letter version of the Greek letter *lambda* (Λ). See Figure 6.28[7] for an illustration of the posterior view of the skull depicting the lambdoid suture.
- **Squamous suture**. The squamous suture is located on each side of the skull. It unites the temporal bone with the parietal bone. See Figure 6.27 for an illustration of the lateral view of the skull depicting the squamous suture.
- **Pterion**: The pterion is a small, capital-H-shaped region that unites the frontal bone, parietal bone, temporal bone, and sphenoid bone. The bone here is thinner, making it the weakest part of the skull. See Figure 6.27 for an illustration of the lateral view of the skull with the pterion circled.

6. OpenStax College. (2013). *705_Lateral_View_of_Skull-01* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:705_Lateral_View_of_Skull-01.jpg
7. OpenStax College. (2013). *730_Posterior_View_Skull* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:730_Posterior_View_Skull.jpg

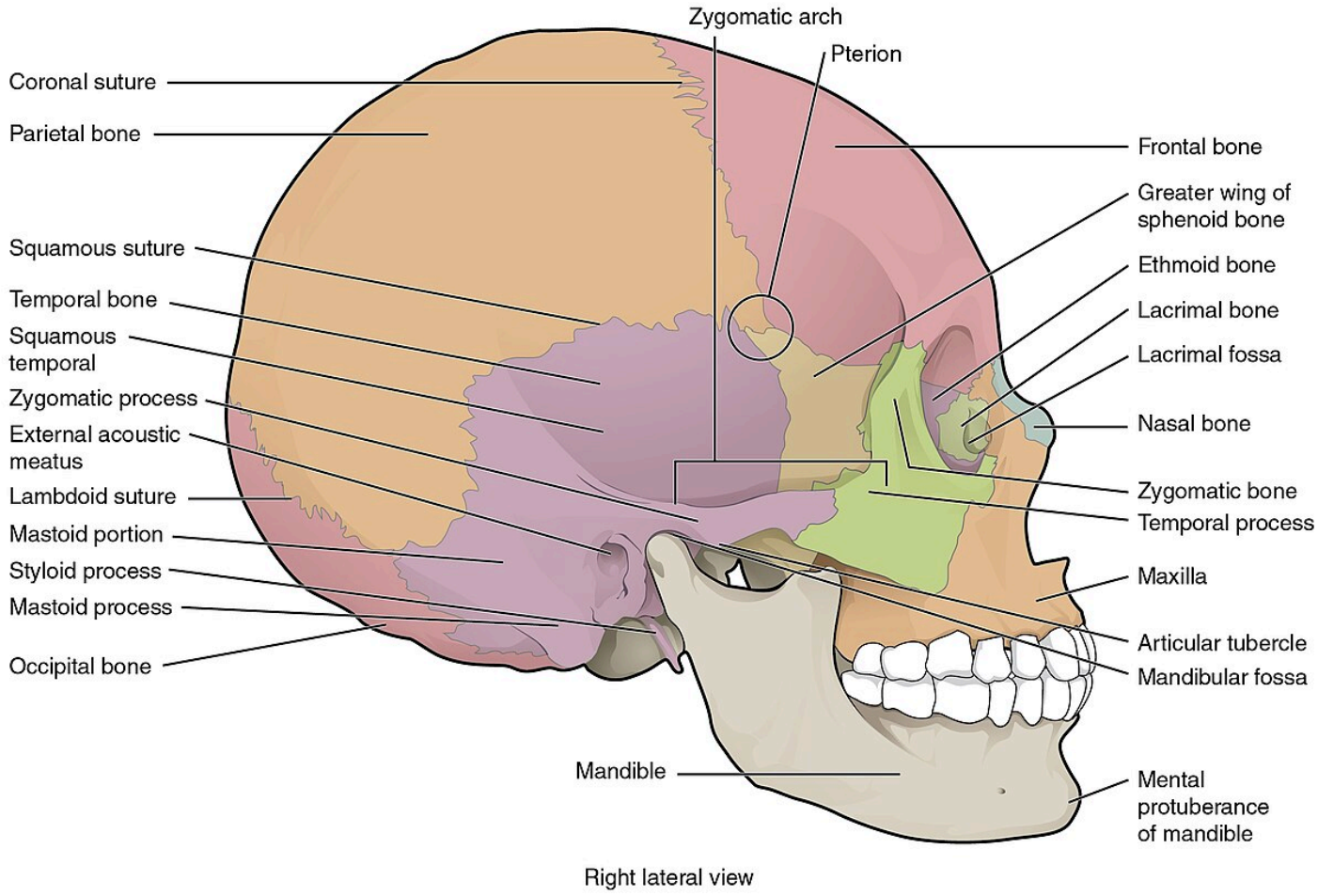


Figure 6.27 Lateral View of the Skull

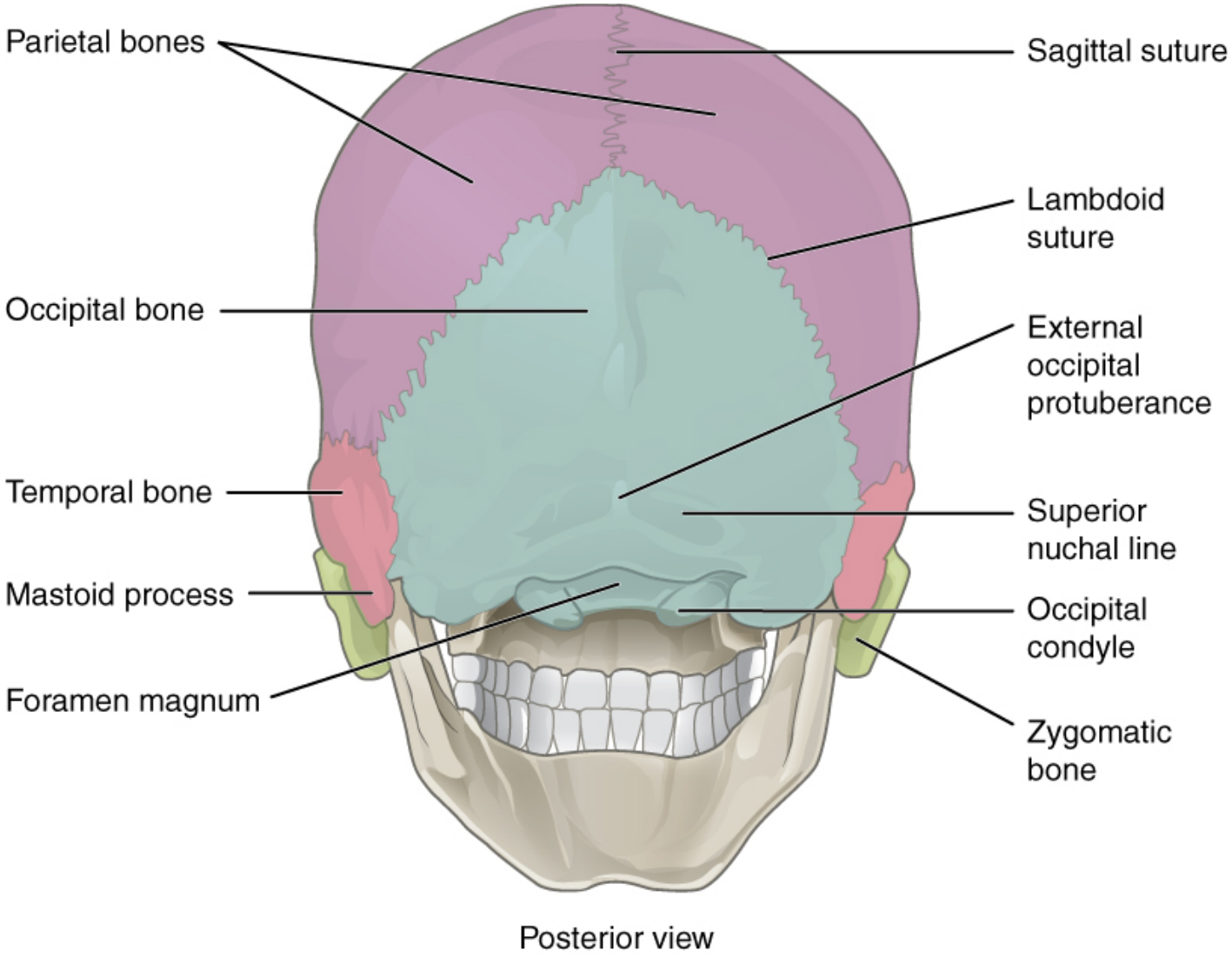


Figure 6.28 Posterior View of the Skull

Paranasal Sinuses

The **paranasal sinuses** (also called sinuses) are hollow, air-filled spaces located within certain bones of the skull. All the sinuses connect with the nasal cavity (*paranasal* = "next to the nasal cavity") and are lined with nasal mucosa.

The sinuses reduce bone mass to lighten the skull and add resonance to the voice. This is most obvious when you have a cold or sinus congestion. Swelling of the mucosa and excess mucus production can block the narrow passageways between the sinuses and the nasal cavity, causing the voice to sound different. This blockage can also allow the sinuses to fill with fluid, producing pain and discomfort.

A paranasal sinus is named for the skull bone in which it resides:

- **Frontal sinus**: The frontal sinus is located just above the eyebrows in the frontal bone.
- **Maxillary sinus**: The maxillary sinuses are the largest sinus. They are paired and located within the right and left maxillary bones, where they occupy the area just below the eyes. The maxillary sinuses are most commonly involved during sinus infections because their location can make drainage difficult.
- **Sphenoid sinus**: The sphenoid sinus is a single sinus located within the body of the sphenoid bone near the sella turcica.
- **Ethmoid air cells**: The ethmoid bone contains small spaces called ethmoid air cells separated by very thin bony walls.

See Figure 6.29[8] for an illustration of the paranasal sinuses.

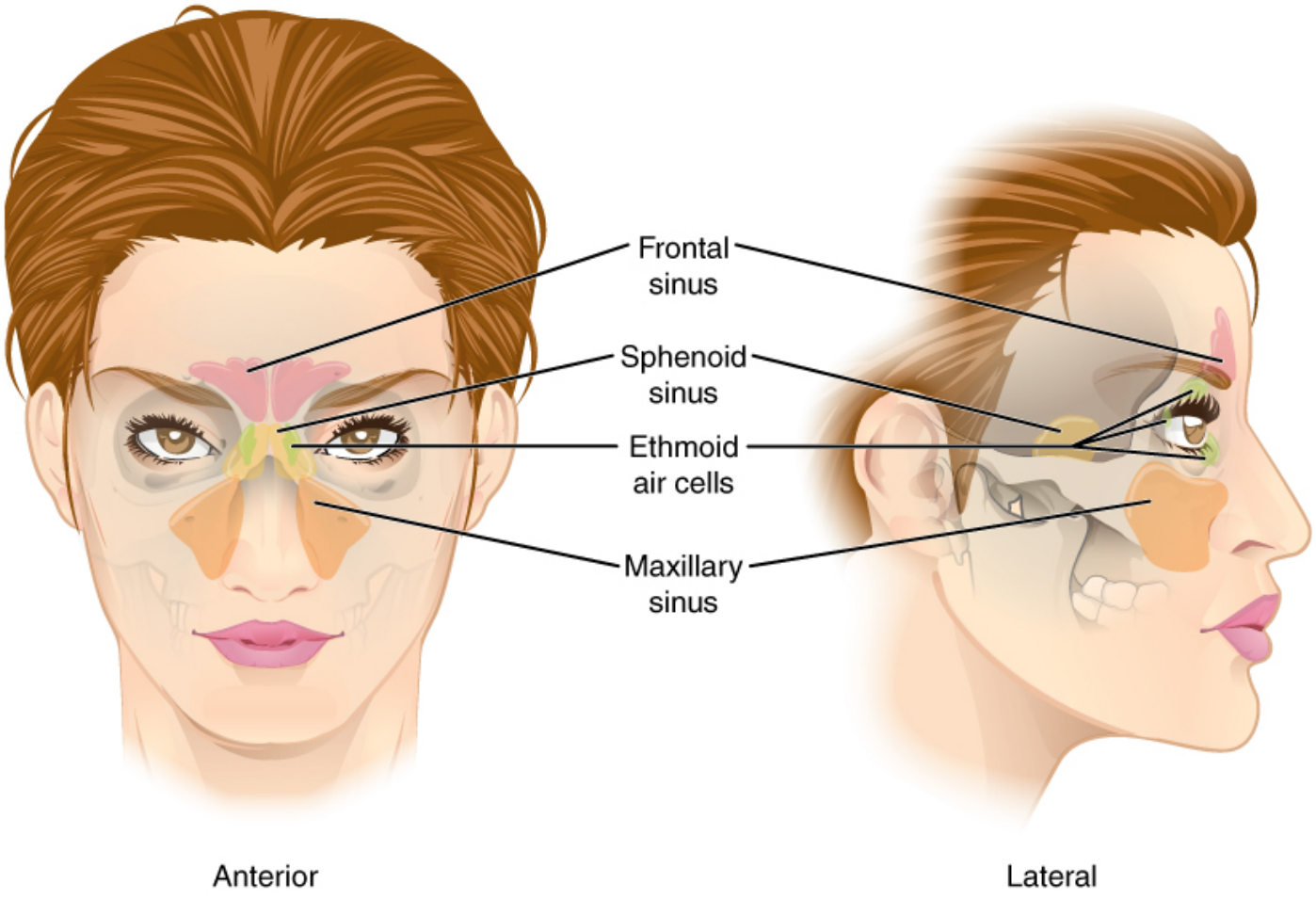


Figure 6.29 Paranasal Sinuses

8. OpenStax College. (2013). *724_Paranasal_Sinuses* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:724_Paranasal_Sinuses.jpg

Major Facial Bones and Features:

The facial bones form the upper and lower jaws, the nose, nasal cavity and nasal septum, and the eye orbits. The facial bones include 14 bones, with six paired bones and two unpaired bones. Refer back to Figure 6.20 of the illustration of the anterior skull to view the following facial bones:

- **Zygomatic bones**: Pair of bones on the right and left side of the anterior face; also called the "cheekbones."
- **Maxillae**: Pair of fused bones on the right and left side of the face forming the upper jaw and hard palate (roof of the mouth). If these bones don't join together correctly, a person will have a cleft palate.
- **Palatine bones**: Pair of fused L-shaped bones on the right and left side of the face that form part of the hard palate, walls of the nasal cavity, and the orbital floor of the eye.
- **Nasal bones**: Pair of fused bones on the right and left side of the face that form the bridge of the nose.
- **Lacrimal bones**: Pair of bones on the right and left side of the face that form the walls of the medial orbit (eye socket).
- **Inferior nasal conchae (Turbinates)**: Group of irregularly shaped bones (right and left) that form the lower lateral (outside) walls of the nasal cavity.
- **Vomer**: Thin bone that forms the nasal septum, which separates the left and right nostrils.
- **Mandible**: Bone forming the lower jawbone. It is the only movable bone of the skull.

The **temporomandibular joint (TMJ)** is a hingelike joint between the temporal bone and the mandible that allows for the opening, closing, protrusion, retraction, and lateral movement of the lower jaw. Refer back to Figure 6.26 of the illustration of the lateral skull to view the temporomandibular joint.

Hyoid Bone

The **hyoid bone** is an independent bone that doesn't connect to any other bone and is not considered part of the skull. It is a small U-shaped bone located in the upper neck. The hyoid serves as the base for the tongue above and is attached to the voice box below. Movements of the hyoid are coordinated with movements of the tongue, voice box, and

throat during swallowing and speaking. See Figure 6.30[9] for an illustration of the hyoid bone.

9. OpenStax College. (2013). *712 Hyoid Bone* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:712_Hyoid_Bone.jpg

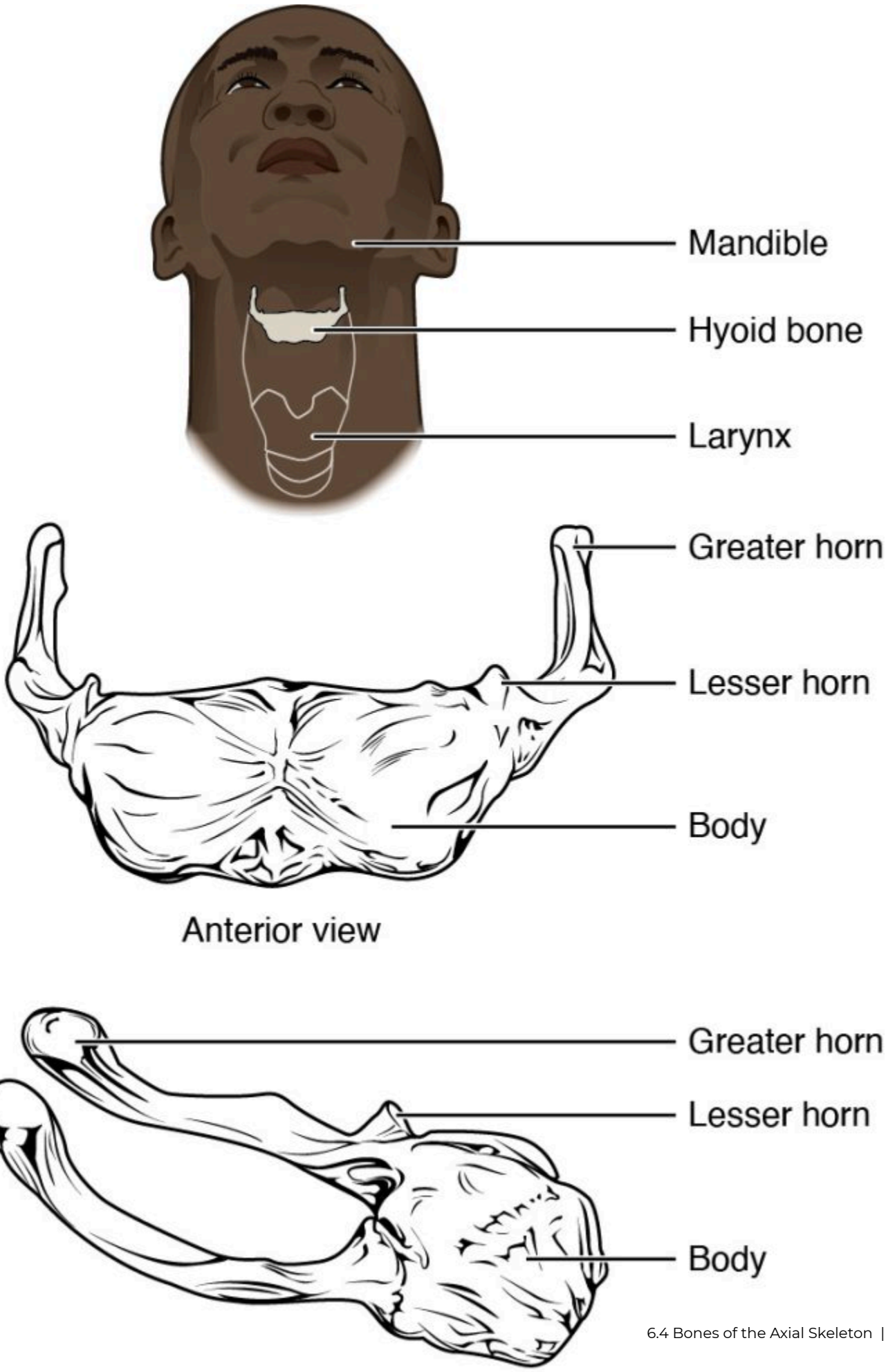

Mandible
Hyoid bone
Larynx
Greater horn
Lesser horn
Body
Anterior view
Greater horn
Lesser horn
Body

Figure 6.30 Hyoid Bone

Vertebral Column and Vertebrae

The **vertebral column** (also referred to as the **spinal column**) is a flexible column of bones that supports the head, neck, and body and protects the spinal cord. It is made up of bones called **vertebrae** (vertebra = singular) that are separated by discs of fibrocartilage called **intervertebral discs**. The spinal cord runs through the center of the vertebrae. See Figure 6.31[10] for an illustration of the vertebral column.

10. OpenStax College. (2013). *715 Vertebral Column* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:715_Vertebral_Column.jpg

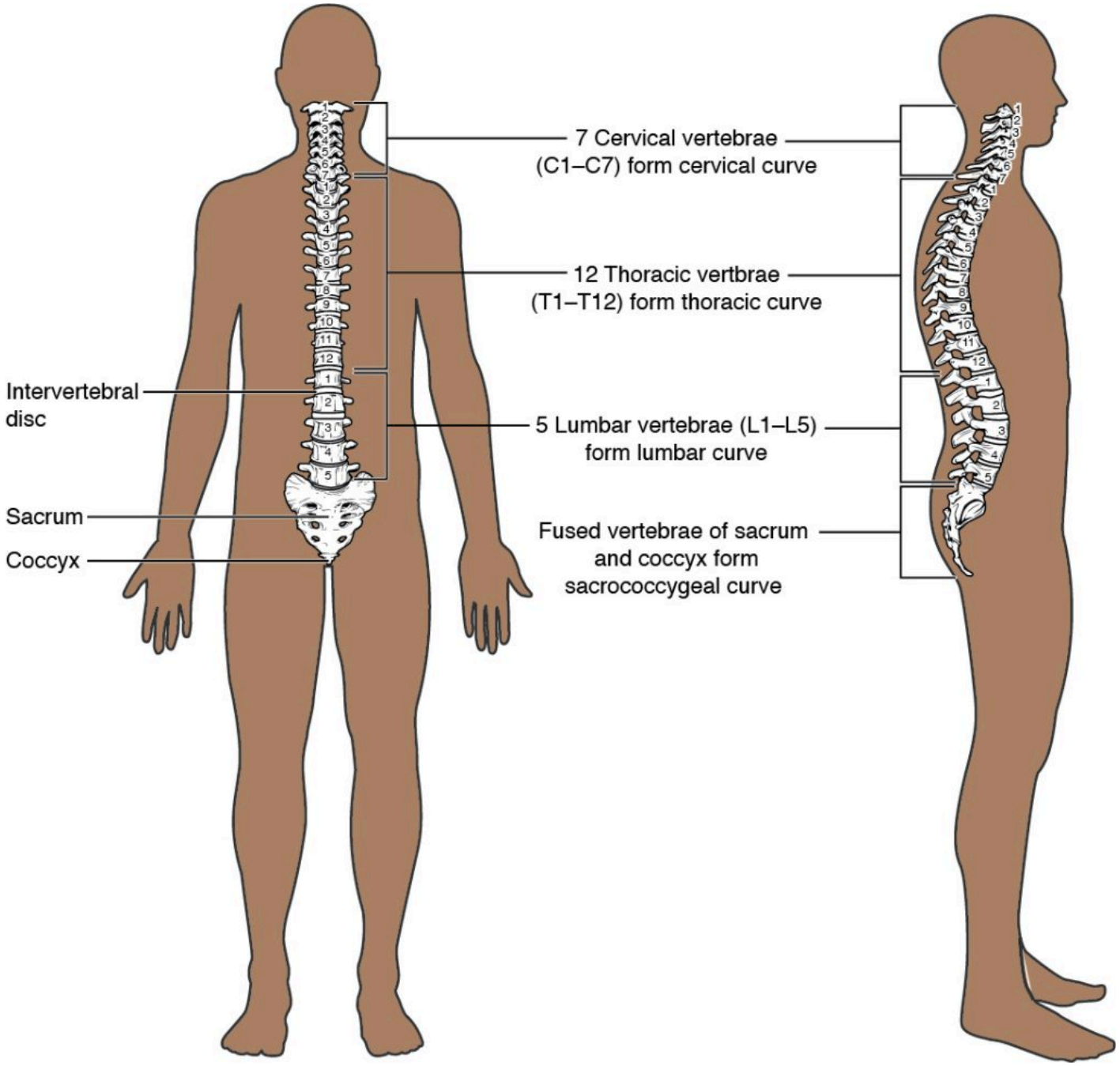


Figure 6.31 Vertebral Column

General Structure of a Vertebra

Within the different regions of the vertebral column, vertebrae vary in size and shape, but they all follow a similar structural pattern. A typical vertebra consists of a body, a vertebral arch, and seven processes.

- The **body** is the anterior portion of each vertebra and is the part that supports body

weight. Because of this, the vertebral bodies increase in size and thickness moving down the vertebral column. In between the bodies of the vertebrae are the intervertebral discs. They help form joints connecting individual vertebrae together in the vertebral column.

- The **vertebral arch** forms the posterior portion of each vertebra. The large opening between the vertebral arch and body is the **vertebral foramen** (plural = foramina), which contains the spinal cord. The vertebral foramina of all the vertebrae align to form the **vertebral (spinal) canal**, which serves as the bony protection and passageway for the spinal cord down the back. When the vertebrae are aligned together in the vertebral column, notches are found between the vertebrae. Each notch is called an **intervertebral foramen** and forms an opening through which a spinal nerve travels through the vertebral column.
- Seven processes arise from the vertebral arch.

See Figure 6.32[11] for an illustration of the major parts of a vertebra.

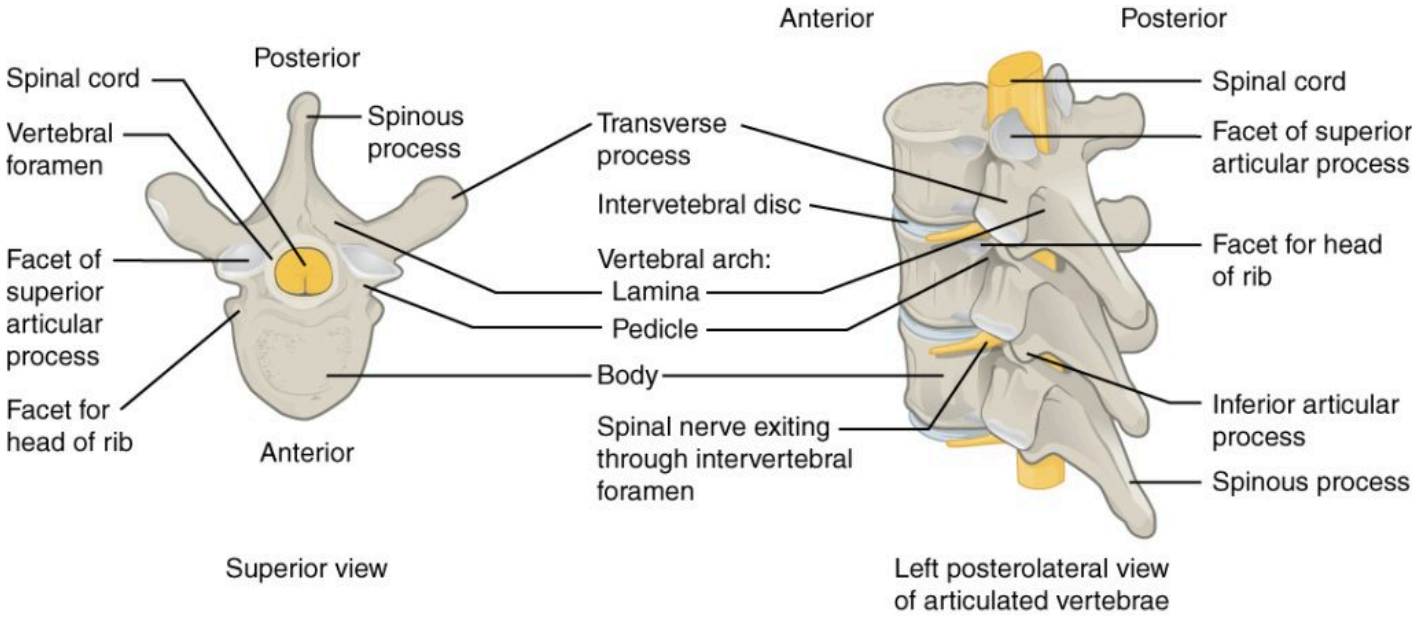


Figure 6.32 Major Parts of a Vertebra

Seven processes of a vertebra include the following:

- **Transverse process**: A pair of processes projecting laterally on each side, serving as important muscle attachment sites.

11. OpenStax College. (2013). *718_Vertebra* [Diagram]. Wikimedia Commons. CC BY 3.0. https://en.wikipedia.org/wiki/File:718_Vertebra.jpg

- **Spinous process**: A single process that projects posteriorly at the midline. These processes can easily be felt as a series of bumps just under the skin down the middle of the back. The spinous process also serves as an important muscle attachment site.
- **Superior articular process**: Pair of processes that extend or face upward.
- **Inferior articular process**: Pair of processes that face or project downward on each side of a vertebra.

See Figure 6.33[12] for an illustration of the seven vertebral processes. The paired superior articular processes of one vertebra join with the corresponding paired inferior articular processes from the next higher vertebra. These junctions form slightly movable joints between the adjacent vertebrae. The shape and orientation of the articular processes vary in different regions of the vertebral column and play a major role in determining the type and range of motion available in each region.

12. OpenStax College. (2013). *725_Lumbar_Vertebrae* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:725_Lumbar_Vertebrae.jpg

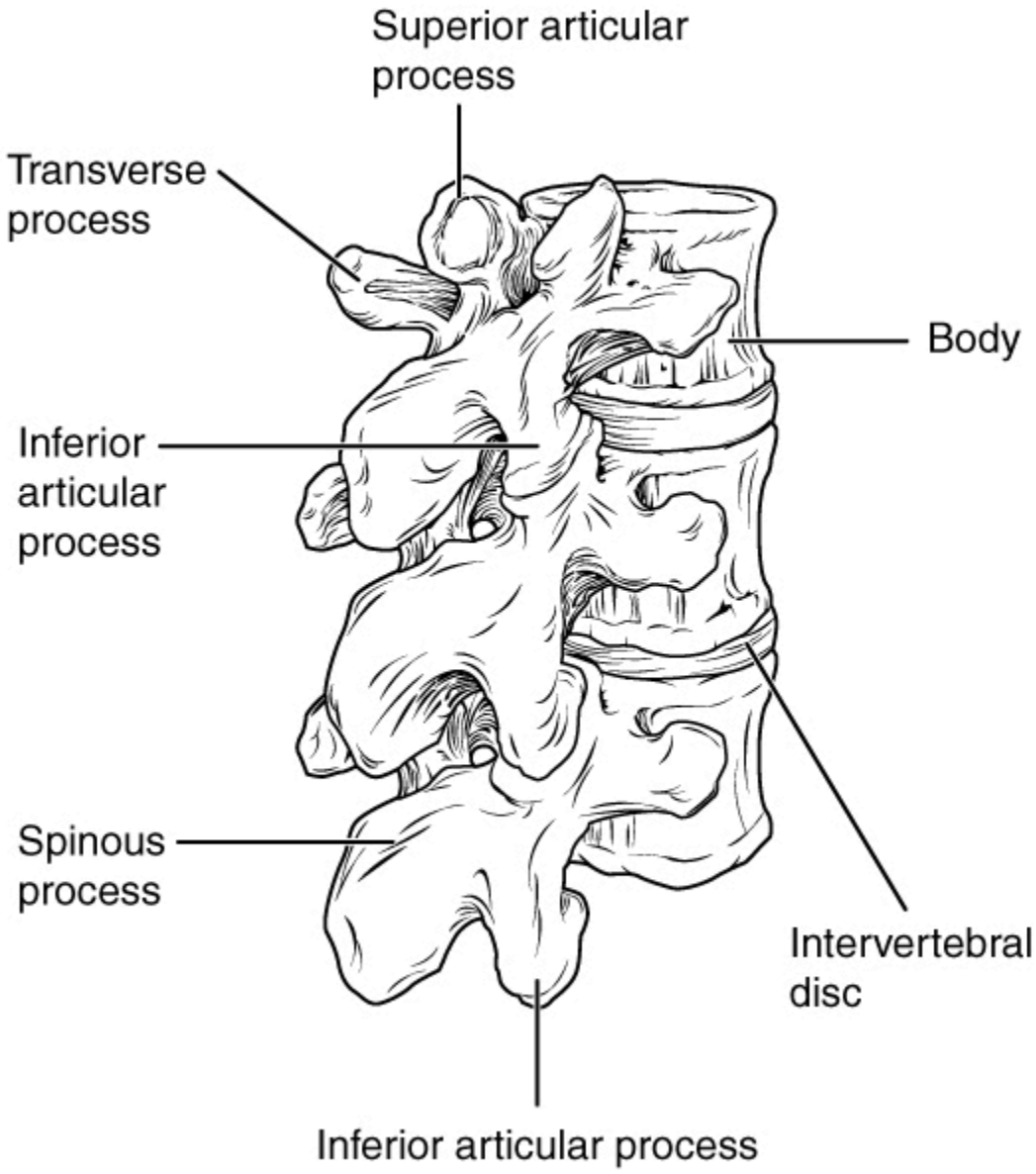


Figure 6.33 Vertebral Processes

Vertebrae Regions

The vertebrae are divided into five regions called the cervical, thoracic, lumbar, sacral, and coccyx. Refer back to Figure 6.30 for an illustration of vertebra regions. The vertebrae in each of these regions are further described in the following subsections.

Cervical Vertebrae

The first seven cervical vertebrae in the neck region are designated by the letter “C”

and are numbered C1 to C7. Cervical vertebrae have a small body because they carry the least amount of body weight. Cervical vertebrae usually have a bifid (Y-shaped) spinous process. You can find these vertebrae by running your finger down the midline of the posterior neck until you encounter the prominent C7 spine located at the base of the neck. Each transverse process also has an opening called the **transverse foramen**. An important artery that supplies the brain ascends up the neck by passing through these openings. The first two cervical vertebrae have their own names, called the atlas and axis:

- **Atlas (C1)**: The first cervical vertebra, called the atlas, supports the skull on top of the vertebral column. (In Greek mythology, Atlas was the god who supported the heavens on his shoulders.) The C1 vertebra does not have a body or spinous process. Instead, it is ring-shaped with transverse processes extending laterally.
- **Axis (C2)**: The second cervical vertebra, called the axis, serves as the axis for rotation when turning the head toward the right or left. The axis resembles typical cervical vertebrae in most respects, but is easily distinguished by the **dens** (odontoid process), a bony projection that extends upward from the vertebral body.

  See Figure 6.34[13] for an illustration of the cervical vertebrae.

13. OpenStax College. (2013). *723_Cervical_Vertebrae* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:723_Cervical_Vertebrae.jpg

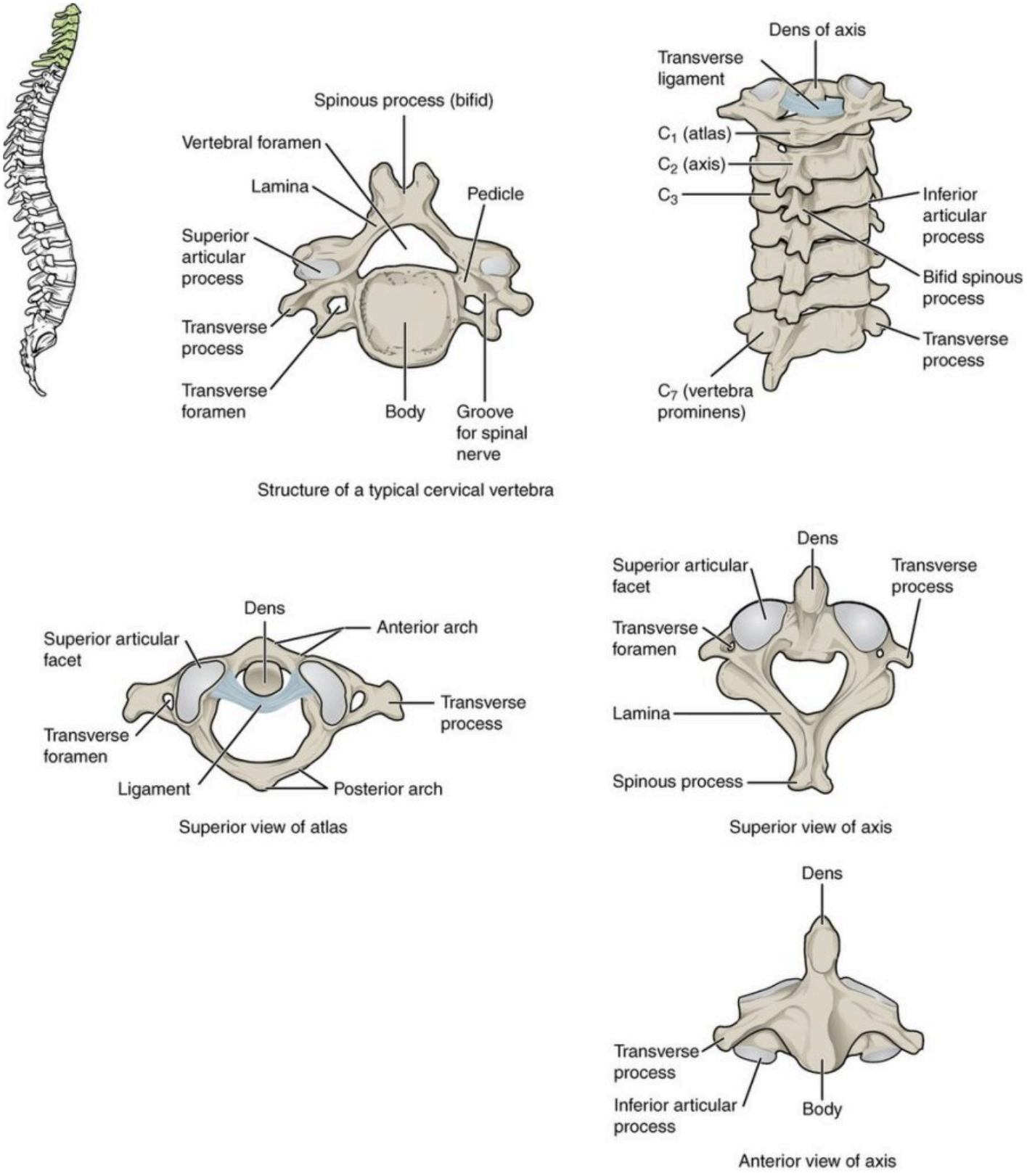


Figure 6.34 Cervical Vertebrae

Thoracic Vertebrae

Twelve thoracic vertebrae form the outward curvature of the spine and the back of the thoracic cage. These vertebrae are designated by the letter "T" and are numbered T1 to T12. The bodies of the thoracic vertebrae are larger than those of the cervical vertebrae. The spinous process is long and has a pronounced downward angle that causes it to overlap the next inferior vertebra. Thoracic vertebrae have **facets** on their transverse processes where ribs attach. See Figure 6.35[14] for an illustration of a thoracic vertebra.

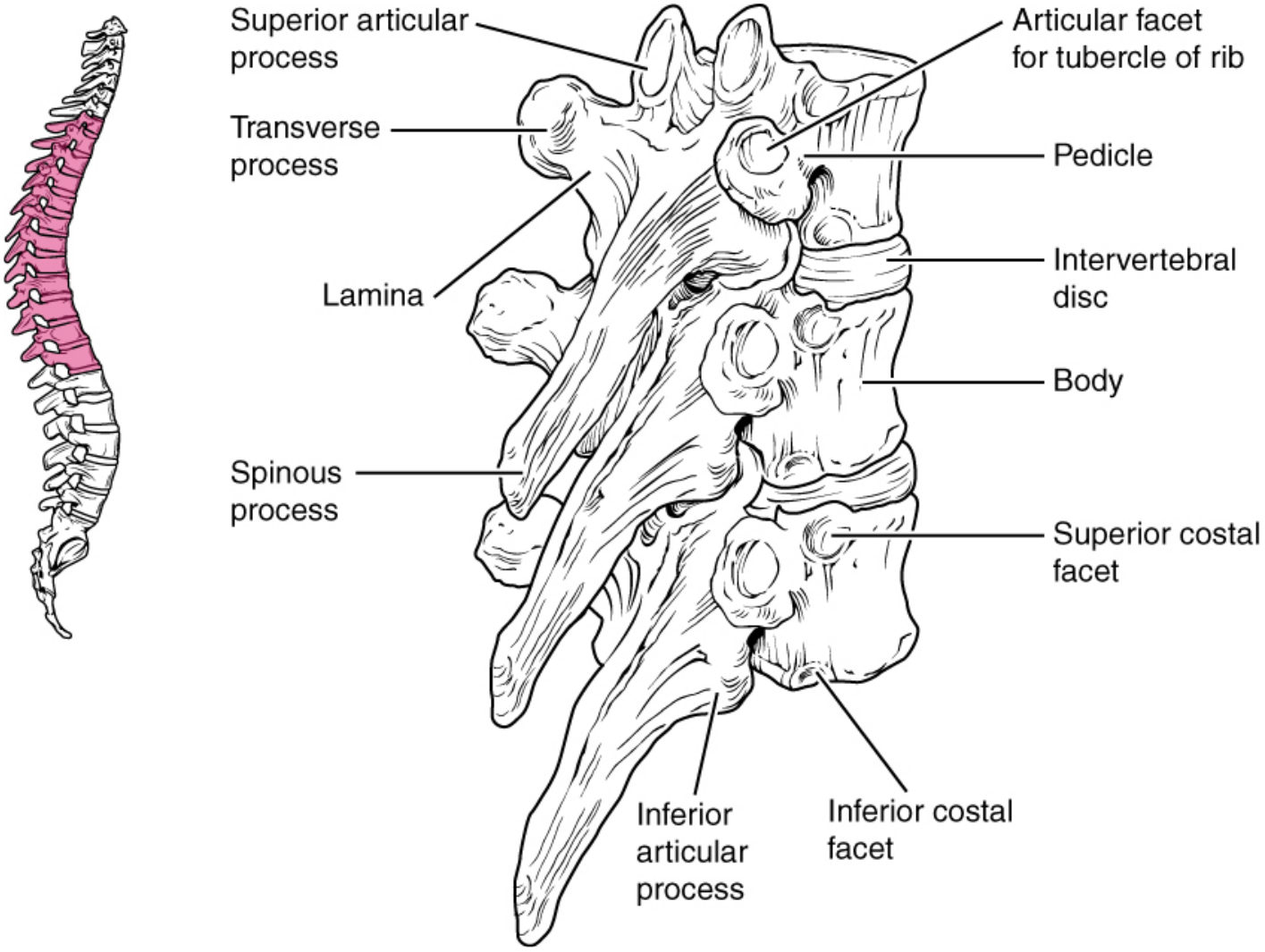


Figure 6.35 Thoracic Vertebrae

14. OpenStax College. (2013). *719_Thoracic_Vertebra* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:719_Thoracic_Vertebra.jpg

Lumbar Vertebrae

There are five vertebrae that form the inner curvature of the lower spine. They form the lower back. These vertebrae are designated with the letter "L" and are numbered L1 to L5. Lumbar vertebrae carry the most body weight, so they are larger and have a thicker vertebral body. They have short transverse processes and a short, rounded spinous process. The articular processes are large, with the superior process facing medially and the inferior process facing laterally. See Figure 6.36[15] for an illustration of the lumbar vertebrae.

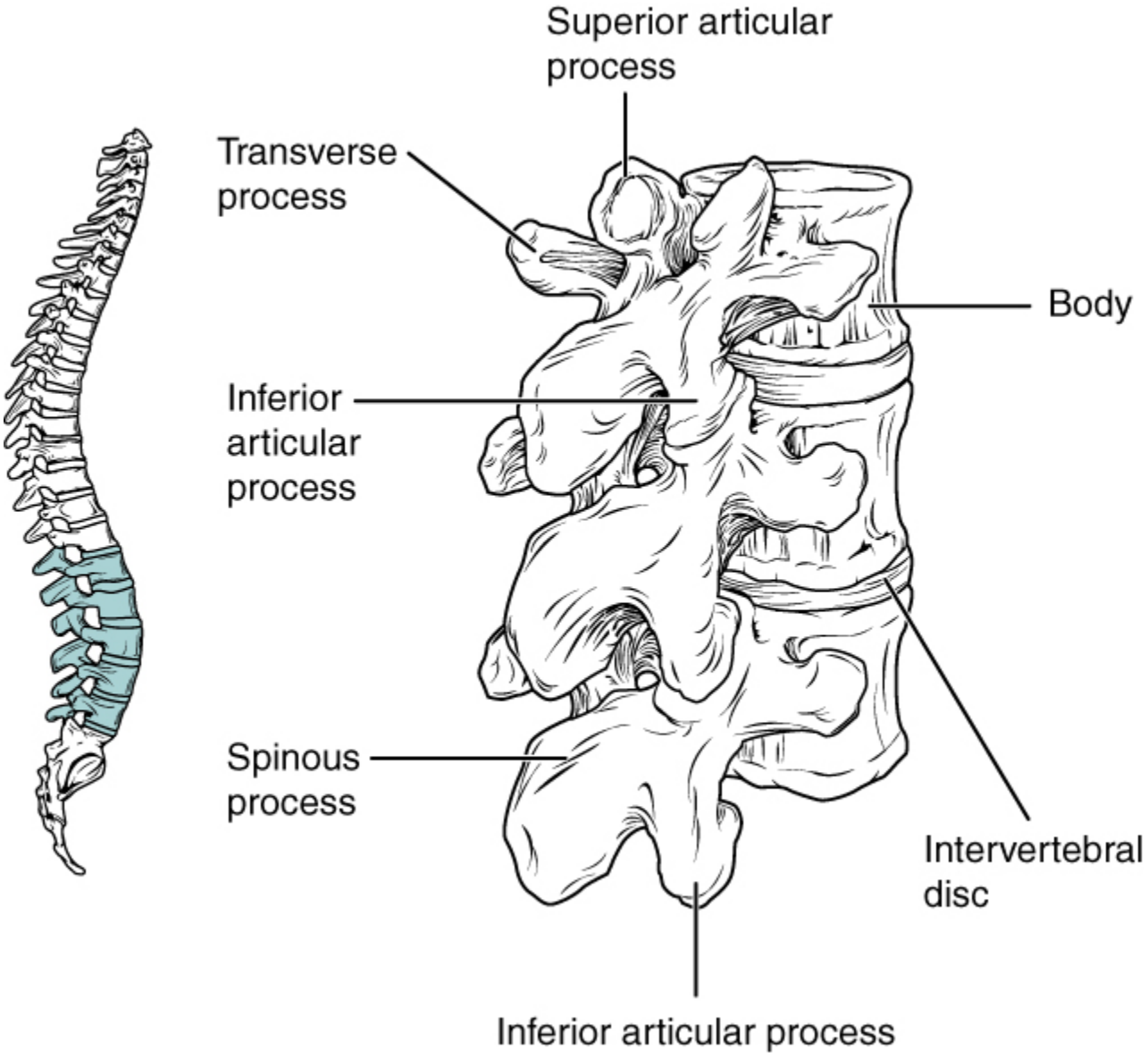


Figure 6.36 Lumbar Vertebrae

15. OpenStax College. (2013). *725_Lumbar_Vertebrae* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:725_Lumbar_Vertebrae.jpg

Sacral Vertebrae (Sacrum)

The **sacrum** is a triangular-shaped bone that is thick and wide across the top, where it is weight-bearing, and then tapers down to the inferior, non-weight-bearing apex. It is formed by the fusion of five sacral vertebrae, a process that does not begin until after the age of 20. See Figure 6.37[16] for an illustration of the sacrum.

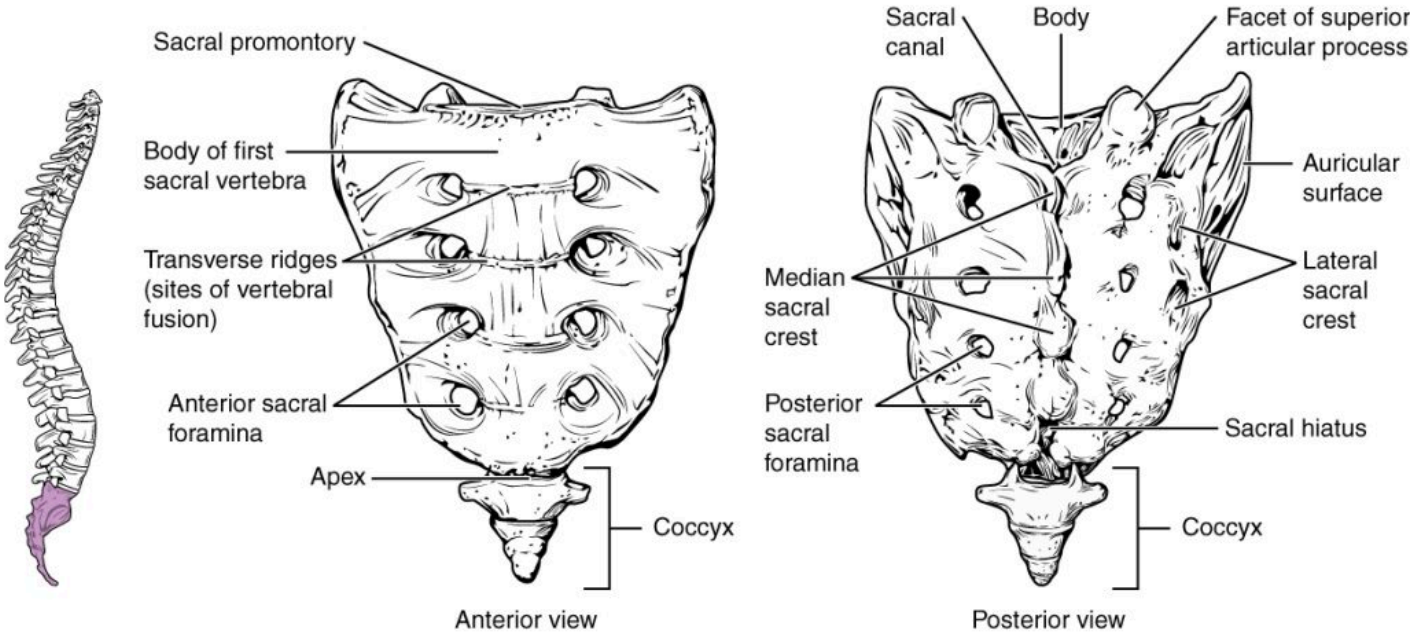


Figure 6.37 Sacrum and Coccyx

Coccyx

The **coccyx** (commonly referred to as the tailbone) is formed by the fusion of four very small coccygeal vertebrae. It articulates (forms a joint) with the inferior tip of the sacrum. It is not weight-bearing in the standing position, but may receive some body weight when sitting. Review Figure 6.36 for an illustration of the coccyx.

Vertebral Curvatures

The adult vertebral column does not form a straight line but instead has four

16. OpenStax College. (2013). *720_Sacrum_and_Coccyx* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:720_Sacrum_and_Coccyx.jpg

curvatures. (Review Figure 6.30 of the vertebral column for an illustration of these curvatures). These curves increase the vertebral column's strength, flexibility, and ability to absorb shock. When the load on the spine is increased, such as when carrying a heavy backpack, for example, the curvatures increase in depth (become more curved) to accommodate the extra weight. They then spring back when the weight is removed.

The four adult curvatures are classified as either primary or secondary curvatures. Primary curves are retained from the original fetal curvature, whereas secondary curvatures develop after birth. The vertebral column has two primary curvatures (thoracic and sacrococcygeal curves) and two secondary curvatures (cervical and lumbar curves). Read about medical disorders with abnormal curvatures in the "**Skeletal System Disorders**" section.

Thoracic Cage

The thoracic cage (commonly called the rib cage) forms the thorax (chest), protecting the heart and lungs. It consists of the sternum and 12 pairs of ribs. The ribs are connected posteriorly to the 12 thoracic vertebrae. See Figure 6.38[17] for an illustration of the thoracic cage.

17. OpenStax College. (2013). *721_Rib_Cage* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:721_Rib_Cage.jpg

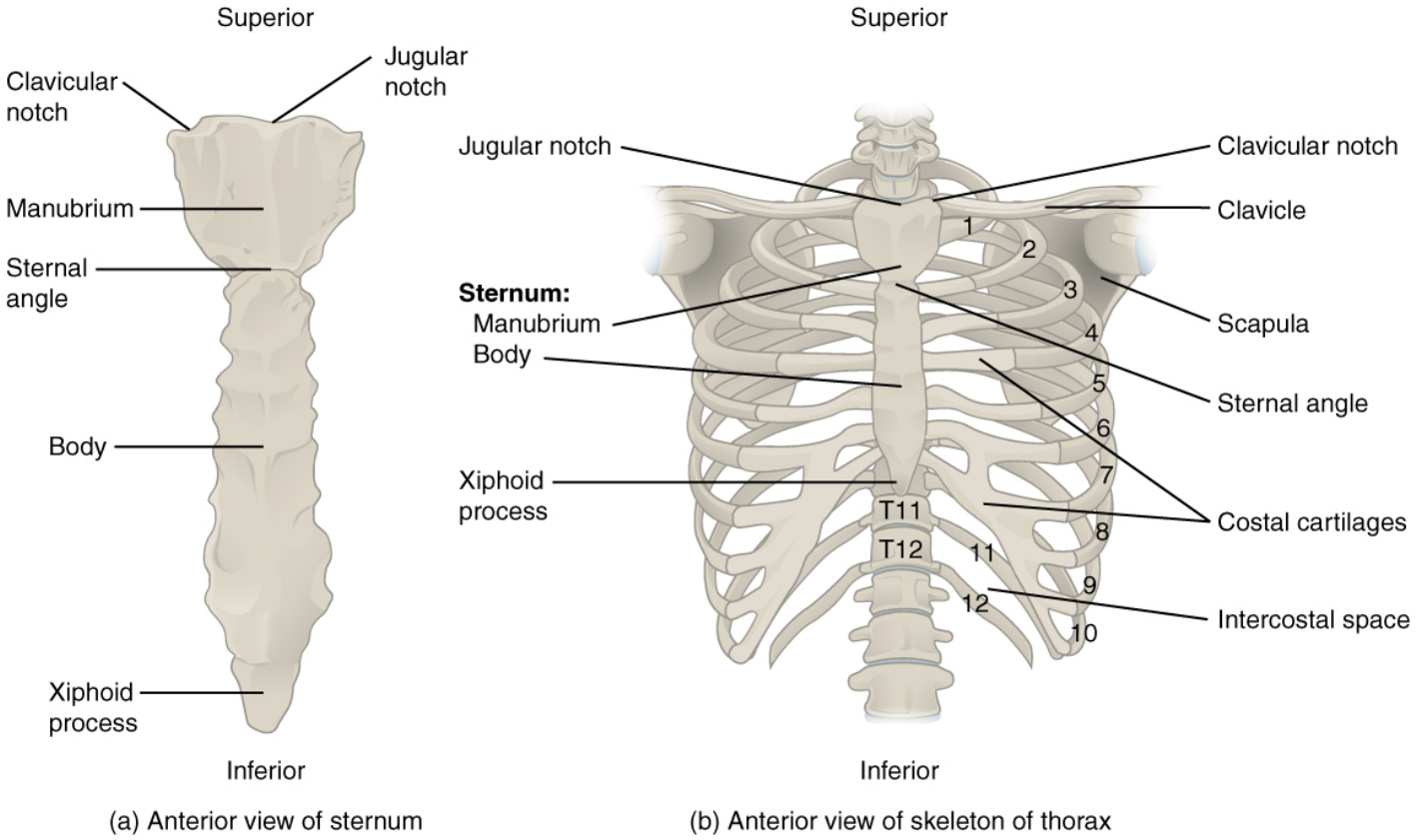


Figure 6.38 Thoracic Cage

Sternum

The **sternum** (commonly called the breastbone) is divided into three parts:

- **Manubrium**: The upper portion of the sternum
- **Body**: The middle portion of the sternum
- **Xiphoid process**: The lower portion of the sternum made of cartilage early in life but gradually ossifies starting in middle age.

Ribs

There are 12 pairs of ribs numbered 1 through 12 in accordance with the thoracic vertebrae. Each rib is a curved, flattened bone that makes up part of the wall of the thorax or chest cavity. They meet posteriorly with the T1 to T12 thoracic vertebrae, and most attach anteriorly with cartilage to the sternum.

The 12 pairs of ribs can be classified as true ribs, false ribs, and floating ribs:

- **True ribs**: Ribs 1 to 7 are attached directly to the anterior sternum by costal (rib) cartilage.
- **False ribs**: Ribs 8, 9, and 10 are attached to the costal cartilage of the seventh rib (and are, therefore, indirectly attached to the sternum).
- **Floating ribs**: Ribs 11 and 12 are not attached to the sternum at all.[18]

18. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical Terminology 2e.* Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/

6.5 Bones of the Appendicular Skeleton

The appendicular skeleton includes the upper and lower limbs (i.e., the arms and legs) and the bones that attach each limb to the axial skeleton.[1]

Refer back to Figure 6.21 in Section 6.3 for an illustration of the appendicular skeleton.

Bones of the Upper Limbs

The bones of the upper limbs include the bones of the arms, wrists, and hands. The shoulder attaches the upper limbs to the axial skeleton. See Figure 6.39[2] for an illustration of the bones of the upper limbs.

1. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical Terminology 2e.* Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/
2. Villarreal, M.R.. (2007). *Human_arm_bones_diagram* [Diagram]. Wikimedia Commons. Public Domain. https://en.wikipedia.org/wiki/File:Human_arm_bones_diagram.svg

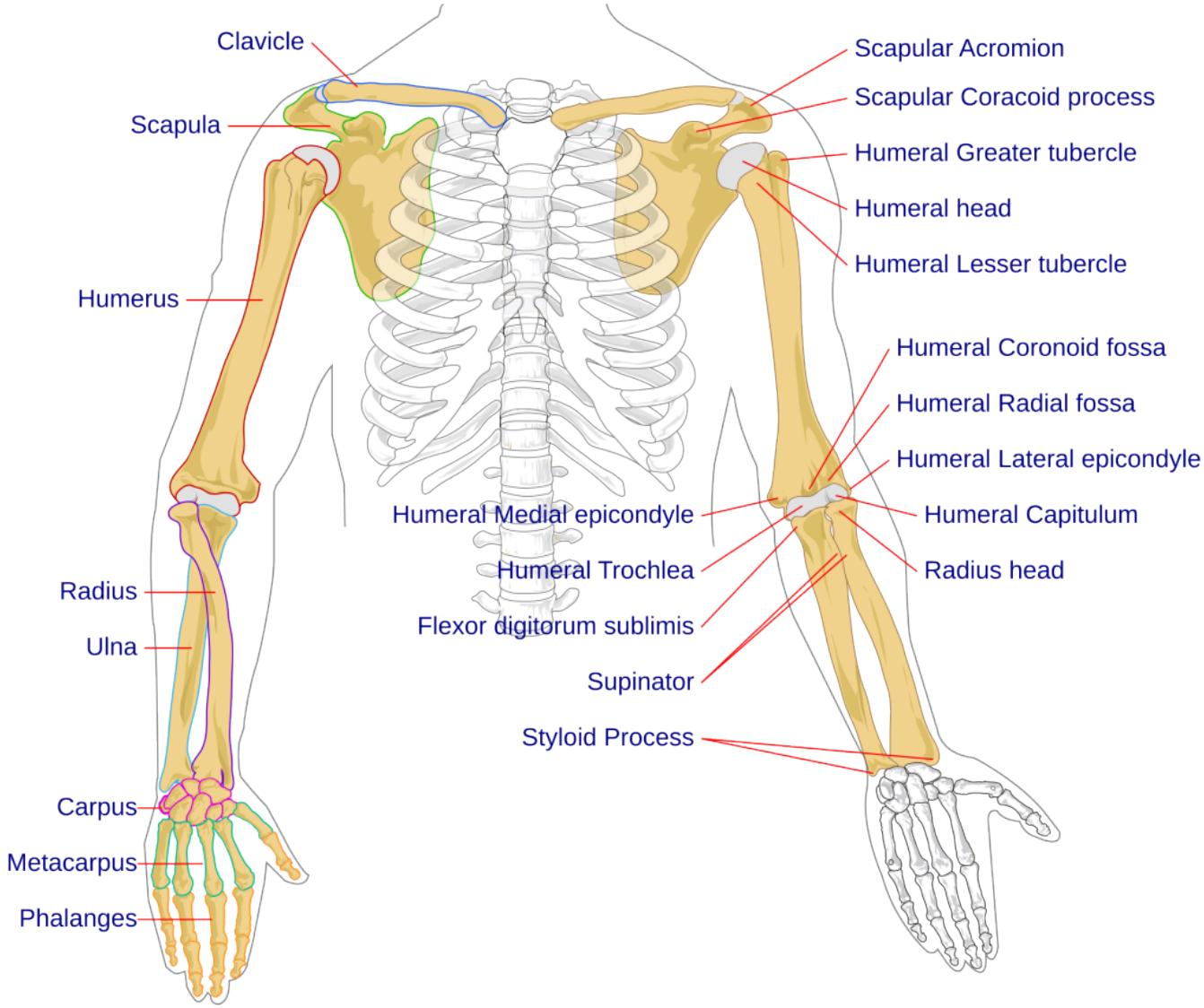


Figure 6.39 Bones of the Upper Limbs

Bones of The Shoulder (Pectoral Girdle)

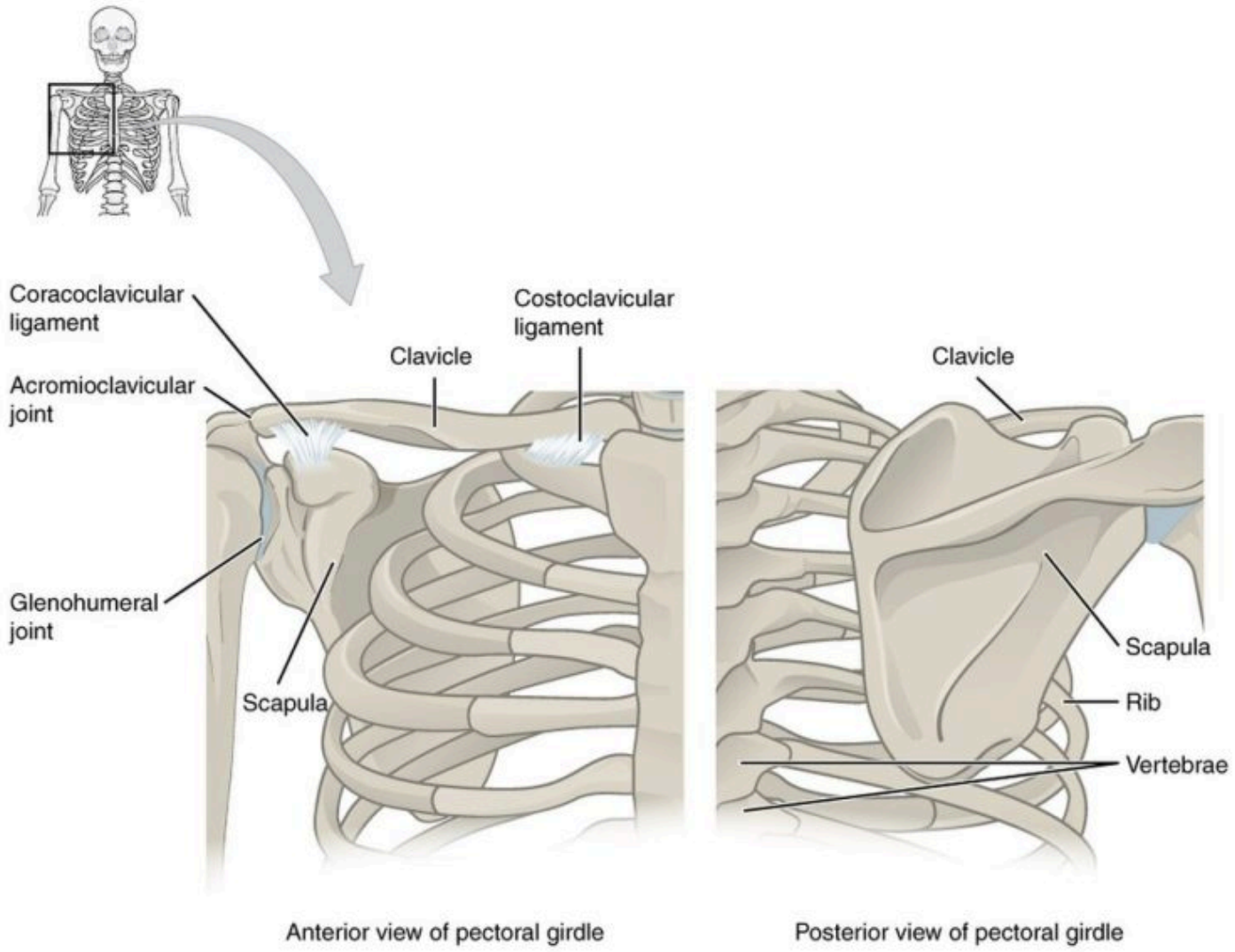
The shoulder connects the arms to the axial skeleton, forming the **pectoral girdle**. The bones of the pectoral girdle include the following:

- **Clavicle**: The bone connecting the sternum to the scapula and also known as the collarbone.
- **Scapula**: The bone commonly known as the shoulder blade.
  - **Acromion**: A bony extension from the scapula that forms the highest superior point or "tip" of the shoulder.

- **Glenoid fossa**: (Also known as glenoid cavity) Shallow depression located on the lateral scapula, between the superior and lateral borders.

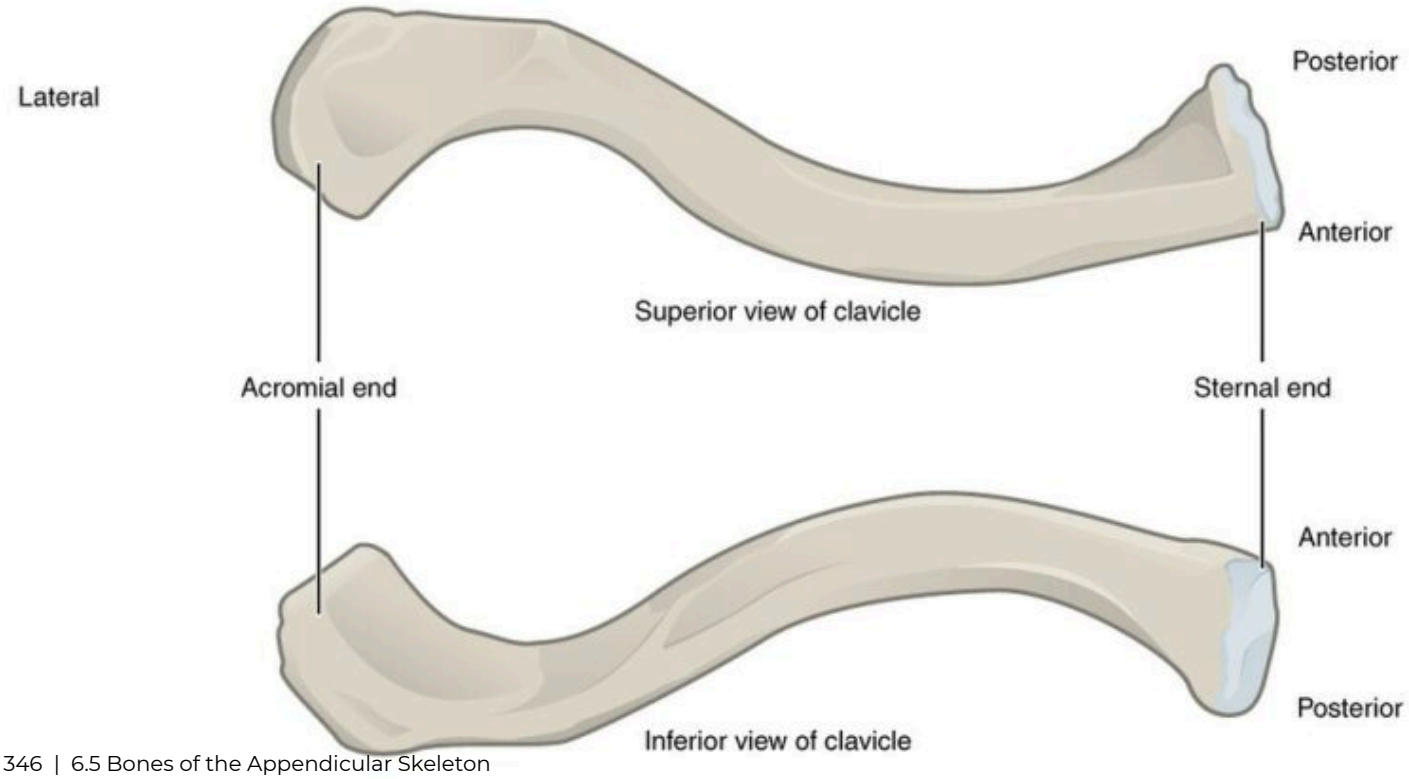
See Figure 6.40[3] for a detailed illustration of the bones of the pectoral girdle.

3. OpenStax College. (2013). *802_Pectoral_Girdle* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:802_Pectoral_Girdle.jpg



Anterior view of pectoral girdle

Posterior view of pectoral girdle



Superior view of clavicle

Inferior view of clavicle

Figure 6.40 Pectoral Girdle

Bones of the Upper Extremity

There are three bones in each upper extremity, including the following:

- **Humerus**: The upper arm bone.
  - **Humeral head**: The smooth, rounded region on the medial side of the proximal humerus; articulates with the glenoid fossa of the scapula to form the glenohumeral (shoulder) joint.
- **Radius**: The bone on the lateral or thumb side of the forearm.
- **Ulna**: The bone on the medial or pinky finger side of the forearm.

Bones of the Wrists and Hands

The bones of the hand and wrist include the carpals, metacarpals, and phalanges:

- **Carpals**: There are eight carpal bones that make up the wrist bones. They are the scaphoid, lunate, triquetrum (triangular), pisiform, trapezium, trapezoid, hamate, and capitate.
- **Metacarpals**: A group of five bones making up the palm of the hand.
- **Phalanges**: The bones that make up the fingers (and toes). A single finger bone is called a **phalanx**. Each finger (except the thumb) is composed of three bones: the distal phalanx, the middle or intermediate phalanx, and the proximal phalanx. The exception is the thumb, which only has two bones, the distal and proximal phalanges.

See Figure 6.41[4] for a detailed illustration of the bones of the wrist, hand, and fingers.

4. OpenStax College. (2013). *806_Hand_and_Wrist* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:806_Hand_and_Wrist.jpg

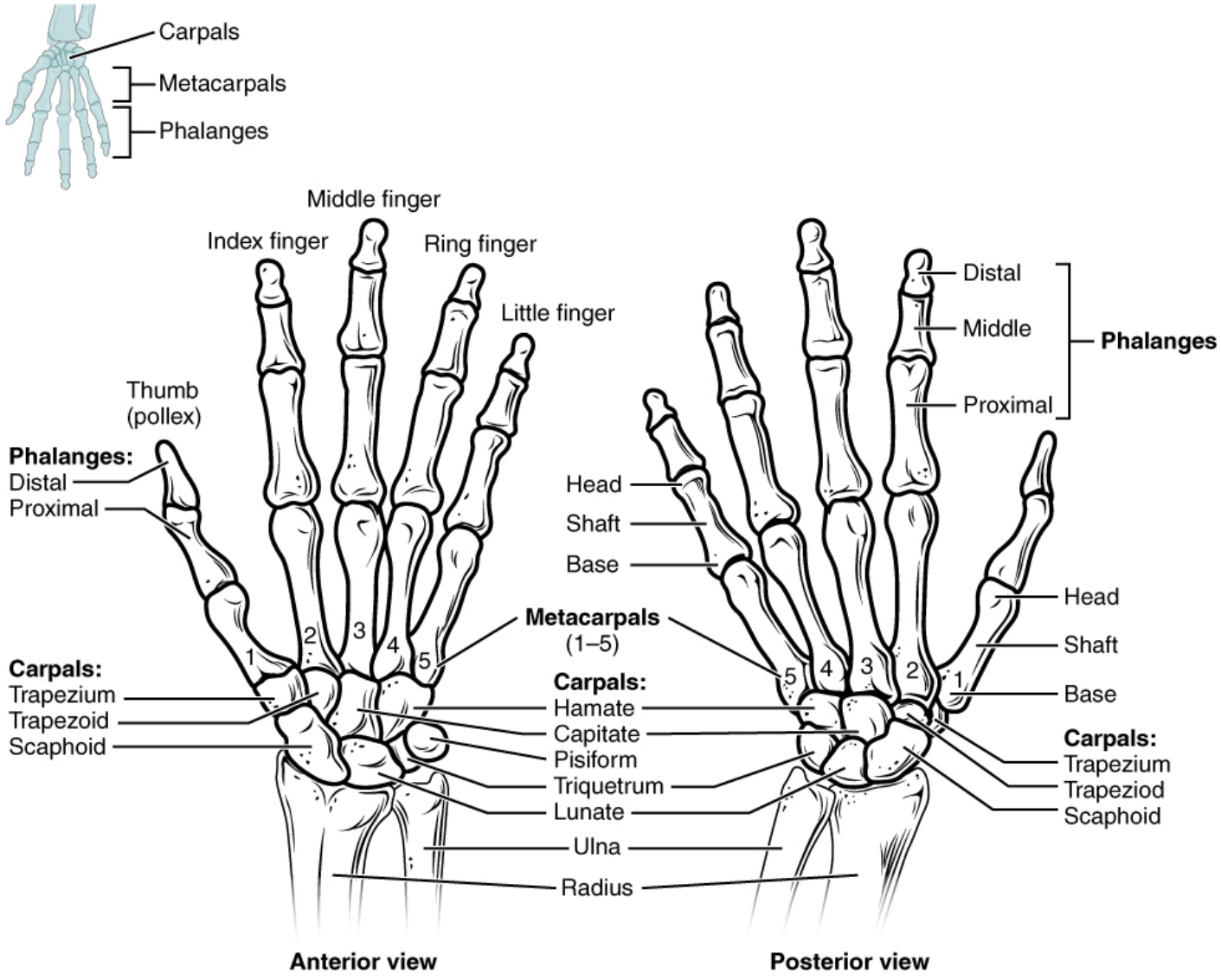


Figure 6.41Bones of the Hand, Wrist, and Fingers

Bones of the Lower Limbs

The pelvic girdle (hip and pelvis) attaches the lower limbs to the axial skeleton. The bones of the lower limb include the bones of the legs and the feet.

Bones of the Hip and Pelvis

The hip serves as the attachment point for each lower limb at the **acetabulum**, the large cup-like socket that holds the head of the femur. Each adult hip bone is formed by

three separate pelvic bones (the ilium, ischium, and pubis) that fuse together during the late teenage years:

- **Ilium**: The ilium is the superior region that forms the largest part of the hip bone. It is attached to the sacrum at the sacroiliac joint. If you place your hands on your hips, you can feel the curved, superior margin of the ilium, which is the **iliac crest**.
- **Ischium**: The ischium forms the inferior region of each hip bone and supports the body when sitting.
- **Pubis (or pubic bone)**: The pubis forms the anterior (front) portion of the hip. The pubis curves medially, where it joins to the pubis of the opposite hip bone at a specialized joint called the **pubic symphysis**.

  See Figure 6.44[5] for an illustration of the hip and pelvis.

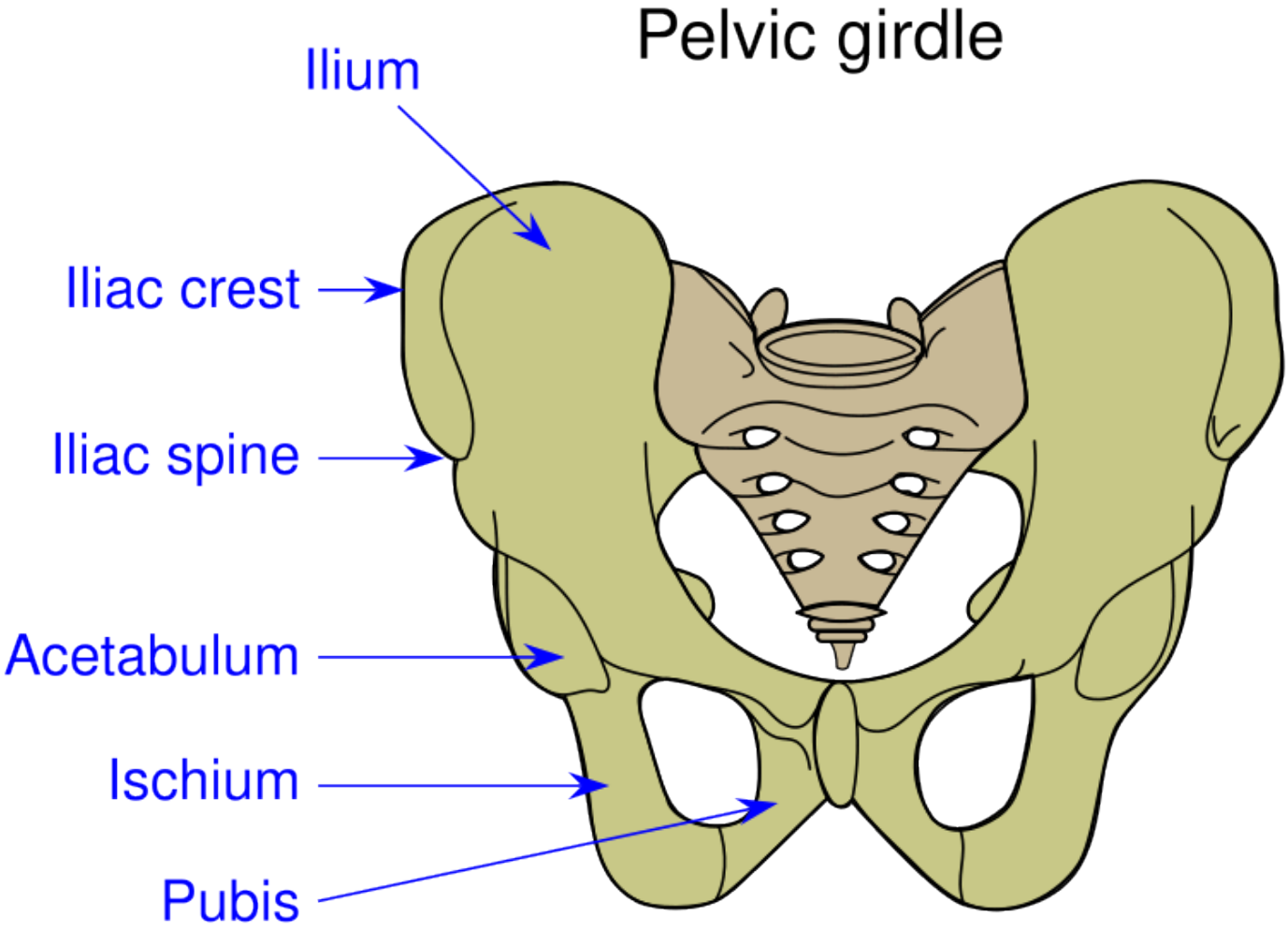
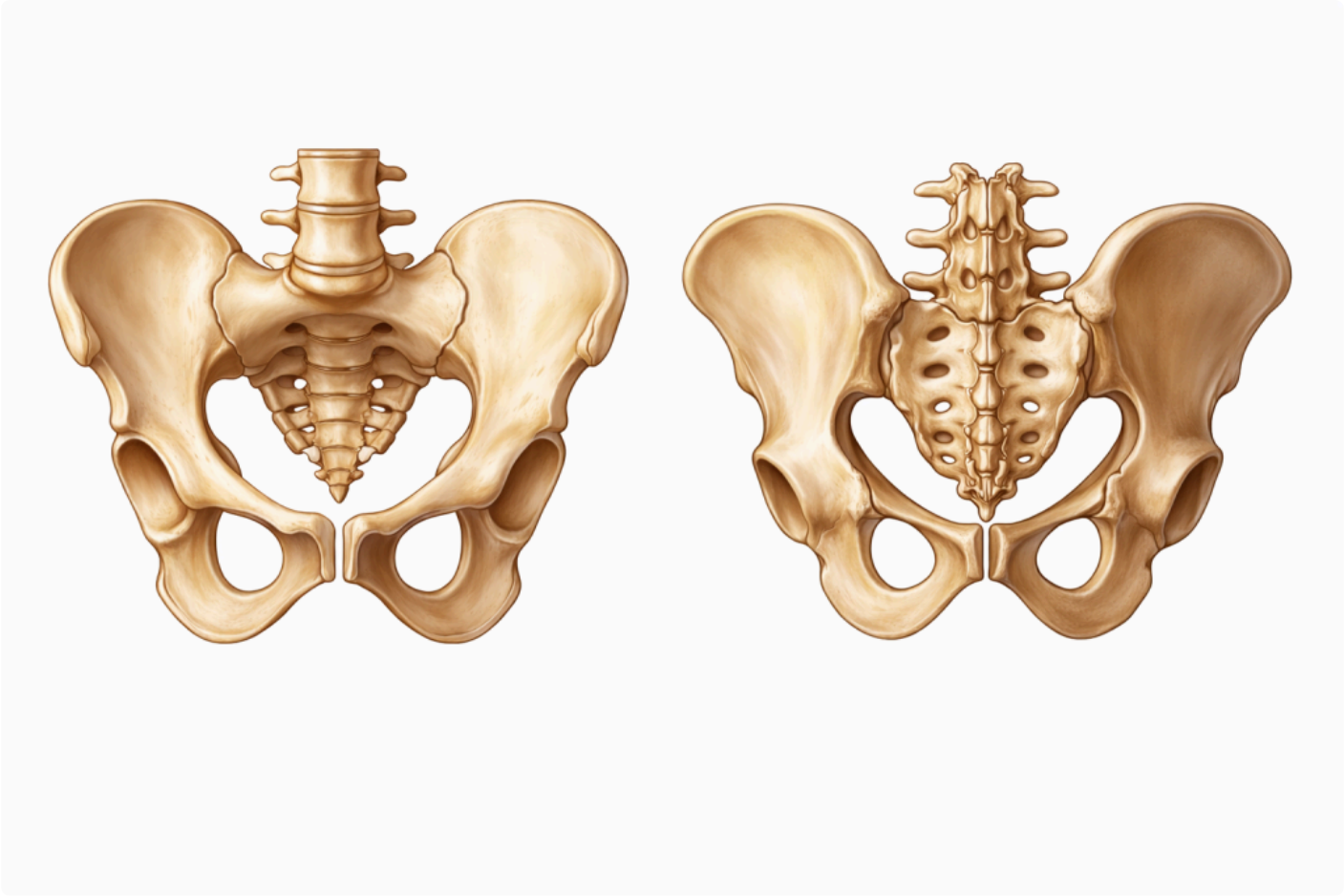


Figure 6.44 Bones of the Hip and Pelvis (Pelvic Girdle)

5. U.S. National Cancer Institute. (2014). *Pelvic_girdle_illustration* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Pelvic_girdle_illustration.svg

The **pelvis** refers to the entire structure formed by the hip bones, the sacrum, and the coccyx. See Figure 6.45[6] for an illustration of the pelvis.



6.45 Anterior (Left) and Posterior (Right) View of the Pelvis

The shape of the pelvis is different for males and females. In general, the bones of the male pelvis are thicker and heavier because they have adapted to support a male's typically heavier physical build. Because the female pelvis has adapted for childbirth, it is wider than the male pelvis. The shape and size of the pelvis can be used during forensic assessment to identify if skeletal remains are male or female. See Figure 6.46[7] for a comparison of the female and male pelvis.

6. OpenAI. (2026, January 10). *Anterior and posterior view of the pelvis* [Large language model prompt]. ChatGPT. chatgpt.com

7. OpenStax College. (2013). *809_Male_Female_Pelvic_Girdle* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:809_Male_Female_Pelvic_Girdle.jpg

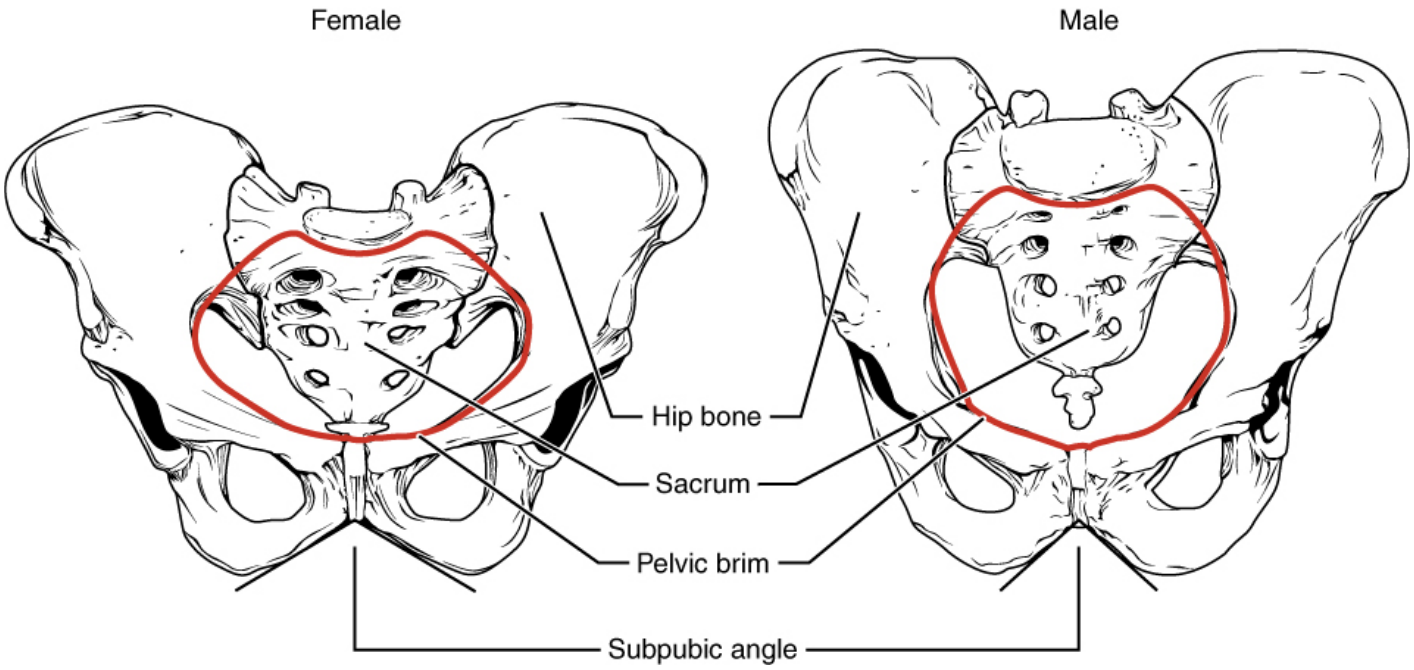


Figure 6.46 Comparison of the Female and Male Pelvis

See Table 6.5 for an overview of the differences between the female and male pelvis.

Table 6.5. Overview of Differences Between the Female and Male Pelvis[8]

Characteristic	Female Pelvis	Male Pelvis
Pelvic Weight	Bones of the pelvis are lighter and thinner	Bones of the pelvis are thicker and heavier
Pelvic Inlet Shape	Pelvic inlet has a round or oval shape	Pelvic inlet is heart-shaped
Subpubic Angle	Subpubic angle is greater than 80 degrees	Subpubic angle is less than 70 degrees
Pelvic Outlet Shape	Pelvic outlet is rounded and larger	Pelvic outlet is smaller

8. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Bones of the Lower Extremity

The bones of the lower extremity include the femur, patella, tibia, and fibula.

Femur

The femur, or thigh bone, is the single bone of the upper leg. It is the longest and strongest bone of the body and accounts for approximately one quarter of a person's total height.

Some landmarks of the proximal femur include the following:

- **Femoral head**: The rounded, proximal end is the head of the femur, which articulates with the acetabulum (hip socket) of the pelvis to form the hip joint.
- **Femoral neck**: The narrowed region below the head is the neck of the femur, which is a common area for fractures.
- **Linea aspera**: Longitudinally running bony ridge located in the middle third of the posterior femur.
- **Greater trochanter**: The greater trochanter is the large, upward, bony projection located above the base of the neck. The greater trochanter can be felt just under the skin on the lateral side of your upper thigh.
- **Lesser trochanter**: The lesser trochanter is a small, bony prominence that lies on the medial side of the femur, just below the neck.

Some landmarks of the distal femur include the following:

- **Lateral condyle**: The smooth surface that forms the distal and posterior sides of the lateral expansion of the distal femur.
- **Lateral epicondyle**: The rough area on the outer, lateral side of the lateral condyle.
- **Medial condyle**: The smooth, articulating surface that forms the distal and posterior sides of the medial expansion of the distal femur.
- **Medial epicondyle**: A roughened area of the distal femur located on the medial side of the medial condyle.
- **Patellar surface**: A smooth groove located on the anterior side of the distal femur between the medial and lateral condyles and is the site of articulation for the patella.

See Figure 6.47[9] for an illustration of the femur and its landmarks.

9. OpenStax College. (2013). *810_Femur_and_Patella* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:810_Femur_and_Patella.jpg

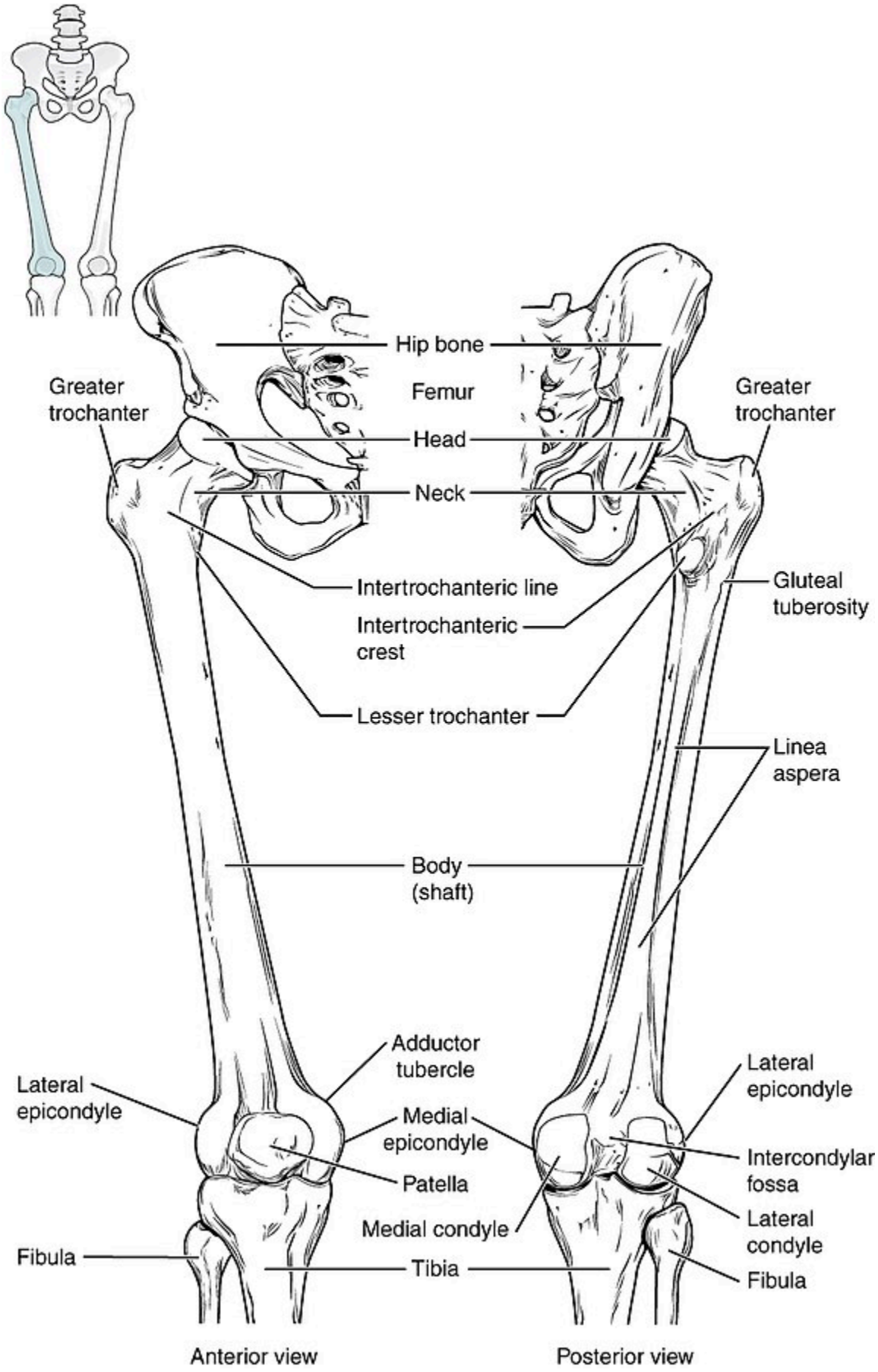


Figure 6.47 Femur and Its Landmarks

Patella

The **patella** is a small, sesamoid bone located in the anterior knee and commonly referred to as the kneecap.

Tibia

The tibia is the medial bone of the lower leg and is commonly called the shin bone. It is the main weight-bearing bone. The distal end of the tibia forms the **medial malleolus**, which forms the bony protrusion on the medial side of the ankle. The **tibial tuberosity** is an elevated area on the anterior side of the tibia, near its proximal end. It is the site of attachment for the muscle tendon associated with the patella. See Figure 6.48[10] for an anterior and posterior view.

Fibula

The fibula is the thinner, lateral bone of the lower leg. The distal end of the fibula forms the **lateral malleolus**, which forms the bony protrusion on the lateral side of the ankle. See Figure 6.48 for an anterior and posterior view.

10. OpenStax College. (2013). *811 Tibia and fibula* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:811_Tibia_and_fibula.jpg

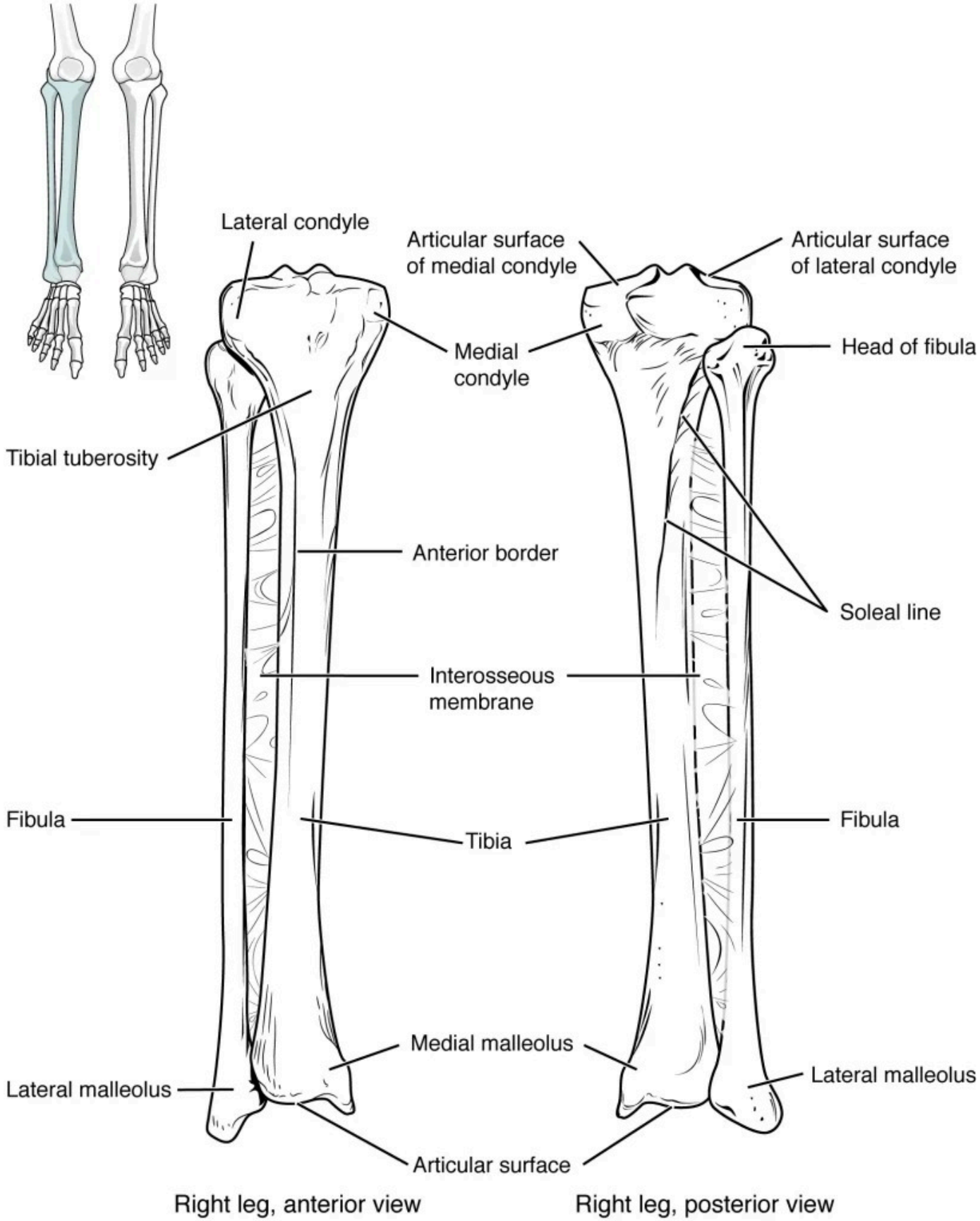


Figure 6.48 Right Tibia and Fibula, Anterior and Posterior View

Bones of the Ankles and Feet

The major bones of the ankles and feet include the tarsals, metatarsals, and phalanges:

- **Tarsals**: The tarsals are a group of seven bones in the posterior half of the foot. The tarsals include the calcaneus (heel bone), talus, navicular, medial (1st) cuneiform, intermediate (2nd) cuneiform, lateral (3rd) cuneiform, and cuboid bones.
- **Metatarsals**: A group of five bones found in the anterior half of the foot
- **Phalanges**: Group of 14 bones that make up the toes (and fingers). The **hallux** is the great toe. Like the fingers, the toes are composed of three bones called the distal phalanx, middle or intermediate phalanx, and proximal phalanx, with the exception of the great toe, which only has two bones, the distal and proximal phalanges.

See Figure 6.49[11] for an illustration of the bones of the ankles and feet.

11. OpenStax College. (2013). *812_Bones_of_the_Foot* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:812_Bones_of_the_Foot.jpg

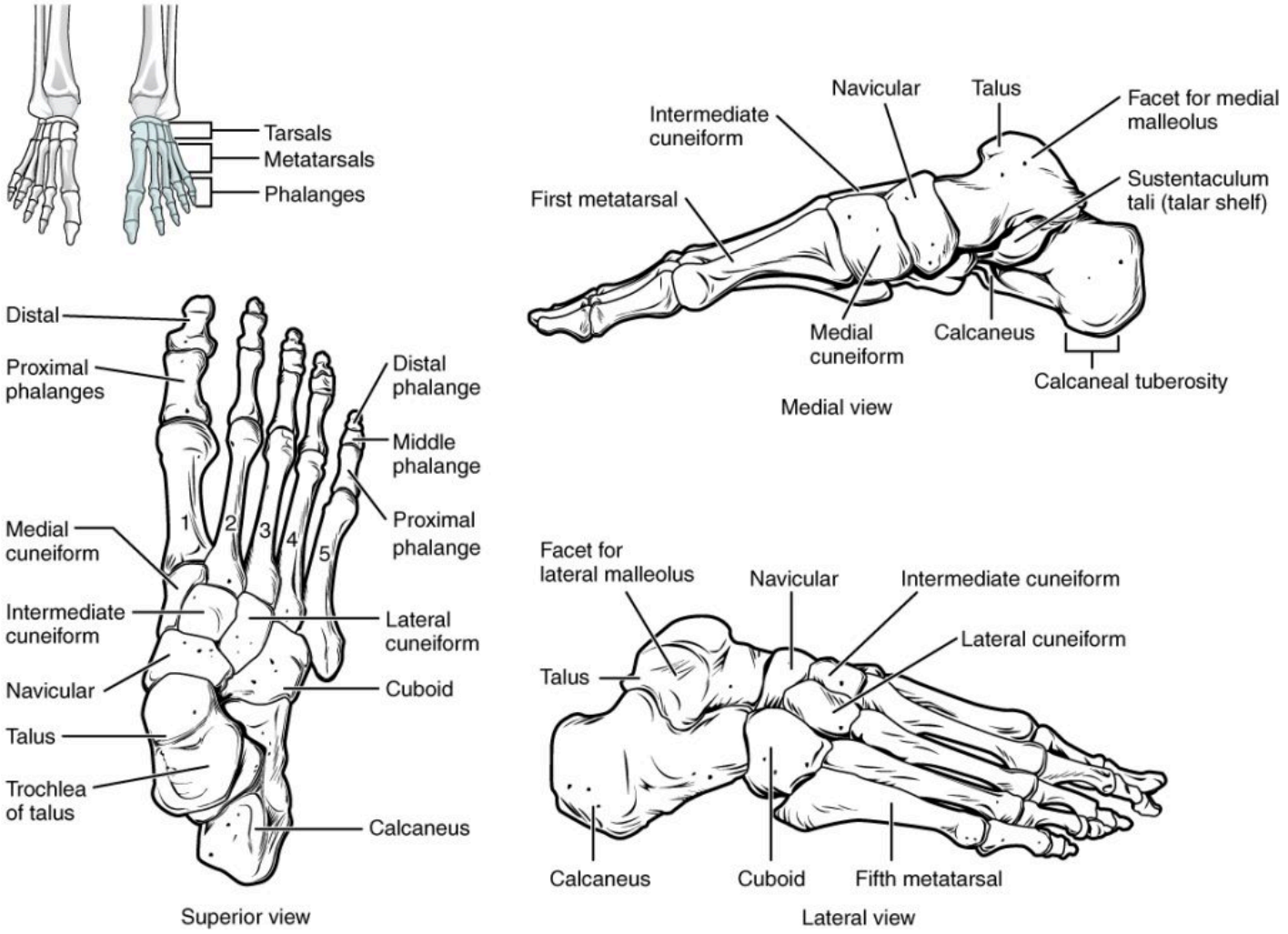


Figure 6.49 Bones of the Feet

6.6 Joints

Joints (also called articulations or arthroses) are where two bones, bone and cartilage, or bone and teeth, meet and connect together. The adult human body has 206 bones, and with the exception of the hyoid bone in the neck, each bone is connected to at least one other bone in the body.[1]

Many joints allow for movement between the bones. At these joints, the articulating surfaces can move smoothly against each other. However, the bones of other joints may be joined to each other by connective tissue or cartilage. These joints are designed for stability and provide for little or no movement. Joint stability and movement are inversely related characteristics. Stable joints allow for little or no movement, whereas joints that provide the most movement between bones are the least stable. Additionally, in stable joints, the articulating surfaces are strongly connected to each other. Understanding the relationship between joint structure and function helps explain why particular types of joints are found in certain areas of the body. Consider the following examples:

- Most of the joints of the skull are held together by fibrous connective tissue that does not allow for movement between the bones. This lack of mobility is important because the skull bones serve to protect the brain. Other joints connected by fibrous connective tissue allow for very little movement, which provides stability and weight-bearing support for the body. For example, the tibia and fibula of the leg are tightly connected to give stability to the body when standing.
- In other joints, the bones are held together by cartilage, which permits limited movements between the bones. For example, the joints of the vertebral column allow for small movements between vertebrae.
- Joints that allow for greater ranges of motion have articulating surfaces that are not directly connected to each other. Instead, these surfaces are enclosed within a space filled with lubricating fluid, which allows the bones to move smoothly against each other. These joints provide greater mobility, but because the bones are free to move in relation to each other, the joint is less stable. Most of the joints between the bones of the appendicular skeleton are freely movable joints.

1. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/

Video

Watch the video “Joints Explained (Types of Joints and Movement)” below to learn more about joint types and body movement.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Classification of Joints

Joints are classified both functionally and structurally.

Functional Classification

Functional classification describes the degree of movement between the bones, ranging from immobile, freely mobile, or immovable, slightly mobile, to freely moveable joints. The amount of movement in a particular joint is related to the functional requirements for that joint. Immobile or slightly movable joints serve to protect internal organs, give stability to the body, and allow for limited body movement. In contrast, freely movable joints allow for extensive movements of the body and limbs. There are three types of joints based on the amount of movement they allow: synarthrosis, amphiarthrosis, and diarthrosis, which are discussed in more detail in the following sections.

Synarthrosis

An immobile or nearly immobile joint is called a **synarthrosis**. Because they do not move, these joints provide for a strong connection between the articulating bones. This is important for locations where the bones provide protection for internal organs. An example of a synarthrosis is the skull sutures, where the cranial bones meet. See Figure 6.50[2] for an illustration of the suture joints of the skull that are an example of a synarthrosis.

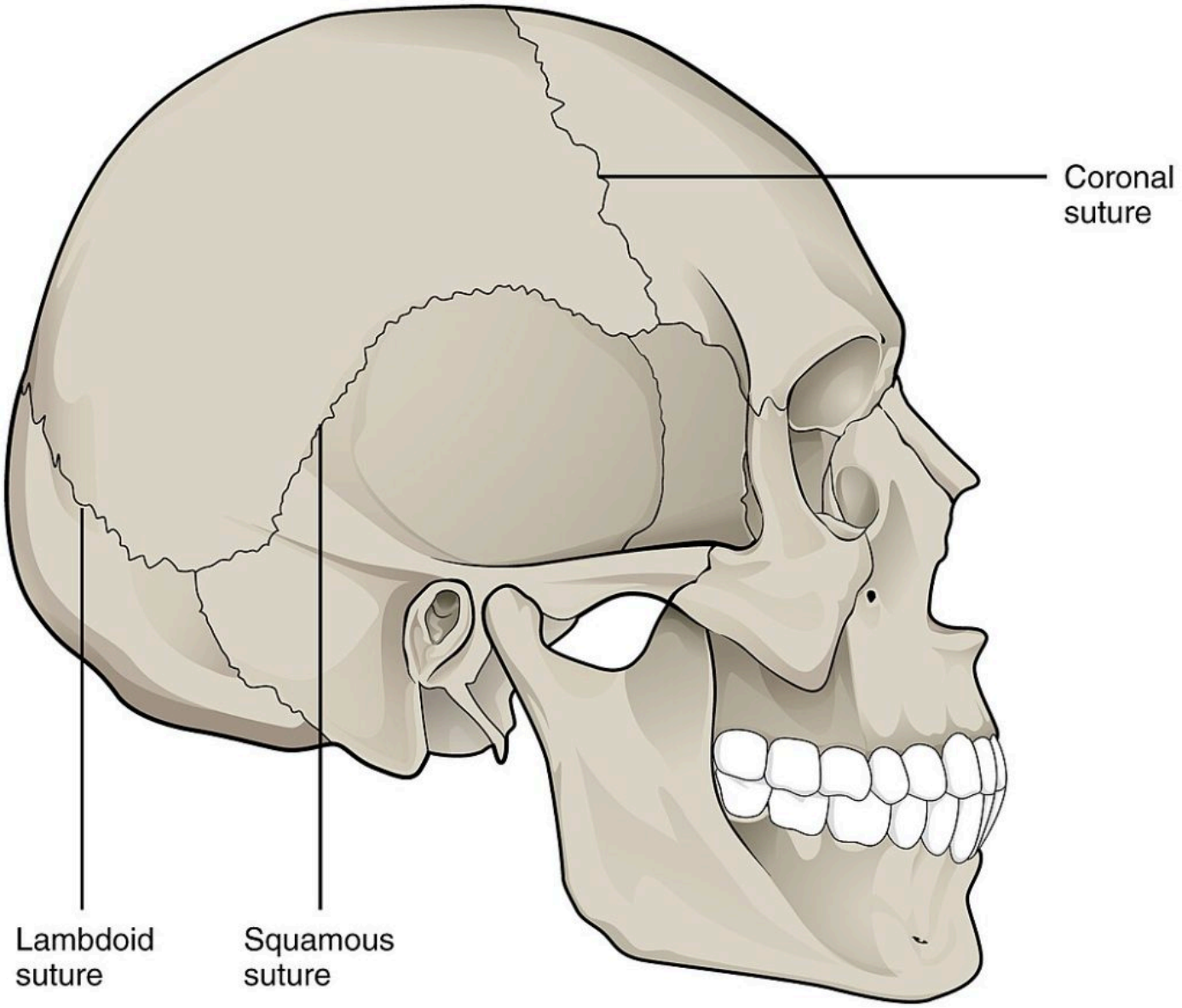


Figure 6.50 The Suture Joints of the Skull Are an Example of a Synarthrosis

2. OpenStax College. (2013). *901_Skull_Sutures* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:901_Skull_Sutures.jpg

Amphiarthrosis

An **amphiarthrosis** is a joint that has limited mobility. An example of a joint that is an amphiarthrosis is the intervertebral disc, a thick pad of fibrocartilage located between two vertebrae. See Figure 6.51[3] for an illustration of an intervertebral disc. Intervertebral discs connect the vertebrae together but still allow for a small amount of movement between them. Another example of an amphiarthrosis is the pubic symphysis of the pelvis. The right and left pubic bones are strongly anchored to each other by fibrocartilage that holds the front of the pelvis together. This joint has very little mobility. The strength of the pubic symphysis is important for weight-bearing stability of the pelvis.

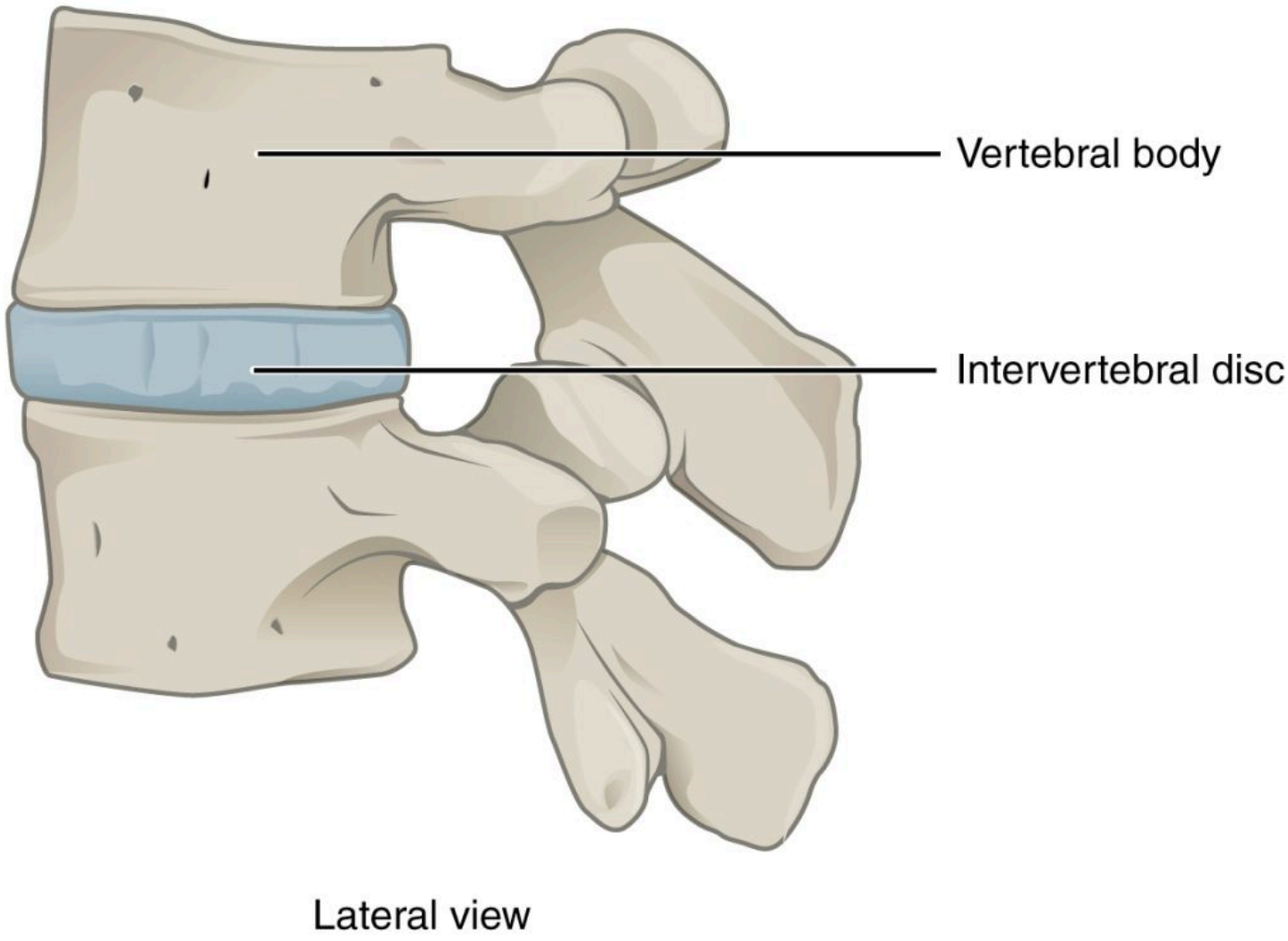


Figure 6.51 Intervertebral Discs Are Examples of an Amphiarthrosis

3. OpenStax College. (2013). *902_Intervertebral_disk-02* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:902_Intervertebral_Disk-02.jpg

Diarthrosis

A freely mobile joint is classified as a **diarthrosis**. Diarthroses include all synovial joints of the body that provide the majority of body movements. Synovial joints are discussed in the following subsection. Most diarthrosis joints are found in the appendicular skeleton and give the limbs a wide range of motion. Diarthroses are divided into three categories, based on the number of axes of motion provided by each. An axis in anatomy is described as the movements in reference to the three anatomical planes: transverse, frontal, and sagittal. Thus, diarthroses are classified by their range of movement: uniaxial (for movement in one plane), biaxial (for movement in two planes), or multiaxial joints (for movement in all three anatomical planes). See Figure 6.52[4] for an illustration of the hip joint, an example of a multiaxial diarthrosis.

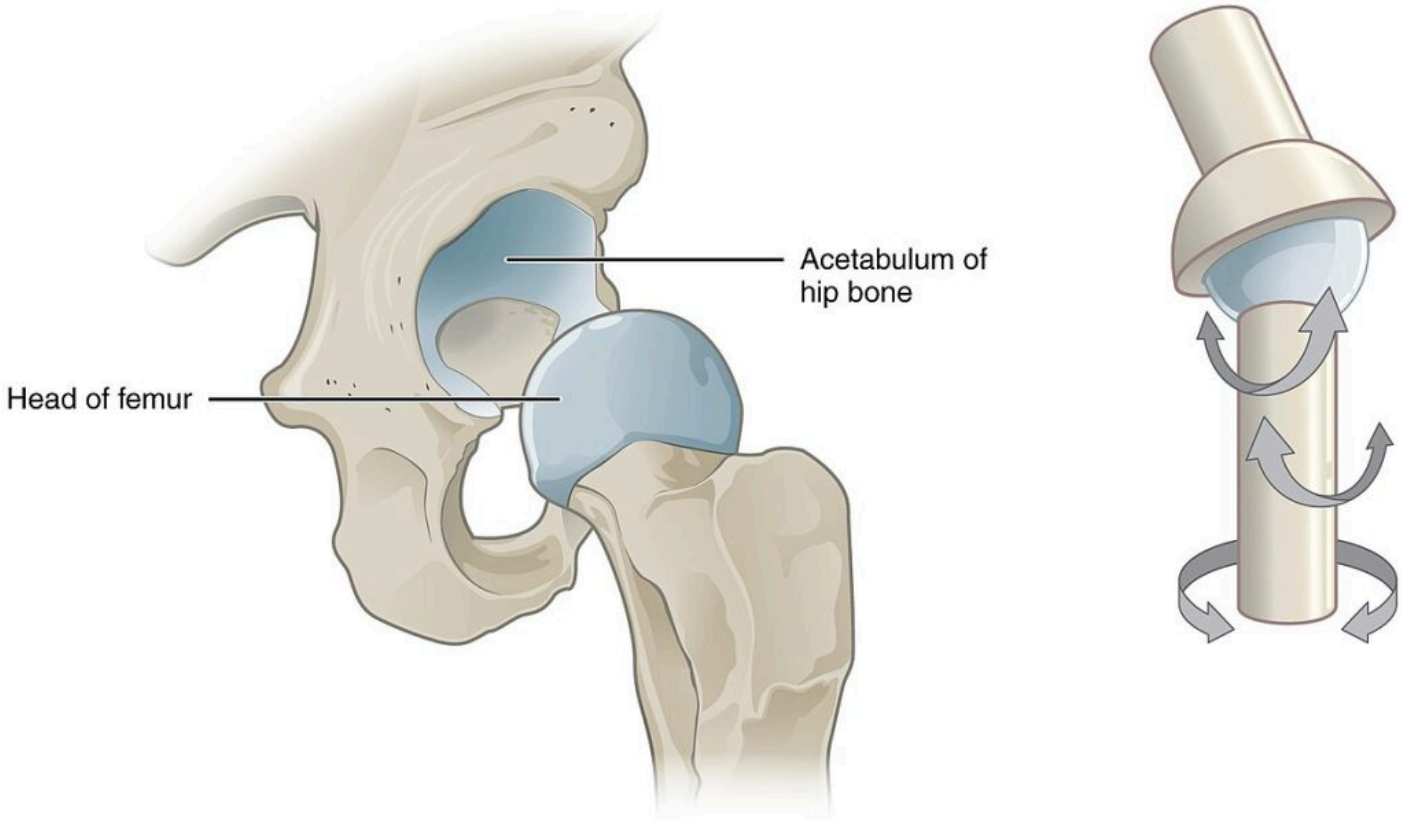


Figure 6.52 The Hip Joint Is a Multiaxial Diarthrosis

4. OpenStax College. (2013). *903_Multiaxial_Joint* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:903_Multiaxial_Joint.jpg

Structural Classification

Structural classification of joints considers how the bones are connected together. They may be connected with fibrous connective tissue, cartilage, or a fluid-filled space called a **joint cavity**. These differences divide the joints of the body into three different types: fibrous, cartilaginous, and synovial joints.

Fibrous Joint

In a**fibrous joint**, bones are held together by fibrous connective tissue. Fibrous joints are also called synarthroses, fixed or non-movable joints. There are three types of fibrous joints: suture, gomphosis, and syndesmosis.

- **Suture**: A suture is a narrow fibrous joint found between most bones of the skull. Examples include the coronal suture, squamous suture, and lambdoid suture.
- **Syndesmosis**: A syndesmosis is a joint held together by a ligament, a type of connective tissue that connects bones together. A syndesmosis connects the radius and ulna of the lower arm together. Another example is the syndesmosis that joins the tibia and fibula of the lower leg.
- **Gomphosis**: A gomphosis is a narrow fibrous joint between the roots of a tooth and the bony socket in the jawbone into which the tooth fits.

  See Figure 6.53[5] for an illustration of the types of fibrous joints.

5. OpenStax College. (2013). *904_Fibrous_Joints* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:904_Fibrous_Joints.jpg

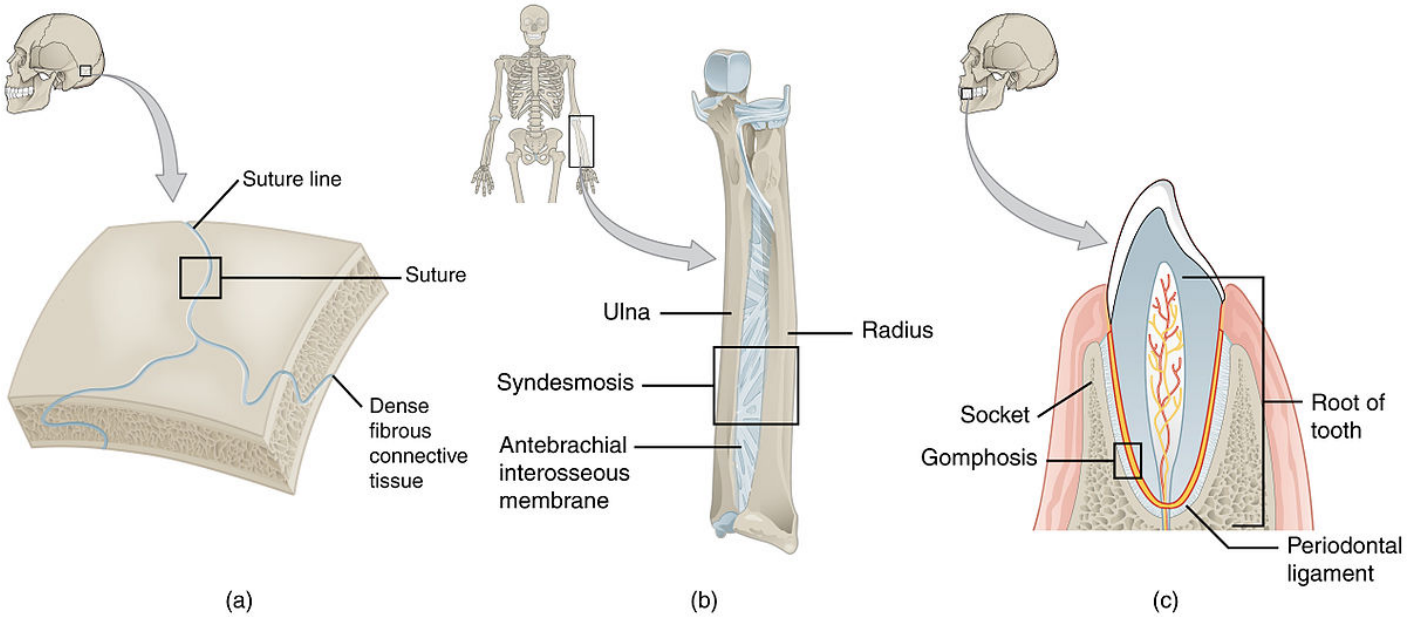


Figure 6.53 Fibrous Joints: (a) Sutures in the Skull, (b) Syndesmosis Between the Radius and Ulna Bones, and (c) a Gomphosis Anchors a Tooth to Its Socket in the Jaw

Cartilaginous Joint

In a **cartilaginous joint**, bones are joined by **cartilage**, a tough but flexible type of connective tissue (either hyaline cartilage or fibrocartilage). Cartilaginous joints are also called amphiarthroses or slightly movable joints. Examples of cartilaginous joints include the pubic symphysis and intervertebral discs. See Figure 6.54[6] for an illustration of cartilaginous joints.

6. OpenStax College. (2013). *906_Cartiliginous_Joints* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:906_Cartiliginous_Joints.jpg

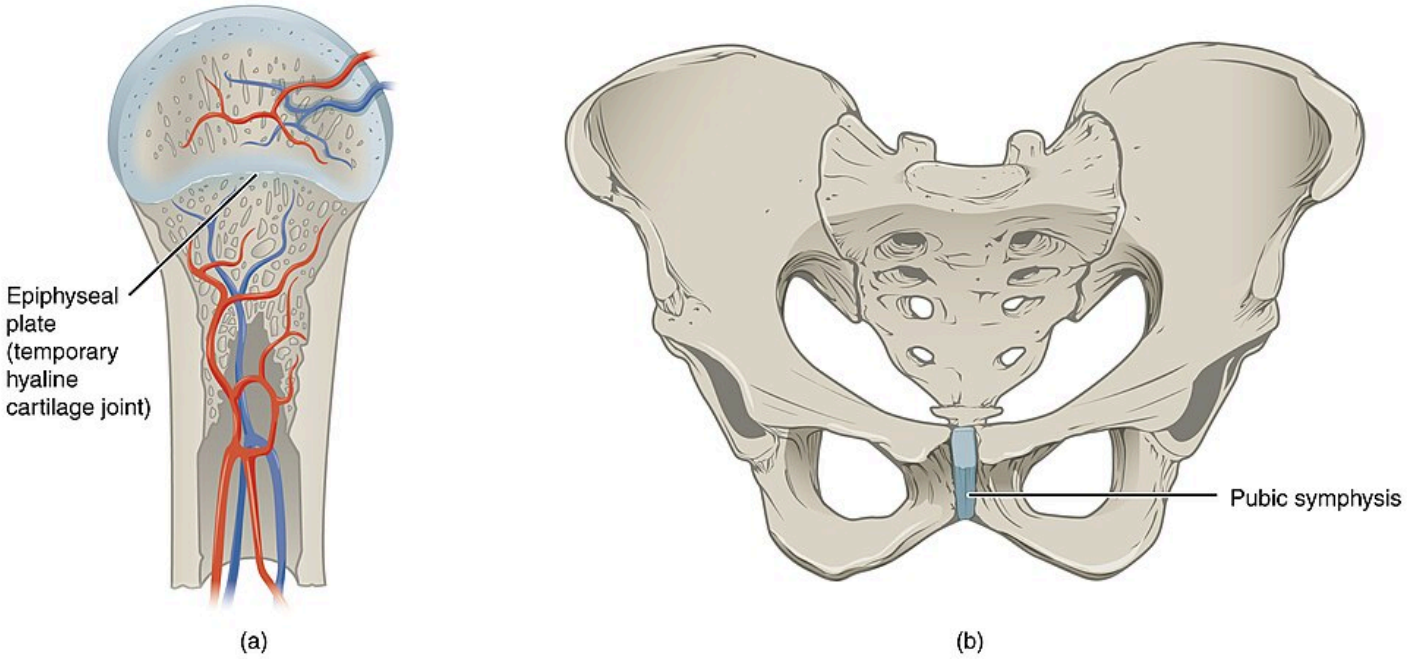


Figure 6.54 Cartilaginous Joints: (a) Epiphyseal Plate and (b) Pubic Symphysis

Synovial Joint

In a **synovial joint**, the bones are not directly connected but instead come together within a joint cavity filled with a lubricating fluid called **synovial fluid**. The joint cavity is enclosed by the articular or joint capsule. The articular capsule consists of an outer fibrous layer and an inner synovial membrane. The **synovial membrane** secretes synovial fluid, which is a thick, slippery fluid that provides lubrication to reduce friction between the bones of the joint. This fluid also acts as a shock absorber and provides nourishment to the **articular cartilage** that does not contain blood vessels. Friction between the bones at a synovial joint is also prevented by the presence of articular cartilage on the ends of the bones, allowing the articulating bones to move smoothly past each other without damaging the underlying bone tissue. Synovial joints allow for free movement between bones and are the most common joints of the body. See Figure 6.55[7] for an illustration of a synovial joint.

Outside of their articulating surfaces, bones are connected together by **ligaments**, which are strong bands of fibrous connective tissue. These strengthen and support the joint by anchoring the bones together and preventing their separation. Ligaments allow

7. OpenStax College. (2013). *907_Synovial_Joints* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:907_Synovial_Joints.jpg

for normal movements at a joint, but limit the range of these motions, thus preventing excessive or abnormal joint movements.

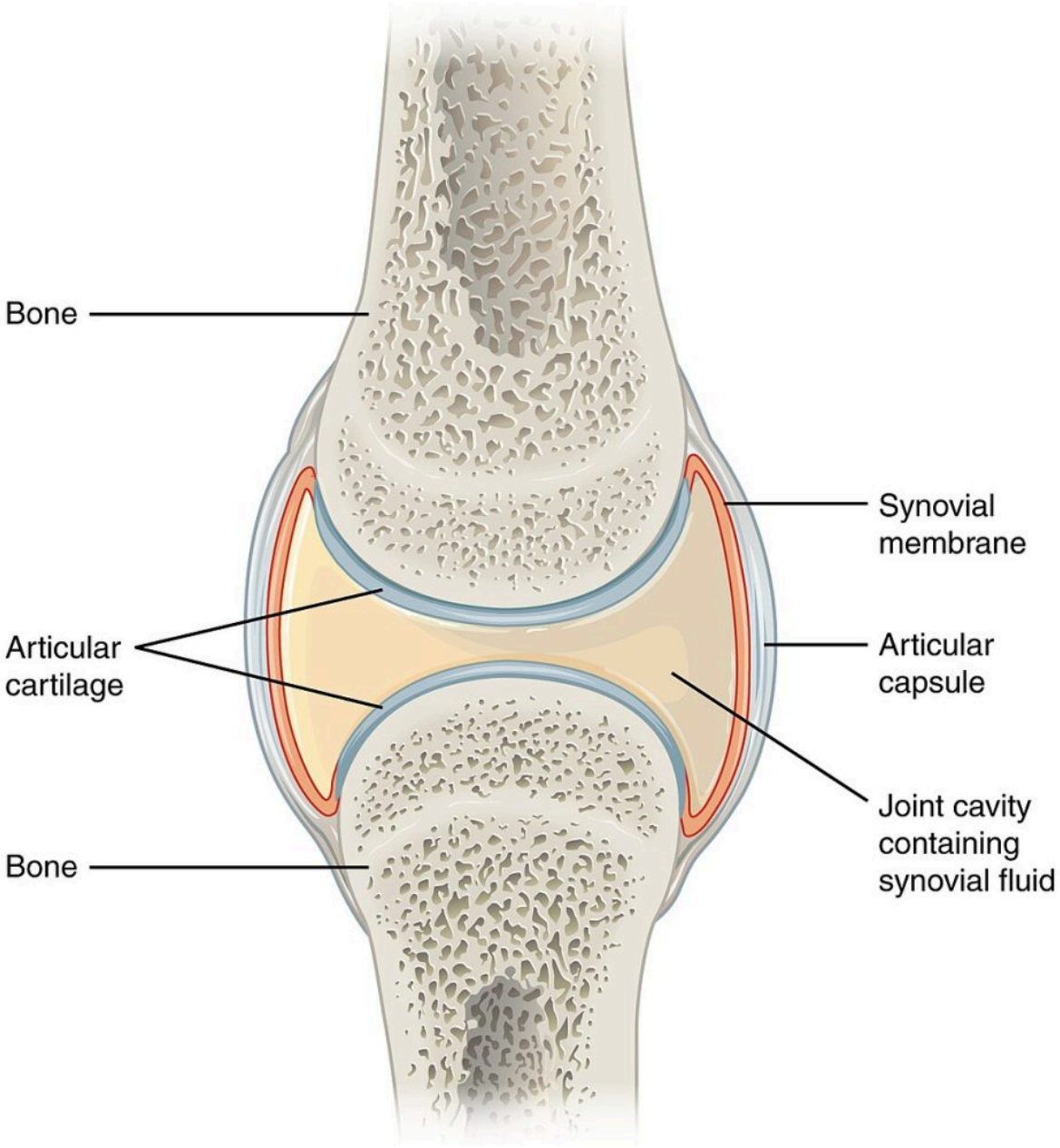


Figure 6.55 Synovial Joints

Types of Synovial Joints

Synovial joints are subdivided based on the shapes of the articulating surfaces of the bones that form each joint. The six types of synovial joints are pivot, hinge, condyloid, saddle, plane, and ball-and-socket joints:

- **Ball and Socket**: Synovial joint formed between the spherical end (ball) of one bone that fits into a cuplike depression (socket) of a second bone. The hip and shoulder joints are ball-and-socket joints.
- **Hinge**: Synovial joint formed by the convex surface of one bone meeting with the concave surface of a second bone. Hinge joints include the elbow, knee, and interphalangeal joints.
- **Saddle**: Synovial joint in which the ends of the bones have a saddle shape, which is concave in one direction and convex in the other. This allows the two bones to fit together like a rider sitting on a saddle. The joint at the base of the thumb is a saddle joint.
- **Plane**: Synovial joint formed between the flattened surfaces of two bones. The joints between the tarsals of the foot are an example of plane joints.
- **Pivot**: Synovial joint where the rounded portion of a bone rotates within a ring formed by a ligament and a bone. The joint between the atlas (C1) and the axis (C2) is an example of a pivot joint.
- **Condyloid**: Synovial joint formed by the shallow depression at the end of one bone receiving a rounded end from an adjacent bone or bones. They are found at the metacarpophalangeal joints of the fingers or the radiocarpal joint of the wrist. This joint is also known as an ellipsoid joint.

  See 6.56[8] for an illustration of the different types of synovial joints.

8. OpenStax College. (2013). *909_Types_of_Synovial_Joints* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:909_Types_of_Synovial_Joints.jpg

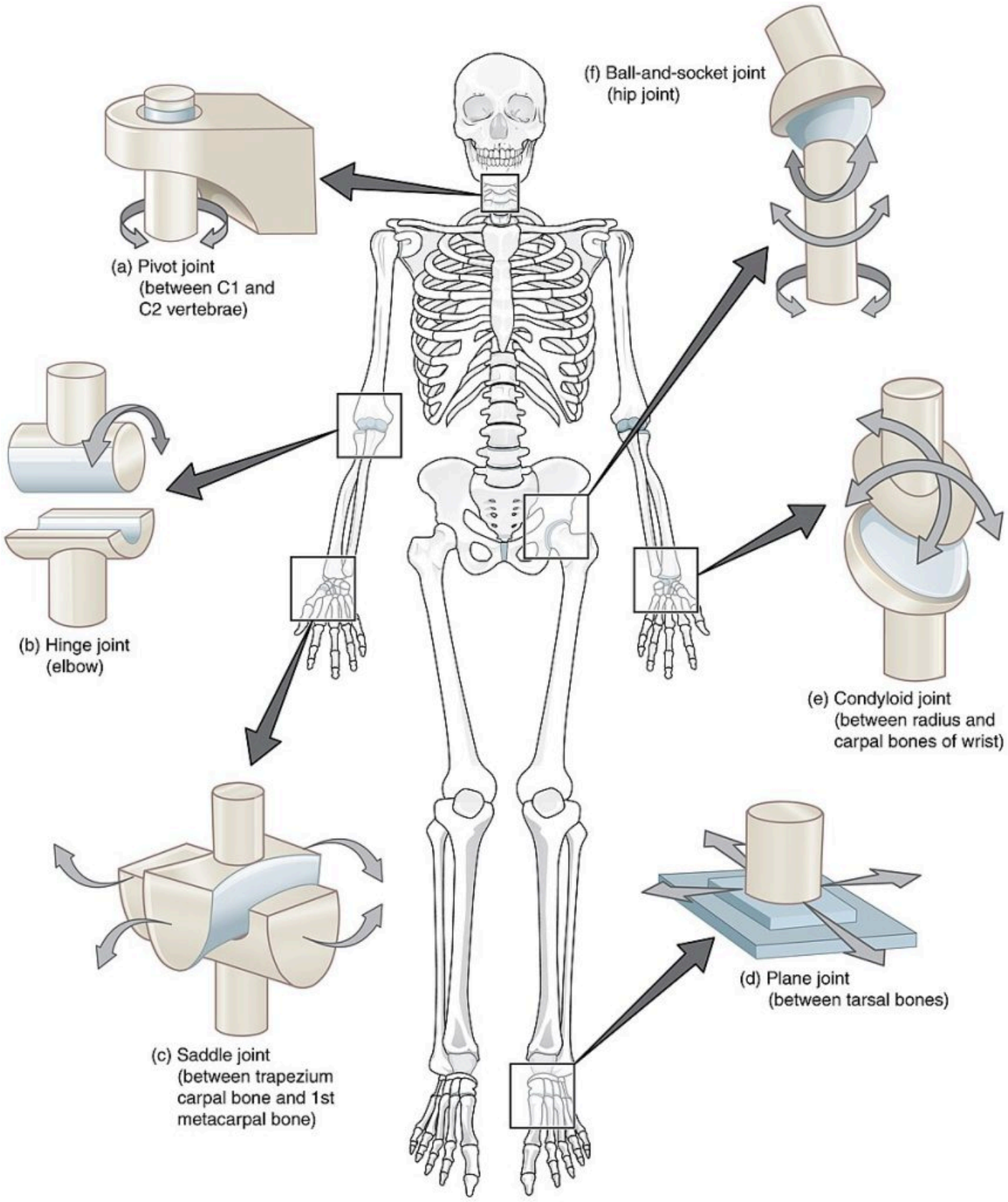


Figure 6.56 Types of Synovial Joints

Read more about movements at joints caused by the contraction of muscles in the "**Skeletal Muscle**" section of the "Muscular System" chapter.

Other Features of Synovial Joints

A few synovial joints of the body have a fibrocartilage structure located between the bones called an articular disc or meniscus. **Articular discs** are generally small and oval-shaped whereas a **meniscus** is larger and C-shaped. For example, the knee connects the femur (upper leg bone) to the tibia (one of the lower leg bones) with a meniscus and will be discussed in detail below.

In addition to the meniscus, the knee also contains ligaments, tendons, and additional cartilage. Ligaments in the knee include the **anterior cruciate ligament (ACL)**, **lateral collateral ligament (LCL)**, **medial collateral ligament (MCL)**, and **posterior cruciate ligament (PCL)**. See Figure 6.57[9] for an illustration of these structures in the knee joint.

9. Mysid. (2011). *Knee_diagram* [Diagram]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Knee_diagram.svg

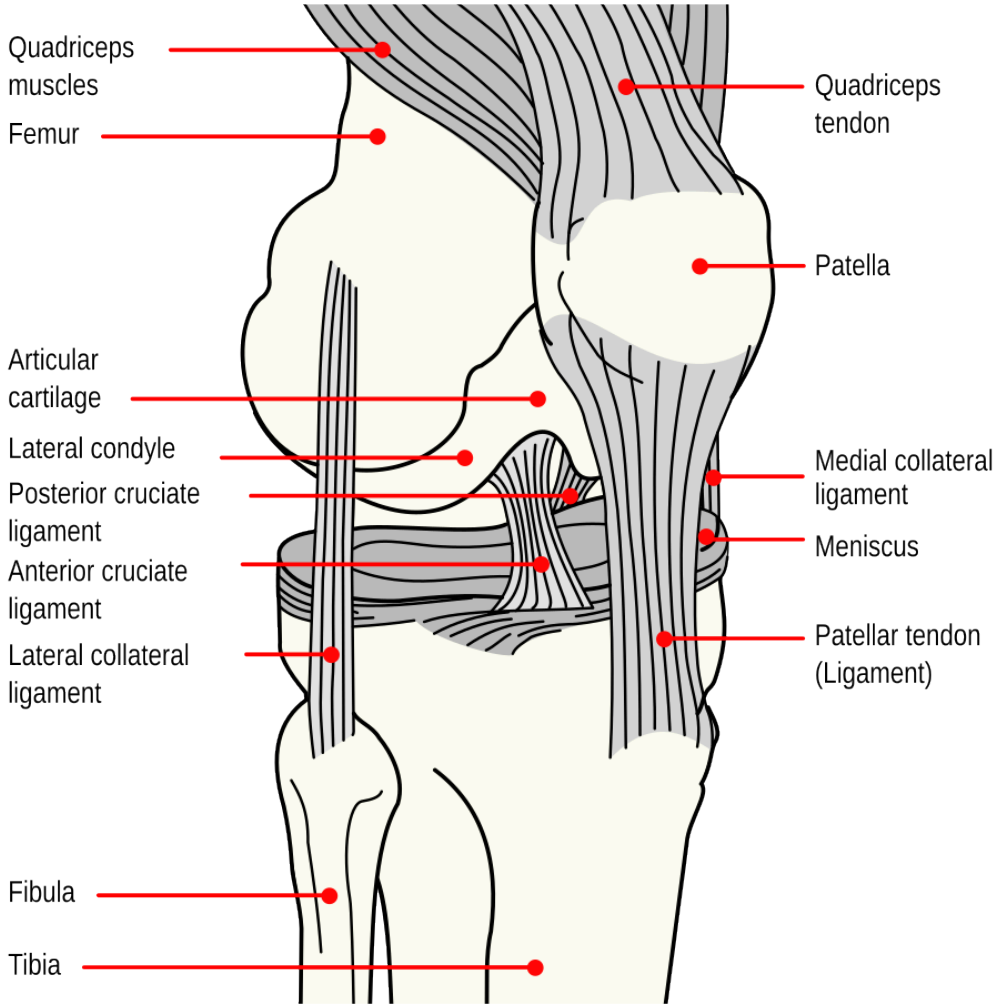


Figure 6.57 The Knee Joint Contains Ligaments, Tendons, Cartilage, and a Meniscus

Another structure found superficial to a synovial joint is a bursa. A **bursa** is a thin connective tissue sac filled with fluid, and they are typically found in areas where skin, ligaments, muscles, or tendons rub against each other. Bursae are classified by their location. For example, a subcutaneous bursa is located between the skin and an underlying bone and allows the skin to move smoothly over the bone. Examples of subcutaneous bursae are the suprapatellar bursa, prepatellar bursa, and infrapatellar bursa located in the knee, as seen in Figure 6.58.[10]

10. OpenStax College. (2013). *908_Bursa* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:908_Bursa.jpg

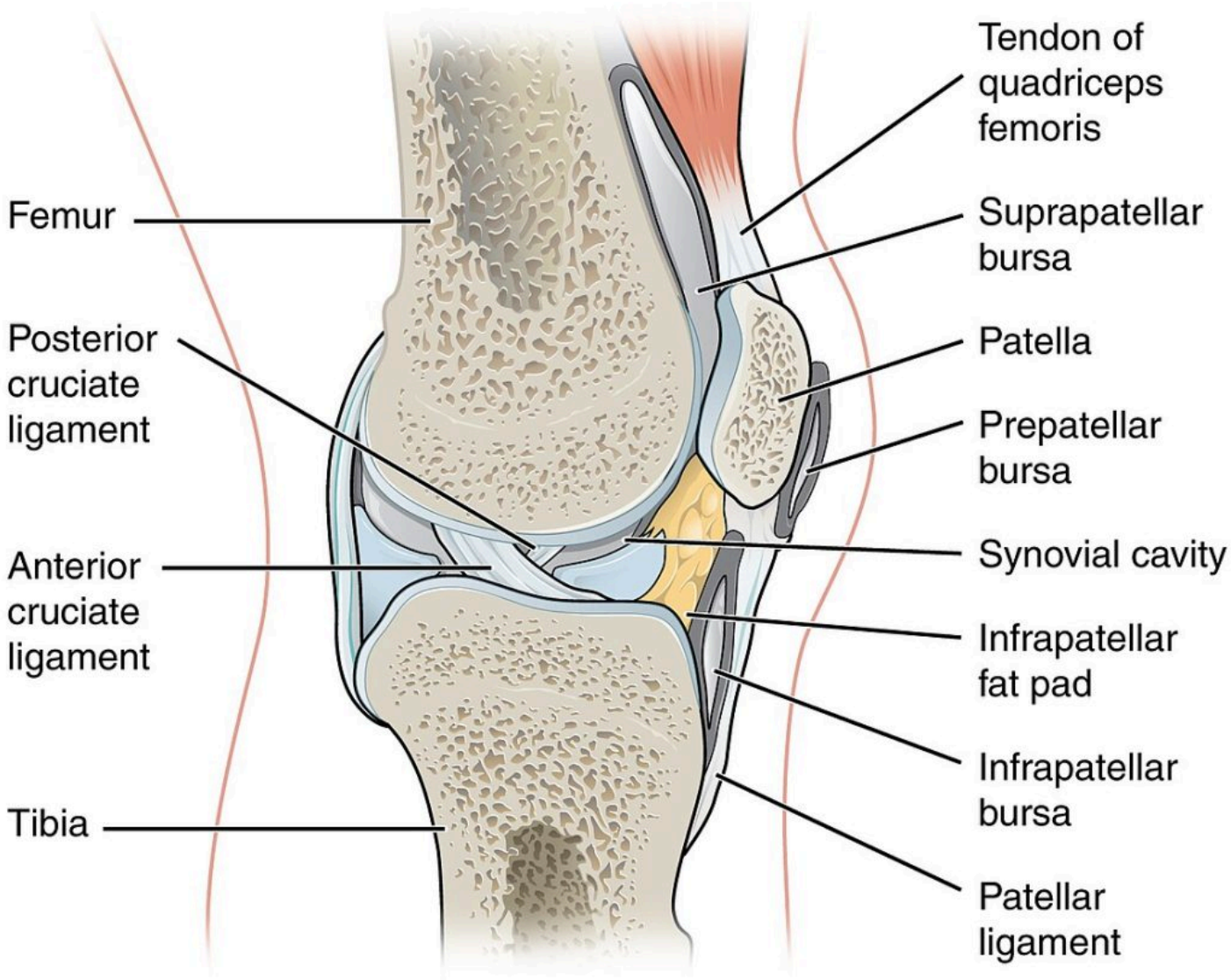


Figure 6.58 Bursa in the Knee

Video

*]:pointer-events-auto [content-visibility:auto] supports-[content-visibility:auto]:[contain-intrinsic-size:auto_100lvh] R6Vx5W_threadScrollVars scroll-mb-[calc(var(--scroll-root-safe-area-inset-bottom,0px)+var(--thread-response-height))] scroll-mt-[calc(var(--header-height)+min(200px,max(70px,20svh)))]" dir="auto" data-turn-id="request-69f3891f-cad4-8328-be35-d4d3dbd28b71-40" data-testid="conversation-turn-72" data-scroll-anchor="false" data-turn="assistant">

Watch the video “Joints: Crash Course Anatomy & Physiology #20” below to learn about the different types of joints in the body and how they allow for movement and flexibility.[11]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

11. CrashCourse. (2015, May 26). *Joints: Crash Course Anatomy & Physiology #20* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=DLxYDoN634c

6.7 Skeletal System Disorders

Arthritis

Arthritis is a general term related to inflammation of a joint. This common disorder often results in significant joint pain, along with swelling, stiffness, and reduced joint mobility. There are more than 100 different forms of arthritis. Arthritis may arise from aging, damage to the articular cartilage, autoimmune diseases, bacterial or viral infections, or unknown (probably genetic) causes. The most common type of arthritis is osteoarthritis, caused by wear and tear on the joint due to aging. Read more about this condition below in the "Osteoarthritis" subsection. A second type of arthritis is rheumatoid arthritis, caused by an autoimmune disease. Read more about this condition below in the "Rheumatoid Arthritis" subsection. Gout is a third common type of arthritis, caused by the deposit of uric acid crystals in a joint. Read more about this condition in the "Gout" subsection below.

See Figure 6.59[1] for an illustration comparing a normal joint with osteoarthritis and rheumatoid arthritis.

1. Laboratoires Servier. (2019). *Osteoarthritis_and_rheumatoid_arthritis_-_Normal_joint_Osteoarthr_–_Smart-Servier* [Diagram]. Wikimedia Commons. CC BY-SA 3.0.

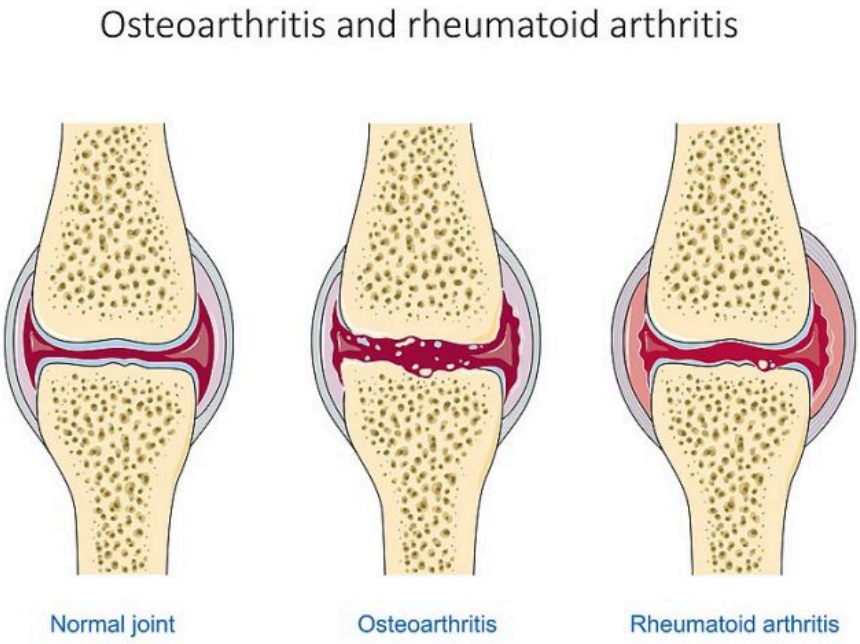


Figure 6.59 Osteoarthritis and Rheumatoid Arthritis

Bursitis

Bursitis is the inflammation of a bursa near a joint. It can cause pain, swelling, tenderness, and joint stiffness. Bursitis is commonly associated with the bursae in the shoulder, hip, knee, or elbow joints. Bursitis can be either acute (lasting only a few days) or chronic. It can arise from muscle overuse, trauma, excessive or prolonged pressure on the skin, rheumatoid arthritis, gout, or infection of the joint. Repeated acute episodes of bursitis can result in a chronic condition. Treatments for the disorder include antibiotics if the bursitis is caused by an infection or anti-inflammatory agents, such as nonsteroidal anti-inflammatory drugs (NSAIDs) or corticosteroids, if the bursitis is due to trauma or overuse. Chronic bursitis may require that fluid be drained, but additional surgery is usually not required. See Figure 6.60[2] for an image of bursitis.

2. NJC123. (2007). *Bursitis_Elbow_WCArrow* [Photograph]. Wikimedia Commons. CC0, Public domain. https://commons.wikimedia.org/wiki/File:Bursitis_Elbow_WCArrow.jpg

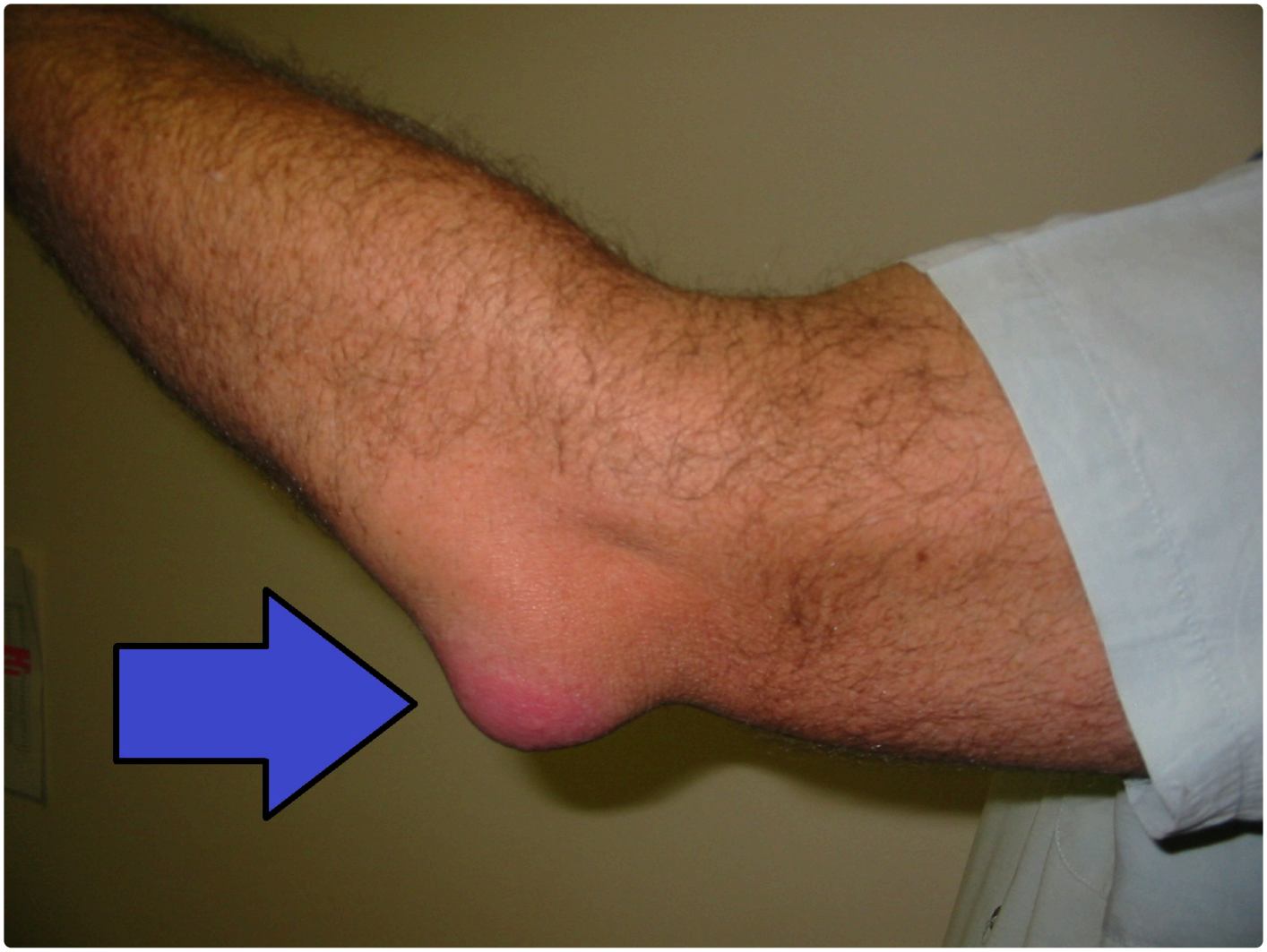


Figure 6.60 Bursitis

Dislocation

A **dislocation** (or luxation) is an injury that forces the bones in a joint out of position. The cause is usually a fall, a car accident, or an injury during contact sports. Dislocation mostly involves the body's larger joints. The most common site of dislocation is the shoulder. For young children, the elbow is a common site. Smaller joints, such as the thumbs and fingers, can also be dislocated if bent the wrong way with force. Dislocation may cause sudden and severe pain and swelling. It requires prompt medical attention to move the bones back in place.[3]

3. Mayo Clinic. (2024). *Dislocation: First aid*. https://www.mayoclinic.org/first-aid/first-aid-dislocation/basics/art-20056693

Subluxation is a partial dislocation of a bone. See Figure 6.61[4] for an illustration of subluxation in the elbow.

4. InjuryMap. (2023). *Elbow_subluxation_2* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Elbow_subluxation_2.svg

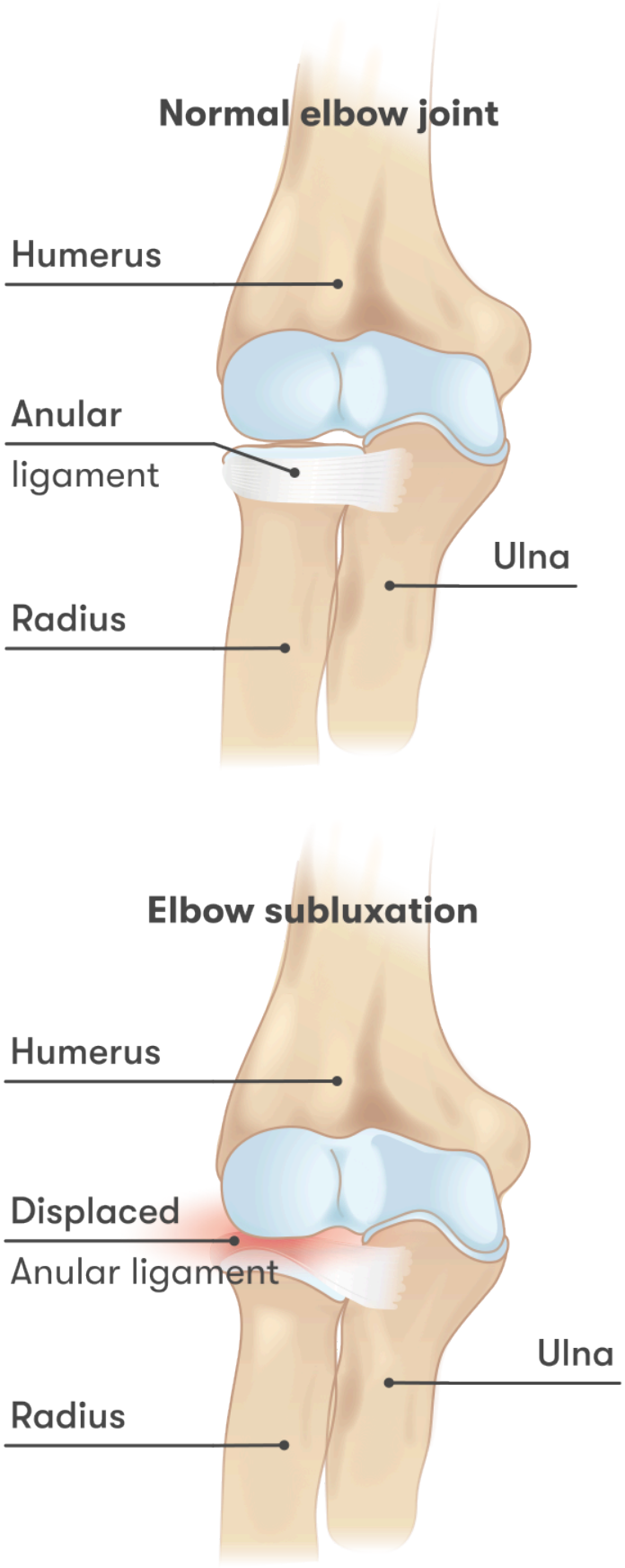


Figure 6.61 Normal Elbow Joint and Elbow Subluxation

Gout

Gout is a form of arthritis caused when uric acid crystals (a waste product from nucleic acid breakdown) are deposited in a body joint. Usually, only one or a few joints are affected, such as the big toe, knee, or ankle. The attack may only last a few days, but may return to the same or a different joint. Gout occurs when the body makes too much uric acid, or the kidneys do not remove it properly. A diet with excessive fructose (a simple sugar) has been shown to increase the chances of developing gout in some people. See Figure 6.62[5] for an illustration of gout.



Figure 6.62 Gout

Herniated Disc

A **herniated disc** is a condition in which an intervertebral disc protrudes beyond the normal limits of the vertebrae and puts pressure on a spinal nerve, causing pain. The

5. ScientificAnimations.com. (2019). *Gout_Signs_and_Symptoms* [Image]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Gout_Signs_and_Symptoms.jpg

most common sites for disc herniation are the L4/L5 or L5/S1 intervertebral discs, which can cause sciatica. A herniated disc is also known as a ruptured or slipped disc. View supplementary videos in the following box to learn more about herniated discs and their treatment. See Figure 6.63[6] for an illustration of a herniated disc.

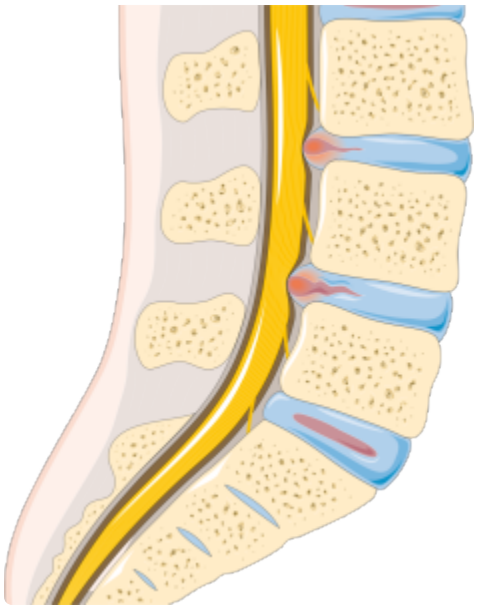


Figure 6.63 Herniated Disc

Multiple Myeloma

Multiple myeloma is a cancer of the white blood cells that causes them to overgrow and crowd out normal cells in the bone marrow that make red blood cells, platelets, and other white blood cells. Advanced symptoms of multiple myeloma often include severe bone pain, especially in the back or ribs, and multiple fractures.[7]

Osteoarthritis

The most common type of arthritis is **osteoarthritis**, which is associated with aging

6. Smart Servier. (2019). *Disc_herniation_–_Smart-Servier* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Disc_herniation_–_Smart-Servier.png

7. Centers for Disease Control and Prevention. (2025). *Myeloma basics.* https://www.cdc.gov/myeloma/about/index.html

and “wear and tear” of the articular cartilage. Risk factors that may lead to osteoarthritis later in life include injury to a joint, jobs that involve physical labor, sports with twisting or throwing actions, and being overweight. These factors put stress on the articular cartilage that covers the surfaces of bones at synovial joints, causing the cartilage to gradually become thinner. As the articular cartilage layer wears down, more pressure is placed on the bones. The joint responds by increasing production of the lubricating synovial fluid, but this can lead to swelling of the joint cavity, causing pain and joint stiffness as the articular capsule is stretched. The bone tissue underlying the damaged articular cartilage also responds by thickening, producing irregularities, and causing the articulating surfaces of the bones to become rough or bumpy. Joint movement then results in pain and inflammation. In its early stages, symptoms of osteoarthritis may be reduced by mild activity that “warms up” the joint, but the symptoms may worsen following exercise. In individuals with more advanced osteoarthritis, the affected joints can become more painful and, therefore, are difficult to use effectively, resulting in decreased mobility. There is no cure for osteoarthritis, but several treatments can help alleviate the pain. Treatments may include lifestyle changes, such as weight loss and low-impact exercise, and over-the-counter or prescription medications that help to alleviate the pain and inflammation. For severe cases, joint replacement surgery (arthroplasty) may be required. See Figure 6.64[8] for an illustration comparing a normal hip joint to one with osteoarthritis.

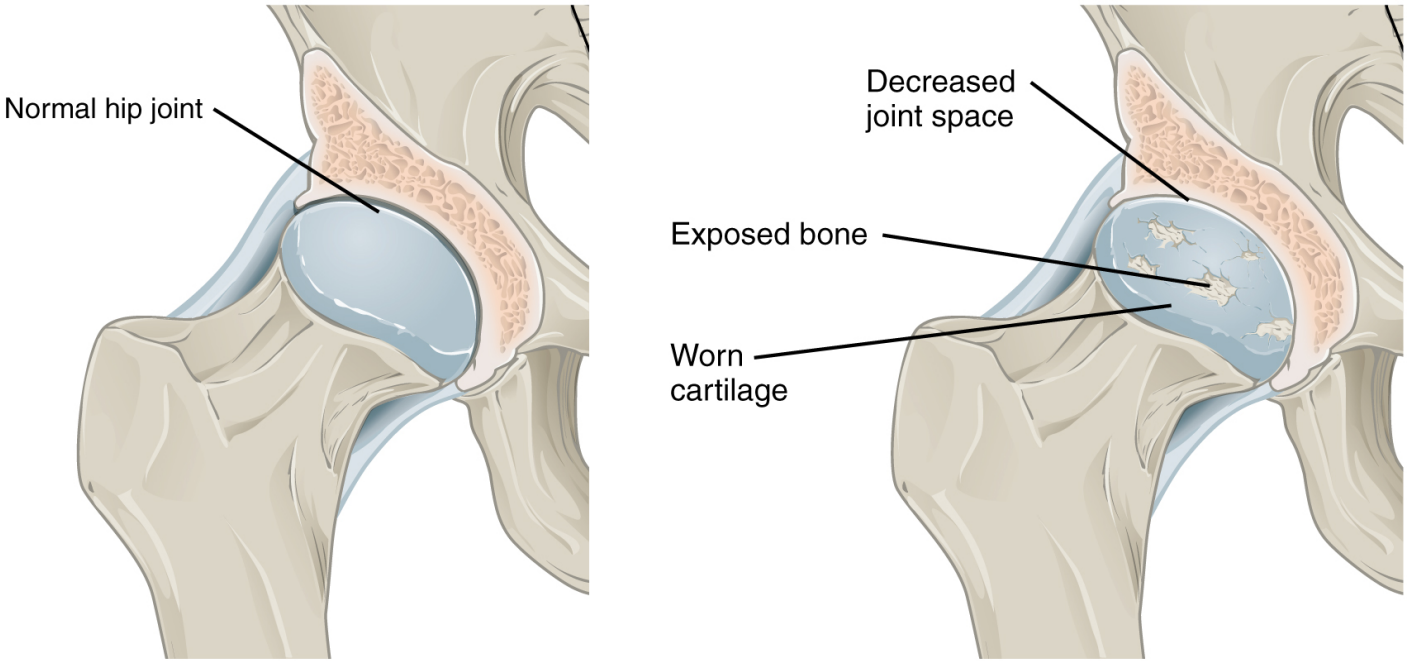


Figure 6.64 Osteoarthritis

8. OpenStax College. (2016). *Osteoarthritis* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:0910_Oateoarthritis_Hip.jpg

Osteomalacia and Rickets

Osteomalacia is the softening of the bones due to a lack of mineralization with calcium and phosphate, and most often caused by a lack of vitamin D. In children, osteomalacia is termed **rickets**.[9] See Figure 6.65[10] for an image of a child with rickets before and after treatment.

9. Mayo Clinic. (2021). *Rickets.* https://www.mayoclinic.org/diseases-conditions/rickets/symptoms-causes/syc-20351943

10. Wellcome Trust. (n.d.). *Before and after photographs for therapy for rickets* [Photograph]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Before_and_after_photographs_for_therapy_for_rickets_Wellcome_L0074524.jpg

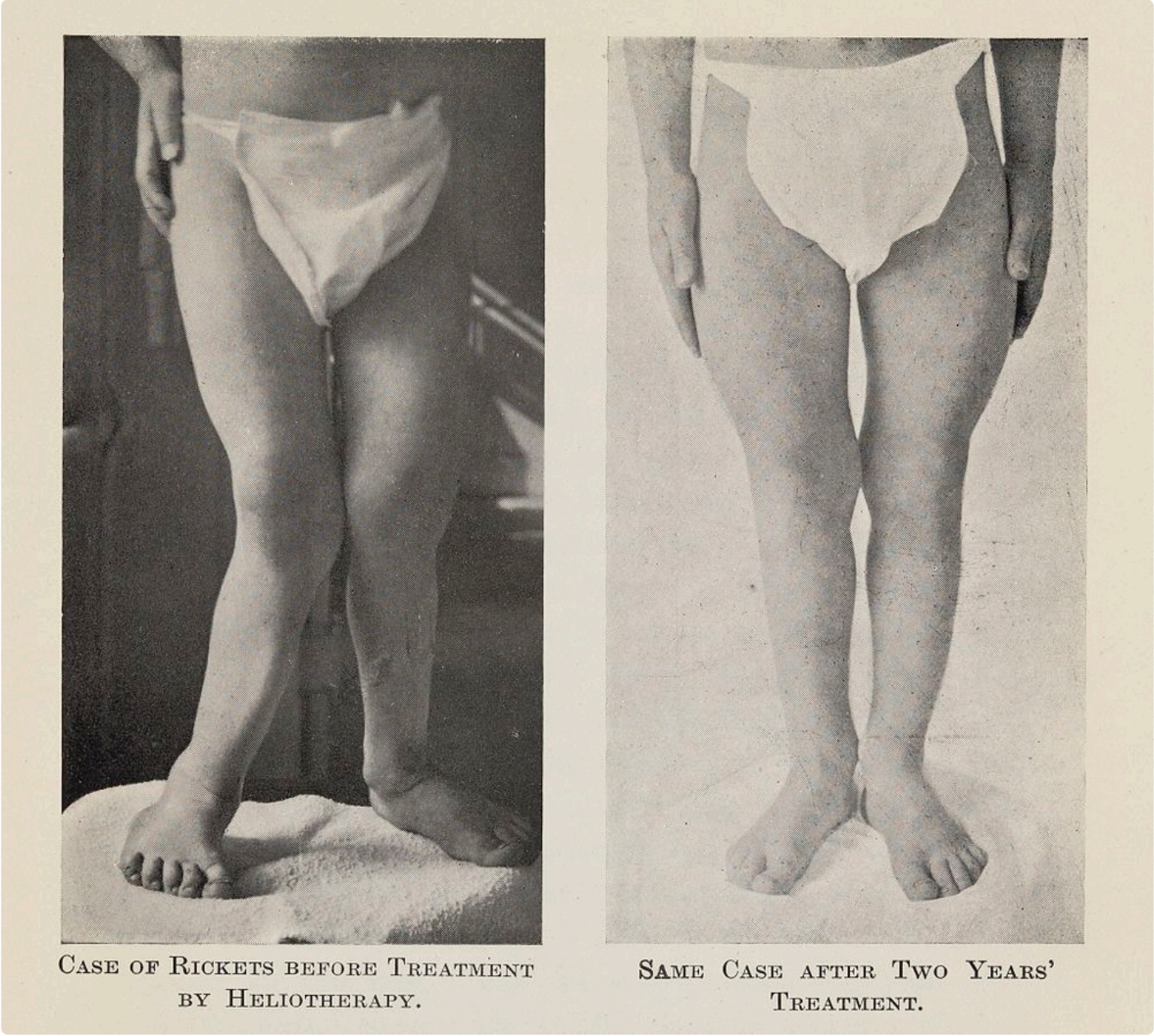


Figure 6.65 Rickets

Osteomyelitis

Osteomyelitis is an infection in a bone. It can affect one or more parts of a bone. Infections can reach a bone through the bloodstream or from nearby infected tissue. Infections can also begin in the bone if an injury opens the bone to germs. People who smoke and people with chronic health conditions, such as diabetes or kidney failure, are at higher risk of getting osteomyelitis. People who have diabetes with foot ulcers

may get osteomyelitis in the bones of their feet.[11] See Figure 6.66[12] for an illustration of osteomyelitis.

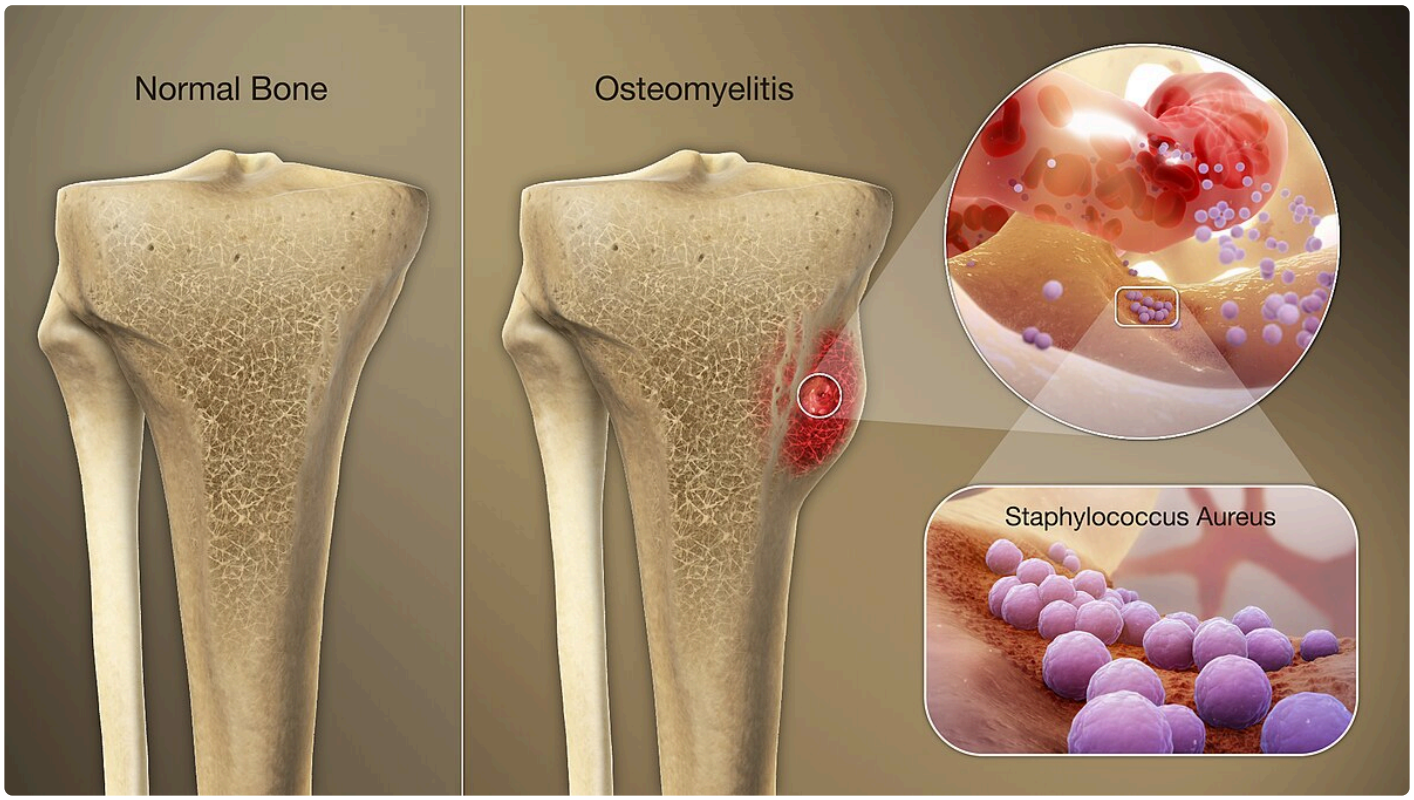


Figure 6.66 Osteomyelitis

Osteonecrosis

Osteonecrosis, also known as avascular necrosis, is the death of bone tissue due to a lack of blood supply. It can lead to tiny breaks in the bone and cause the bone to collapse. The process usually takes months to years. Osteonecrosis is often associated with long-term use of high-dose steroid medications and too much alcohol. Anyone can be affected, but the condition is most common in people between the ages of 30 and 50.[13]

11. Mayo Clinic. (2024). *Osteomyelitis*. https://www.mayoclinic.org/diseases-conditions/osteomyelitis/symptoms-causes/syc-20375913
12. ScientificAnimations.com. (2020). *3D_Medical_Animation_Staphylococcus_Aureus* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:3D_Medical_Animation_Staphylococcus_Aureus.jpg
13. Mayo Clinic. (2022). *Avascular necrosis (osteonecrosis).* https://www.mayoclinic.org/diseases-conditions/avascular-necrosis/symptoms-causes/syc-20369859

Osteoporosis

Osteopenia is the loss of bone mass that may lead to osteoporosis. **Osteoporosis** is a disease characterized by a decrease in bone mass, a common occurrence as the body ages. See Figure 6.67[14] for an illustration of loss of bone mass in males and females due to age. Females lose bone mass more quickly than males starting around age 50 due to the loss of estrogen, a hormone that promotes osteoblastic (bone-building) activity. Family history is another risk factor for developing osteoporosis.

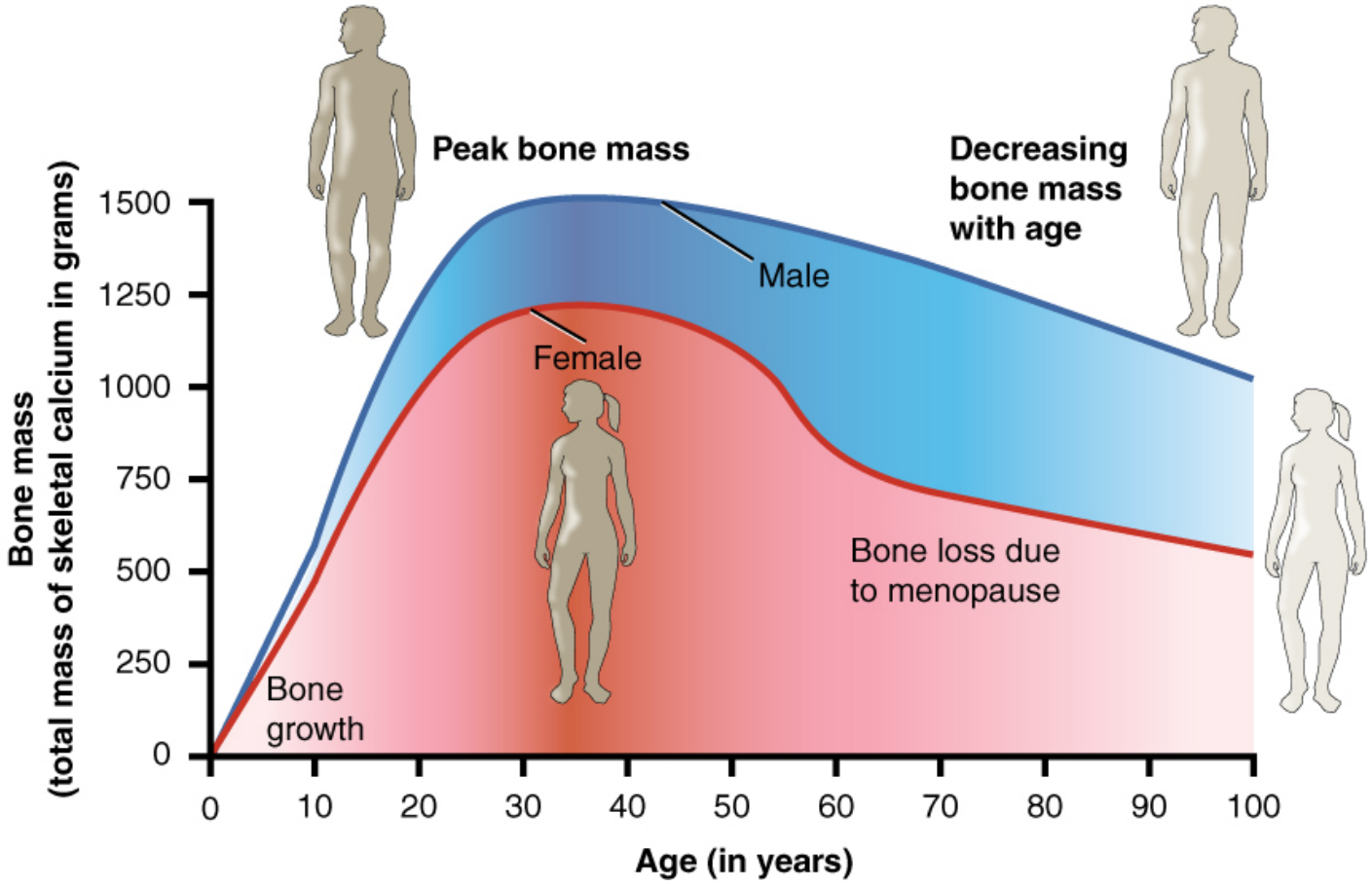


Figure 6.67 Loss of Bone Mass in Males and Females Due to Age

While osteoporosis can involve any bone, it most commonly affects the proximal ends of the femur, vertebrae, and wrist. As a result, these bones may not provide enough support for everyday functions, and something as simple as a sneeze can cause a vertebral fracture. Osteoporosis can result in kyphosis, an excessive outward curvature

14. OpenStax College. (2013). *615_Age_and_Bone_Mass* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:615_Age_and_Bone_Mass.jpg

of the spine in the upper back because of compression and collapse of the vertebrae. See Figure 6.68[15] for an illustration of the effects of osteoporosis, and Figure 6.69[16] for a microscopic image of normal bone tissue and osteoporotic bone.

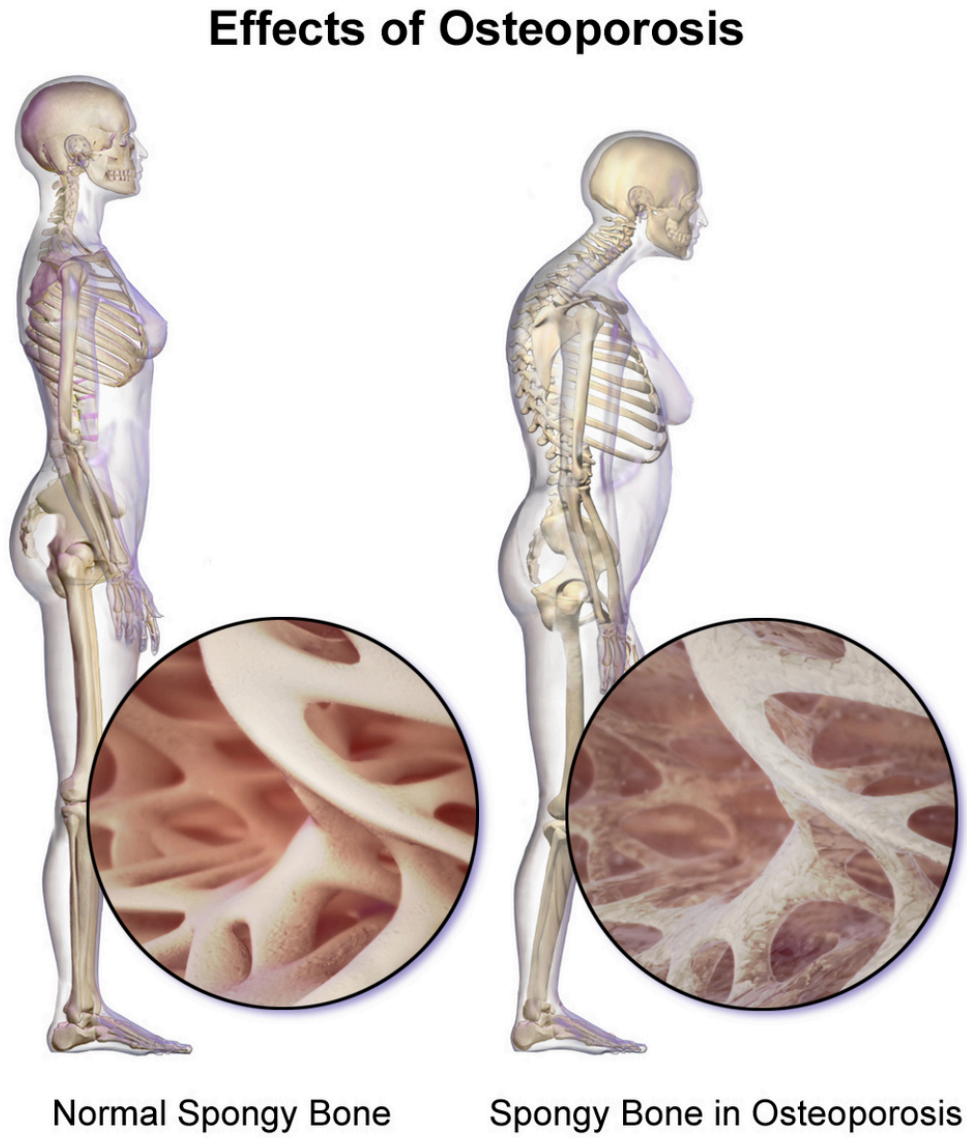


Figure 6.68 Osteoporosis

15. BruceBlaus. (2017). *Osteoporosis_02* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Osteoporosis_02.png

16. Turner Biomechanics Laboratory. (2011). *Bone_Comparison_of_Healthy_and_Osteoporotic_Vertibrae* [Diagam]. Wikimedia Commons. CC0, Public Domain. https://commons.wikimedia.org/wiki/File:Bone_Comparison_of_Healthy_and_Osteoporotic_Vertibrae.png

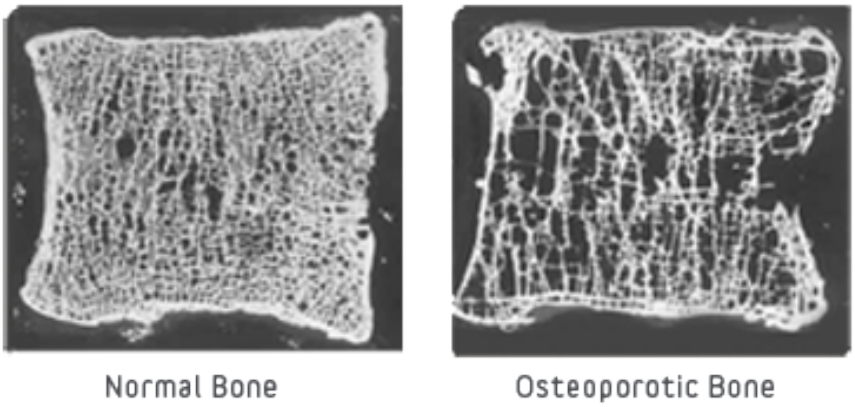


Figure 6.69 Microscopic Image of Normal Bone and Osteoporotic Bone

The best treatment for osteoporosis is prevention, which includes a diet with adequate intake of calcium and vitamin D and daily physical activity that includes weight-bearing exercise. Medications are also prescribed for treating osteoporosis and preventing further loss of bone mass.

Osteosarcoma

Osteosarcoma is a cancer that begins in the cells that form bones. Osteosarcoma tends to happen most often in teenagers and young adults. Osteosarcoma can start in any bone, but it's most often found in the long bones of the legs and sometimes the arms. Very rarely, it happens in soft tissue outside the bone. Advances in the treatment of osteosarcoma have improved the outlook for this cancer.[17]

Paget's Disease

Paget's disease of bone interferes with the body's normal recycling process, in which new bone tissue gradually replaces old bone tissue. Over time, bones can become fragile and misshapen. The pelvis, skull, spine, and legs are most commonly affected.

17. Mayo Clinic. (2023). *Osteosarcoma*. https://www.mayoclinic.org/diseases-conditions/osteosarcoma/symptoms-causes/syc-20351052

The risk of Paget's disease of bone increases with age and if family members have the disorder. Complications can include broken bones, hearing loss, and pinched nerves in your spine.[18] See Figure 6.70[19] for an illustration of Paget's disease.

18. Mayo Clinic. (2023). *Paget's disease of bone*. https://www.mayoclinic.org/diseases-conditions/pagets-disease-of-bone/symptoms-causes/syc-20350811

19. OpenStax College. (2013). *610_Feature_Pagets_Disease* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:610_Feature_Pagets_Disease.png

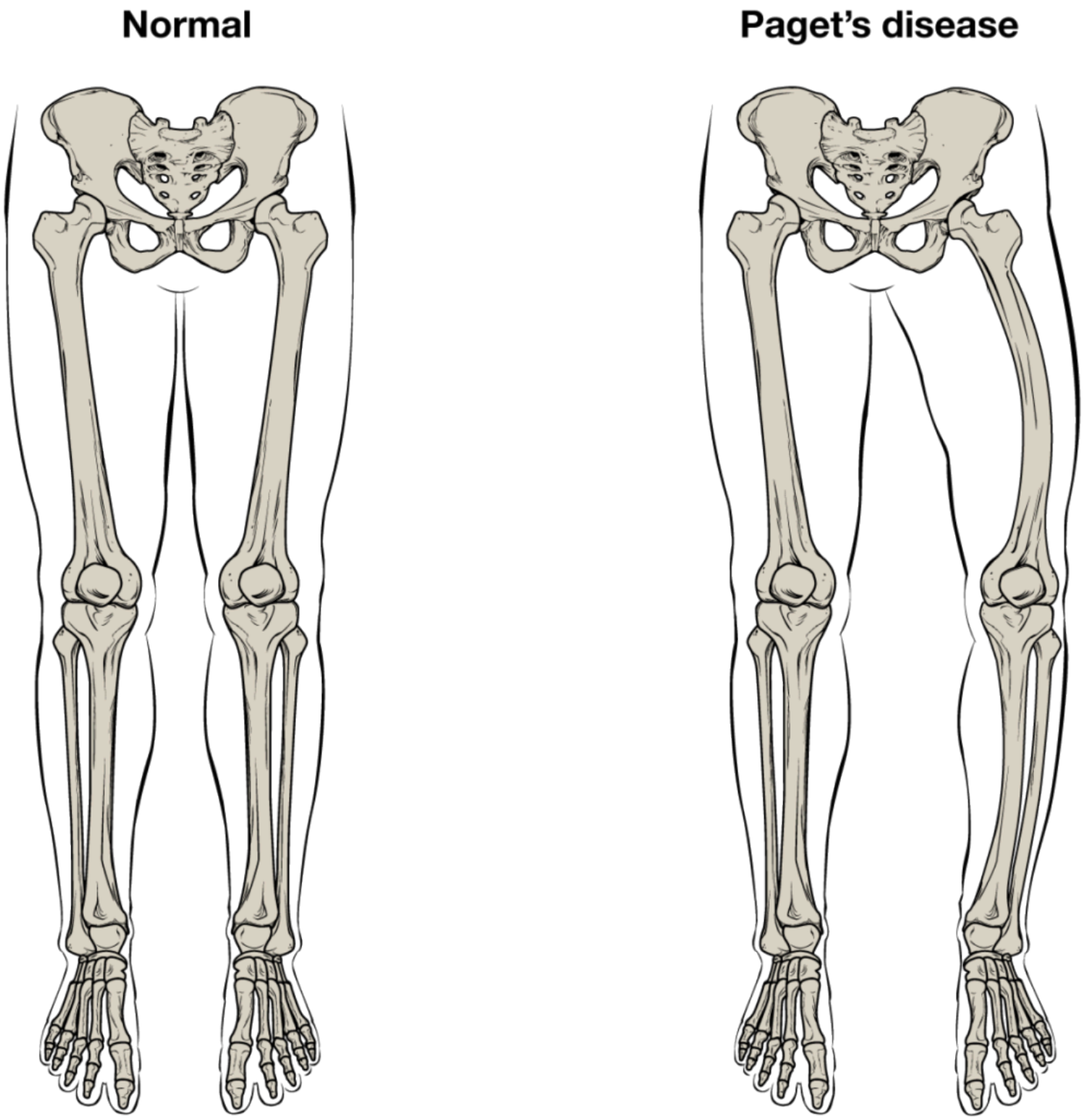


Figure 6.70 Paget's Disease

Patellofemoral Syndrome

Patellofemoral syndrome, also known as "Runner's Knee," is the most common overuse injury among runners. It is most frequent in adolescents and young adults

and is more common in females. It often results from excessive running, particularly downhill, but may also occur in athletes who do a lot of knee bending, such as jumpers, skiers, cyclists, weight lifters, and soccer players. It is felt as a dull, aching pain around the front of the knee and deep to the patella. The pain may be felt when walking or running, going up or down stairs, kneeling or squatting, or after sitting with the knee bent for an extended period. Patellofemoral syndrome may be initiated by a variety of causes, including individual variations of the patella, a direct blow to the patella, flat feet, or improper shoes that cause excessive turning in or out of the feet or leg.

Rheumatoid Arthritis

Rheumatoid arthritis is an autoimmune disease where the immune system attacks the joints. As a result, the joint capsule and synovial membrane become inflamed. As the disease progresses, the articular cartilage is severely damaged or destroyed, resulting in joint deformation, loss of movement, and severe disability. The most commonly involved joints are the hands, feet, and cervical spine, with corresponding joints on both sides of the body usually affected, though not always to the same extent. Rheumatoid arthritis is also associated with lung fibrosis, vasculitis (inflammation of blood vessels), coronary heart disease, and premature mortality. With no known cure, treatments are aimed at alleviating symptoms. Exercise, anti-inflammatory and pain medications, disease-modifying anti-rheumatic drugs, biologic medications that suppress an overactive immune system, or surgery are used to treat rheumatoid arthritis. See Figure 6.71[20] for an image of rheumatoid arthritis in a person's hands.

20. Phoenix119. (2014). *Swan_neck_deformity_in_a_65_year_old_Rheumatoid_Arthritis_patient* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Swan_neck_deformity_in_a_65_year_old_Rheumatoid_Arthritis_patient-_2014-05-27_01-49.jpg



Figure 6.71 Rheumatoid Arthritis

Scoliosis, Kyphosis, and Lordosis

Scoliosis, kyphosis, and lordosis are abnormal curvatures of the spine. **Scoliosis** is an abnormal lateral curvature of the spine accompanied by twisting of the vertebral column. Other curves of the vertebral column may also develop to help keep the head positioned over the feet. Scoliosis is the most common vertebral abnormality among girls. The cause is usually unknown, but it may result from weakness of the back muscles, defects such as different growth rates in the right and left sides of the vertebral column, or differences in the length of the lower limbs. Scoliosis tends to get worse during adolescent growth spurts. Although most individuals do not require treatment, a back brace may be recommended for growing children. In extreme cases, surgery may be required.

Kyphosis is a condition sometimes referred to as humpback or hunchback. It is due to an excessive posterior curvature of the upper thoracic region of the vertebral column.

Lordosis, or swayback, is an excessive anterior curvature of the lumbar region and is most commonly associated with obesity or late pregnancy. The extra body weight in the abdominal region causes a shift in the line of gravity that carries the weight of the body. This causes an anterior tilt of the pelvis and a pronounced enhancement of the lumbar curve.

See Figure 6.72[21] for an illustration of abnormal curvatures of the spine, including scoliosis, kyphosis, and lordosis.

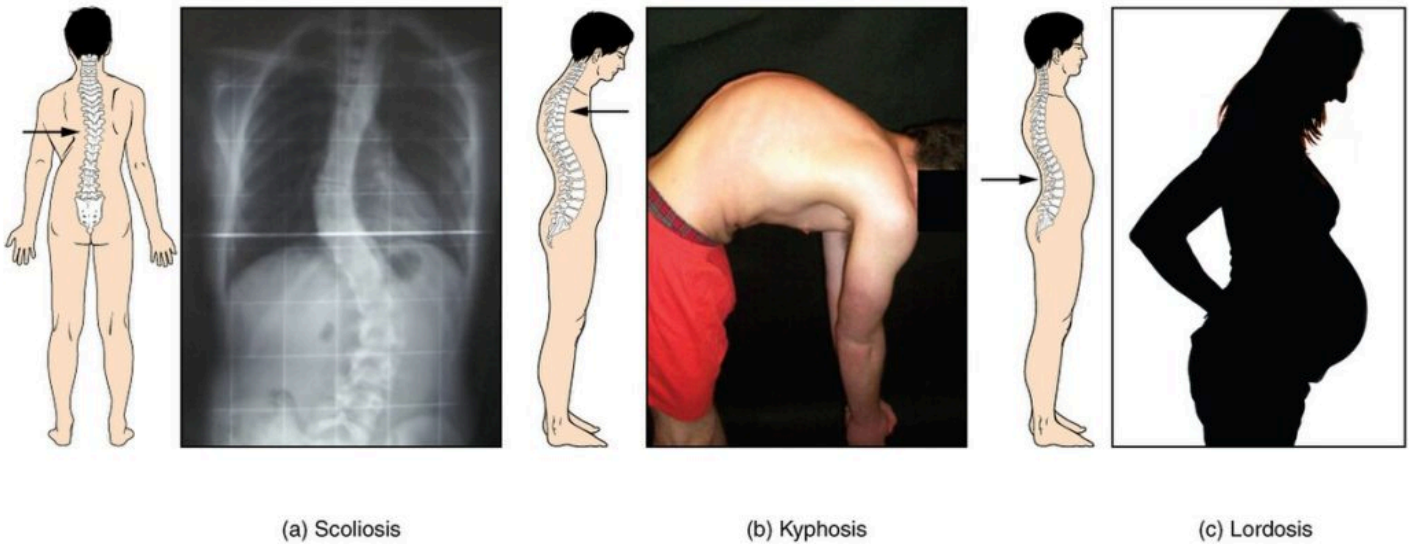


Figure 6.72 Abnormal Curvatures of the Spine a) Scoliosis, b) Kyphosis, and c) Lordosis

Spondylosis

Spondylosis is a painful condition of the spine caused by the breakdown of the intervertebral discs (cartilage found between the vertebrae). See Figure 6.73[22] that compares herniation, spondylosis, disc collapse, and instability.

21. OpenStax College. (2013). *717_Abnormal_Curves_of_Vertebral_Column* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:717_Abnormal_Curves_of_Vertebral_Column.jpg

22. Irina Nefedova. (2018). *Surgical_treatment_options_for_degenerative_changes* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Surgical_treatment_options_for_degenerative_changes.webp

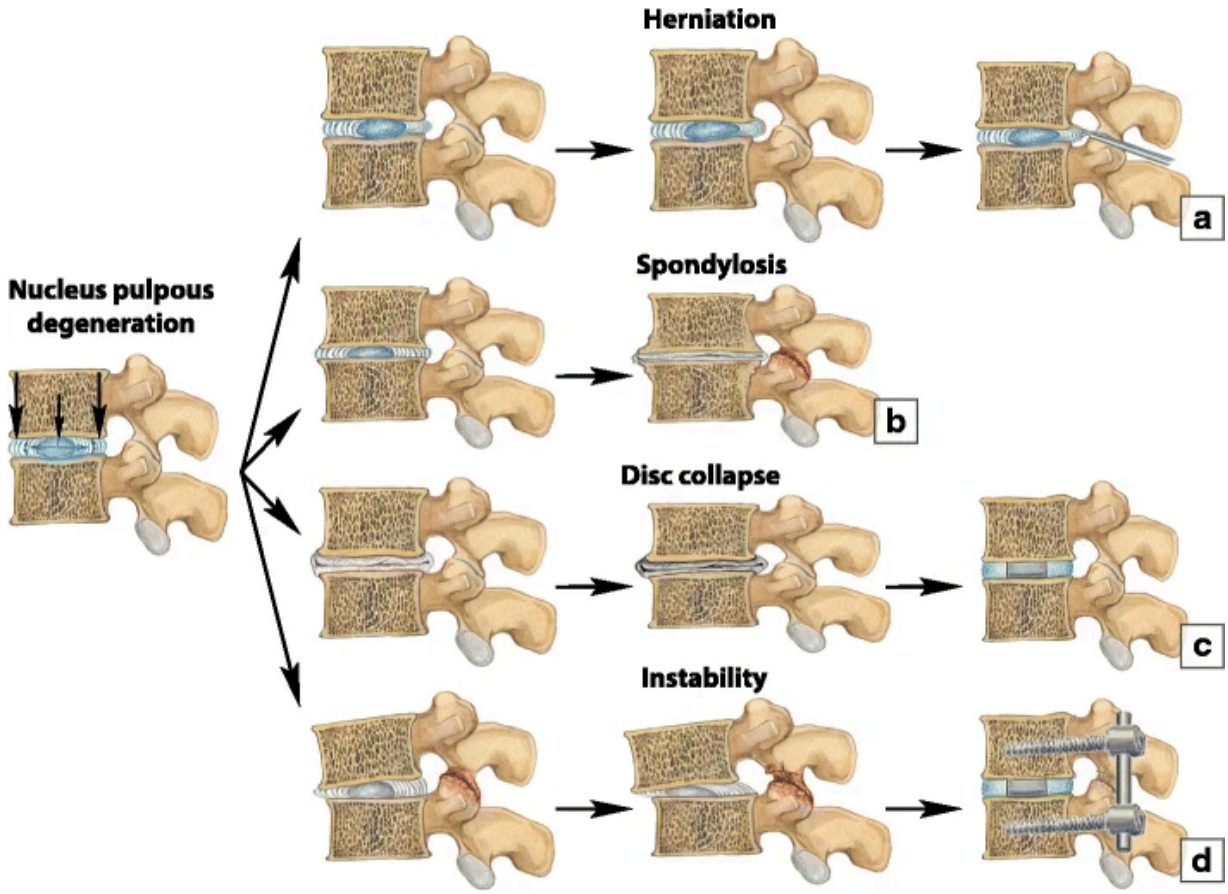


Figure 6.73 Herniation, Spondylosis, Disc Collapse, and Instability

Sprain

A **sprain** is the stretching or tearing of ligaments in a joint. Commonly sprained joints include the ankle, wrist, knee, and thumb.[23]

23. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/

6.8 Career Connections Related to the Skeletal System

The skeletal system includes bones, joints, cartilage, ligaments, and other structures that support the body, protect organs, and help make movement possible. When bones or joints are injured, weakened, or affected by disease, several health care professionals may help with imaging, treatment, surgery, rehabilitation, and patient care. Careers related to the skeletal system can include radiologic technologists, physical therapist assistants, occupational therapy assistants, surgical technologists, and medical assistants.

Radiologic Technologist

Radiologic technologists are health care professionals who perform diagnostic imaging exams, such as X-rays, that help providers identify fractures, joint injuries, bone disease, and other skeletal conditions. They are trained in anatomy, patient positioning, imaging equipment, examination techniques, radiation safety, and patient care.

Physical Therapist Assistant

Physical therapist assistants work under the supervision of physical therapists to help patients improve movement, reduce pain, and regain function after injuries, surgeries, or conditions affecting bones, joints, and muscles. They may assist with exercises, mobility training, therapeutic treatments, and tracking a patient's progress during rehabilitation.

Occupational Therapy Assistant

Occupational therapy assistants work with occupational therapists to help people participate in daily activities after injury, illness, disability, or age-related changes. This career connects to the skeletal system because occupational therapy assistants may

help patients adapt after fractures, joint replacements, arthritis, or other conditions that affect movement and independence.

Surgical Technologist

Surgical technologists are members of the surgical team who help prepare operating rooms, equipment, and supplies for procedures. In relation to the skeletal system, they may assist during orthopedic surgeries, such as procedures to repair fractures, replace joints, or treat spinal conditions.

Medical Assistant

Medical assistants work in clinics and other health care settings where they support patient care and office procedures. In orthopedic or primary care settings, medical assistants may help room patients, collect health information, assist with basic procedures, support documentation, and communicate with patients about follow-up care.

Take a Closer Look

Explore careers related to the human body's skeletal system on these websites.

- Neurodiagnostic technologist from ASET – The Neurodiagnostic Society
- Occupational therapy assistant from the American Occupational Therapy Association
- Physical therapist assistant from the American Physical Therapy Association
- Substance use disorder counselor from the U.S. Bureau of Labor Statistics
- Addiction counseling from NAADAC, the Association for Addiction Professionals
- Medical assistant from the American Association of Medical Assistants

6.9 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

6.10 Glossary

Acetabulum: The large cup-like socket that holds the head of the femur. (**Chapter 6.5**)

Acromion: A bony extension from the scapula that forms the highest superior point or “tip” of the shoulder. (**Chapter 6.5**)

Amphiarthrosis: A joint that has limited mobility. (**Chapter 6.6**)

Anterior cruciate ligament (ACL): A key ligament within the knee joint that connects the thigh bone (femur) to the shin bone (tibia). (**Chapter 6.6**)

Anterior fontanelle: The largest fontanelle is located on the top of the head at the junction of the frontal and parietal bones. (**Chapter 6.4**)

Appendicular skeleton: All bones of the upper and lower limbs, plus the bones that attach each limb to the axial skeleton. (**Chapter 6.3**)

Appositional growth: The process by which bones grow in width or diameter. (**Chapter 6.3**)

Arthritis: A general term related to inflammation of a joint. (**Chapter 6.7**)

Articular cartilage: A thin layer of hyaline cartilage that reduces friction in joints and acts as a shock absorber. (**Chapter 6.3**, **Chapter 6.6**)

Articular discs: Small, oval-shaped fibrocartilage structures located between the bones. (**Chapter 6.6**)

Atlas (C1): The first cervical vertebrae that support the skull on top of the vertebral column. (**Chapter 6.4**)

Axial skeleton: Protects the brain, spinal cord, heart, and lungs, and also serves as the attachment site for muscles that move the head, neck, and back. (**Chapter 6.3**)

Axis (C2): The second cervical vertebrae that serves as the axis for rotation when turning the head toward the right or left. (**Chapter 6.4**)

Ball and socket: A synovial joint formed between the spherical end (ball) of one bone that fits into a cuplike depression (socket) of a second bone. (**Chapter 6.6**)

Body (vertebral): The large anterior portion of a vertebra that supports the weight of the trunk. (**Chapter 6.4**)

Bone density: The total amount of bone tissue a person has. (**Chapter 6.3**)

Bone remodeling: The resorption of old or damaged bone while osteoblasts lay new bone to replace it. (**Chapter 6.3**)

Bursa: A thin connective tissue sac filled with fluid. (**Chapter 6.6**)

Bursitis: The inflammation of a bursa near a joint. (**Chapter 6.7**)

Canaliculi: Tiny, hair-like canals that connect the lacunae (spaces housing osteocytes) to the central canal in compact bone. (**Chapter 6.3**)

Cancellous bone: A light, porous type of bone tissue found primarily at the ends of long bones and within the vertebrae; also known as spongy bone. (**Chapter 6.3**)

Carpals: Eight bones making up the wrist. (**Chapter 6.5**)

Cartilage: A strong, flexible connective tissue that protects your joints and bones. (**Chapter 6.1**, **Chapter 6.6**)

Cartilaginous joint: Bones joined by cartilage. (**Chapter 6.6**)

Central canal: Located at the center of each osteon in compact bone; houses blood vessels, nerves, and lymphatic vessels. (**Chapter 6.3**)

Chondroblasts: Cartilage-forming cells. (**Chapter 6.3**)

Clavicle: The bone connecting the sternum to the scapula; also known as the collarbone. (**Chapter 6.5**)

Closed fracture: A fracture that does not break the skin. (**Chapter 6.3**)

Coccyx: Area formed by the fusion of four very small coccygeal vertebrae; commonly referred to as the tailbone. (**Chapter 6.4**)

Comminuted fracture: Several breaks result in many small pieces between two large segments. (**Chapter 6.3**)

Compact bone: The dense, strong type of bone tissue that provides structural support and protection. (**Chapter 6.3**)

Condyloid: Synovial joint formed by the shallow depression at the end of one bone receiving a rounded end from an adjacent bone or bones. (**Chapter 6.6**)

Coronal suture: Suture that runs from side to side across the top of the skull and joins the frontal bone to the parietal bones. (**Chapter 6.4**)

Dens: A bony projection that extends upward from the vertebral body; also known as the odontoid process. (**Chapter 6.4**)

Diaphysis: The shaft that runs between the proximal and distal ends of the bone. (**Chapter 6.3**)

Diarthrosis: A freely mobile joint. (**Chapter 6.6**)

Dislocation: An injury that forces the bones in a joint out of position. (**Chapter 6.7**)

Endochondral ossification: Process of bone development in which hyaline cartilage is gradually replaced by bone tissue. (**Chapter 6.3**)

Endosteum: A delicate, membranous lining of the medullary cavity where bone growth, repair, and remodeling occur. (**Chapter 6.3**)

Epiphyseal line: The remnant of the epiphyseal plate (growth plate) found in adult bones. (**Chapter 6.3**)

Epiphysis: The wider end of the bone that is made of spongy or cancellous bone tissue. (**Chapter 6.3**)

Ethmoid air cells: Small spaces separated by very thin bony walls located in the ethmoid bone. (**Chapter 6.4**)

Ethmoid bone: A single, irregularly shaped bone forming part of the nose, medial side of the eye orbits, and base of the skull. (**Chapter 6.4**)

External auditory canal (or external auditory meatus): Paired openings (left and right) in the temporal bones; commonly called the “ear canal.” (**Chapter 6.4**)

Facets: Areas on the transverse processes of the thoracic vertebrae where the ribs attach. (**Chapter 6.4**)

False ribs: Ribs 8, 9, and 10 that are attached to the costal cartilage of the seventh rib. (**Chapter 6.4**)

Femoral head: The rounded, proximal end of the femur. (**Chapter 6.5**)

Femoral neck: The narrowed region below the head of the femur. (**Chapter 6.5**)

Fibrous joint: Bones held together by fibrous connective tissue. (**Chapter 6.6**)

Flat bones: Typically, thin and often curved bones. (**Chapter 6.3**)

Floating ribs: Ribs 11 and 12 that are not attached to the sternum at all. (**Chapter 6.4**)

Fontanelles: Soft spots on a baby’s skull. (**Chapter 6.4**)

Foramen magnum: A large hole in the base of the occipital bone. (**Chapter 6.4**)

Fracture: A broken bone. (**Chapter 6.3**)

Fracture hematoma: A mass of clotted blood that forms at the site of a bone fracture. (Chapter 6.3)

Frontal bone: A single bone superior to the eyes. (Chapter 6.4)

Frontal sinus: Sinus located just above the eyebrows in the frontal bone. (Chapter 6.4)

Functional classification: The degree of movement between the bones. (Chapter 6.6)

Fuse: To grow together. (Chapter 6.3)

Glenoid fossa: Shallow depression located on the lateral scapula, between the superior and lateral borders. (Chapter 6.5)

Gomphosis: A narrow fibrous joint between the roots of a tooth and the bony socket. (Chapter 6.6)

Gout: A form of arthritis caused when uric acid crystals are deposited in a body joint. (Chapter 6.7)

Greater trochanter: The large, upward, bony projection on the femur. (Chapter 6.5)

Greenstick fracture: A partial fracture common in children. (Chapter 6.3)

Hallux: The great toe. (Chapter 6.5)

Hemopoiesis: The production of blood cells. (Chapter 6.2)

Herniated disc: A condition in which an intervertebral disc protrudes. (Chapter 6.7)

Hinge: A synovial joint formed by the convex surface of one bone meeting the concave surface of another. (Chapter 6.6)

Holes: An opening or groove in the bone. (Chapter 6.3)

Humeral head: The smooth, rounded region on the medial side of the proximal humerus; articulates with the glenoid fossa of the scapula to form the glenohumeral (shoulder) joint. (Chapter 6.5)

Humerus: The upper arm bone. (Chapter 6.5)

Hyoid bone: An independent bone not connected to any other bone. (Chapter 6.4)

Iliac crest: Superior margin of the ilium. (Chapter 6.5)

Ilium: The superior region forming the largest part of the hip bone. (Chapter 6.5)

Impacted fracture: One bone fragment is driven into the other. (Chapter 6.3)

Inferior articular process: A pair of downward-facing processes on the vertebrae. (Chapter 6.4)

Inferior nasal conchae (turbinates): Bones forming the lower lateral walls of the nasal cavity. (Chapter 6.4)

Interstitial growth: Refers to longitudinal bone growth. (Chapter 6.3)

Intervertebral discs: The soft, cushion-like pads between the vertebrae. (Chapter 6.4)

Intervertebral foramen: The gap between two vertebrae through which spinal nerves exit. (Chapter 6.4)

Intramembranous ossification: Bone formation from mesenchymal tissue. (Chapter 6.3)

Irregular bones: Bones with complex shapes. (Chapter 6.3)

Ischium: The inferior region of each hip bone. (Chapter 6.5)

Joint cavity: A fluid-filled space. (Chapter 6.6)

Joints: Where two bones or other skeletal elements meet. (Chapter 6.6)

Kyphosis: Excessive posterior curvature of the upper thoracic spine. (Chapter 6.7)

Lacrimal bones: Bones forming the walls of the medial orbit. (Chapter 6.4)

Lacunae: Spaces that hold the osteocytes. (Chapter 6.3)

Lambdoid suture: Suture joining the occipital bone to the parietal and temporal bones. (Chapter 6.4)

Lamellae: Circular/concentric rings of calcified matrix. (Chapter 6.3)

Lateral collateral ligament (LCL): Ligament on the outside of the knee. (Chapter 6.6)

Lateral condyle: Smooth surface forming part of the distal femur. (Chapter 6.5)

Lateral epicondyle: Rough area on the outer side of the lateral condyle. (Chapter 6.5)

Lateral malleolus: Distal end of the fibula. (Chapter 6.5)

Lesser trochanter: A small bony prominence on the femur. (Chapter 6.5)

Ligaments: Strong connective tissue bands that connect bones. (Chapter 6.1, Chapter 6.6)

Linea aspera: Longitudinally running bony ridge located in the middle third of the posterior femur. (Chapter 6.5)

Long bones: Cylindrical bones that are longer than they are wide. (Chapter 6.3)

Lordosis: An excessive anterior curvature of the lumbar region. (Chapter 6.7)

Mandible: Bone forming the lower jawbone. (Chapter 6.4)

Manubrium: The upper portion of the sternum. (Chapter 6.4)

Mastoid process(es): Protrusions on the temporal bone. (Chapter 6.4)

Maxillae: Pair of bones forming the upper jaw and hard palate. (Chapter 6.4)

Maxillary sinus: The largest sinus, located in the maxillary bones. (Chapter 6.4)

Medial collateral ligament (MCL): Ligament on the inner side of the knee. (Chapter 6.6)

Medial condyle: Smooth, articulating surface of the medial distal femur. (Chapter 6.5)

Medial epicondyle: Roughened area of the medial distal femur. (Chapter 6.5)

Medial malleolus: The distal end of the tibia. (Chapter 6.5)

Medullary cavity: Hollow region in the diaphysis. (Chapter 6.3)

Meniscus: C-shaped fibrocartilage in the knee. (Chapter 6.6)

Metacarpals: Five bones making up the palm of the hand. (Chapter 6.5)

Metaphysis: The region where the epiphysis meets the diaphysis. (Chapter 6.3)

Metatarsals: Five bones in the front part of the foot. (Chapter 6.5)

Modeling: The process in which old bone is eroded from the inner surface (along the medullary cavity) while new bone is deposited beneath the periosteum. (Chapter 6.3)

Multiple myeloma: A cancer of the white blood cells that causes them to overgrow and crowd out normal cells in the bone marrow that make red blood cells, platelets, and other white blood cells. (Chapter 6.7)

Nasal bones: A pair of fused bones on the right and left sides of the face that form the bridge of the nose. (Chapter 6.4)

Oblique fracture: A fracture that occurs at an angle that is not 90 degrees. (Chapter 6.3)

Occipital bone: A single bone forming the posterior side and base of the skull. (Chapter 6.4)

Open or compound fracture: A fracture in which at least one end of the broken bone tears through the skin; it carries a high risk of infection. (**Chapter 6.3**)

Orthopedists: Medical doctors who complete specialized training in the prevention, diagnosis, treatment, and surgery of disorders and diseases related to the musculoskeletal system. (**Chapter 6.8**)

Ossification: Process of actual bone development. (**Chapter 6.3**)

Osteoarthritis: The most common type of arthritis, which is associated with aging and "wear and tear" of the articular cartilage. (**Chapter 6.7**)

Osteoblasts: Bone-forming cells found mainly in the periosteum and endosteum. (**Chapter 6.3**)

Osteoclasts: Large, bone-breaking cells responsible for the breakdown and resorption of bone tissue. (**Chapter 6.3**)

Osteocytes: A mature bone cell responsible for maintaining bone tissue. (**Chapter 6.3**)

Osteogenic cells: Bone stem cells with the unique ability to divide through mitosis and are found in the deep layers of the periosteum and within the bone marrow. They serve as the origin for other bone cells by developing into osteoblasts, which are responsible for forming new bone tissue. (**Chapter 6.3**)

Osteoid: An uncalcified bone matrix. (**Chapter 6.3**)

Osteomalacia: Softening of the bones due to a lack of mineralization with calcium and phosphate, and most often caused by a lack of vitamin D. (**Chapter 6.7**)

Osteomyelitis: Infection in a bone. (**Chapter 6.7**)

Osteon: Basic structural unit of compact bone. (**Chapter 6.3**)

Osteonecrosis: The death of bone tissue due to a lack of blood supply. (**Chapter 6.7**)

Osteopenia: Loss of bone mass that may lead to osteoporosis. (**Chapter 6.7**)

Osteoporosis: A disease characterized by a decrease in bone mass, a common occurrence as the body ages. (**Chapter 6.7**)

Osteosarcoma: A cancer that begins in the cells that form bones. (**Chapter 6.7**)

Paget's disease: A chronic condition where the body's natural process of bone remodeling is disrupted, leading to bones becoming larger, weaker, and more brittle than normal. (**Chapter 6.7**)

Palatine bones: A pair of fused L-shaped bones on the right and left side of the face

that form part of the hard palate, walls of the nasal cavity, and the orbital floor of the eye. (Chapter 6.4)

Paranasal sinuses: Hollow, air-filled spaces located within certain bones of the skull. (Chapter 6.4)

Parietal bones: A pair of bones (left and right) on the upper sides of the skull above the ears. (Chapter 6.4)

Patella: A small, sesamoid bone located in the anterior knee; commonly referred to as the kneecap. (Chapter 6.5)

Patellar surface: A smooth groove located on the anterior side of the distal femur between the medial and lateral condyles that is the site of articulation for the patella. (Chapter 6.5)

Patellofemoral pain syndrome: A condition characterized by pain around the kneecap (patella) and front of the knee; also known as runner's knee or anterior knee pain. (Chapter 6.7)

Pectoral girdle: Area that serves to attach the upper limb to the sternum of the axial skeleton, consisting of the clavicle and the scapula. (Chapter 6.5)

Pelvis: The entire structure formed by the hip bones, the sacrum, and the coccyx. (Chapter 6.5)

Perforating canal: Channels that run perpendicular to the central canals (Haversian canals) in compact bone. They allow blood vessels, nerves, and lymphatic vessels to extend from the central canals to the periosteum and endosteum, ensuring the bone tissue receives adequate nutrients and communication. Also known as the Volmann's canal. (Chapter 6.3)

Perichondrium: A membrane that surrounds the cartilage model. (Chapter 6.3)

Periosteum: The fibrous membrane layer covering the outer surface of the bone. (Chapter 6.3)

Phalanges: The 14 bones that make up the fingers (and toes). (Chapter 6.5)

Phalanx: Single finger bone. (Chapter 6.5)

Pivot: A synovial joint where the rounded portion of a bone rotates within a ring formed by a ligament and a bone. (Chapter 6.6)

Plane: A synovial joint formed between the flattened surfaces of two bones. (Chapter 6.6)

Posterior cruciate ligament (PCL): One of the four major ligaments in the knee joint, located at the back of the knee. (Chapter 6.6)

Posterior fontanelle: A smaller fontanelle, located on the posterior side of the skull between the parietal and occipital bones. (Chapter 6.4)

Primary ossification center: Region in a developing long bone where bone formation begins during endochondral ossification. (Chapter 6.3)

Projection: An area of a bone that projects above the surface of the bone. (Chapter 6.3)

Proliferative zone: Second layer of the epiphyseal plate located just below the zone of reserve cartilage. It contains stacks of slightly larger chondrocytes that actively divide through mitosis. (Chapter 6.3)

Pterion: A small, capital-H-shaped region that unites the frontal bone, parietal bone, temporal bone, and sphenoid bone. (Chapter 6.4)

Pubis (or pubic bone): Forms the anterior (front) portion of the hip. (Chapter 6.5

Pubic symphysis: A cartilaginous joint in the pelvis that connects the two pubic bones. (Chapter 6.5)

Radiologic technologist (X-ray technician): Medical personnel who perform diagnostic imaging examinations and administer radiation therapy treatments. (Chapter 6.8)

Radiologist: A medical doctor who specializes in diagnosing and treating injuries and diseases using medical imaging and procedures, such as X-rays, computed tomography (CT scans), magnetic resonance imaging (MRI), nuclear medicine, positron emission tomography (PET) scan, and ultrasound. (Chapter 6.8)

Radiology: A branch of medicine that uses imaging technology to diagnose and treat disease. (Chapter 6.8)

Radius: The bone on the lateral or thumb side of the forearm. (Chapter 6.5)

Red bone marrow: A type of bone marrow that produces blood cells. (Chapter 6.2)

Reserve zone: The region closest to the epiphyseal end of the plate, which contains small chondrocytes (cartilage cells) within the matrix. (Chapter 6.3)

Rheumatoid arthritis: An autoimmune disease where the immune system attacks the joints. (Chapter 6.7)

Rickets: Osteomalacia in children. (Chapter 6.7)

Sacrum: A triangular-shaped bone that is thick and wide across the top, where it is weight-bearing, and then tapers down to the inferior, non-weight-bearing apex. (**Chapter 6.4**)

Saddle: A synovial joint in which the ends of the bones have a saddle shape, which is concave in one direction and convex in the other. (**Chapter 6.6**)

Sagittal suture: A suture that extends posteriorly from the coronal suture, along the midline at the top of the skull, uniting the right and left parietal bones. (**Chapter 6.4**)

Scapula: The bone commonly known as the shoulder blade. (**Chapter 6.5**)

Scoliosis: An abnormal lateral curvature of the spine accompanied by twisting of the vertebral column. (**Chapter 6.7**)

Secondary ossification centers: Areas in a developing long bone where bone formation begins after the primary ossification center. It typically appears in the epiphyses (ends) of the bone, where cartilage remains in the form of articular cartilage and the epiphyseal plate (growth plate). (**Chapter 6.3**)

Sella turcica: A bony landmark in the sphenoid bone; also known as “Turkish saddle” due to its resemblance to a horse’s saddle. (**Chapter 6.4**)

Sesamoid bone: A small, round bone shaped like a sesame seed. These bones develop within tendons and serve to protect the tendon and increase its mechanical efficiency. (**Chapter 6.3**, **Chapter 6.4**)

Short bones: Cube-like in shape, with nearly equal length, width, and thickness. In the human body, the only short bones are found in the wrists (carpals) and ankles (tarsals). These bones are designed to provide stability and support while allowing for limited motion. (**Chapter 6.3**)

Sphenoid sinus: Single sinus located within the body of the sphenoid bone near the sella turcica. (**Chapter 6.4**)

Spinal column: A flexible column of bones that supports the head, neck, and body and protects the spinal cord; also known as the vertebral column. (**Chapter 6.4**)

Spinous process: A single process that projects posteriorly at the midline. These processes can easily be felt as a series of bumps just under the skin down the middle of the back. (**Chapter 6.4**)

Spiral fracture: A fracture in which bone segments are pulled apart as a result of a twisting motion. (**Chapter 6.3**)

Spondylosis: A painful condition of the spine caused by the breakdown of the intervertebral discs (cartilage found between the vertebrae). (**Chapter 6.7**)

Spongy bone: A type of bone tissue that is less dense than compact bone and has a porous, honeycomb-like structure. It is typically found in the interior of bones, such as the ends of long bones and in the vertebrae, where it helps reduce the weight of the bone while providing support and housing bone marrow; also known as trabecular or cancellous bone. (**Chapter 6.3**)

Sprain: The stretching or tearing of ligaments in a joint. (**Chapter 6.7**)

Squamous suture: Suture located on each side of the skull. It unites the temporal bone with the parietal bone. (**Chapter 6.4**)

Sternum: A flat T-shaped bone located in the center of the chest; commonly called the breastbone. (**Chapter 6.4**)

Structural classification: Classification that considers how the bones are connected together. (**Chapter 6.6**)

Styloid process(es): A long, slender protrusion off the temporal bone below the ear on the left and right sides of the skull. (**Chapter 6.4**)

Subluxation: A partial dislocation of a bone. (**Chapter 6.7**)

Superior articular process: A pair of processes that extend or face upward. (**Chapter 6.4**)

Suture: A fixed (immobile) joint between bones of the skull. (**Chapter 6.4**, **Chapter 6.6**)

Synarthrosis: An immobile or nearly immobile joint. (**Chapter 6.6**)

Syndesmosis: A joint held together by a ligament, a type of connective tissue that connects bones together. (**Chapter 6.6**)

Synovial fluid: Lubricating fluid within the joint cavity. (**Chapter 6.6**)

Synovial joint: The bones are not directly connected but instead come together within a joint cavity filled with a lubricating fluid called synovial fluid. (**Chapter 6.6**)

Synovial membrane: Secretes synovial fluid. (**Chapter 6.6**)

Tarsals: A group of seven bones in the posterior half of the foot. (**Chapter 6.5**)

Temporal bones: Two bones (left and right) on the lower sides of the skull surrounding the ears. (**Chapter 6.4**)

Temporomandibular joint (TMJ): A hinge-like joint between the temporal bone and

the mandible that allows for the opening, closing, protrusion, retraction, and lateral movement of the lower jaw. (**Chapter 6.4**)

Tendons: A fibrous connective tissue that attaches muscle to bone. (**Chapter 6.1**)

Tibial tuberosity: The elevated area on the anterior side of the tibia, near its proximal end, that is the attachment site for the muscle tendon associated with the patella. (**Chapter 6.5**)

Trabeculae: A lattice-like network of matrix where lacunae and osteocytes are found. Each trabecula forms along lines of stress to provide strength to the bone. (**Chapter 6.3**)

Transverse fracture: A fracture that occurs straight across the long axis of the bone. (**Chapter 6.3**)

Transverse foramen: The opening within the transverse process. (**Chapter 6.1**)

Transverse process: A pair of processes projecting laterally on each side, serving as important muscle attachment sites. (**Chapter 6.4**)

True ribs: Ribs 1–7 that are attached directly to the anterior sternum by costal (rib) cartilage. (**Chapter 6.4**)

Ulna: The bone on the medial or pinky finger side of the forearm. (**Chapter 6.5**)

Vertebrae: Bones in the head, neck, and body that protect the spinal cord. (**Chapter 6.4**)

Vertebral arch: The part of a vertebra that forms the back portion of the vertebral foramen, which is the opening through which the spinal cord passes. (**Chapter 6.4**)

Vertebral (spinal) canal: The tunnel-like passage that runs through the vertebral column and houses the spinal cord and its protective coverings (meninges), along with blood vessels and spinal nerves. (**Chapter 6.4**)

Vertebral column: A flexible column of bones that supports the head, neck, and body and protects the spinal cord, also known as the spinal column. (**Chapter 6.4**)

Vertebral foraman: The large opening between the vertebral arch and body. (**Chapter 6.4**)

Vomer: Thin bone that forms the nasal septum that separates the left and right nostrils. (**Chapter 6.4**)

Wolff's Law: Law developed by Julius Wolff stating that bone in a healthy living being will adapt to the loads under which it is placed. (**Chapter 6.3**)

Xiphoid process: The lower portion of the sternum, made of cartilage early in life, which gradually ossifies starting in middle age. (**Chapter 6.2**, **Chapter 6.4**)

Yellow bone marrow: A type of bone marrow that contains adipose tissue and stores triglycerides that can be used for energy. (**Chapter 6.2**)

Zone of calcified matrix: A layer of the epiphyseal plate that contains chondrocytes that are dying or already dead, as the surrounding matrix becomes calcified. Calcium salts are deposited in the matrix, hardening it and preparing it for the arrival of bone-forming cells. This zone acts as the transition between cartilage and new bone tissue. (**Chapter 6.3**)

Zone of maturation and hypertrophy: A layer of the epiphyseal plate that contains older chondrocytes that have stopped dividing and begin to enlarge (hypertrophy). The lacunae surrounding them also expand, creating spaces that will later become part of the bone's structure. This zone contributes to the lengthening of the bone as the cells grow in size. (**Chapter 6.3**)

Zygomatic bones: Pair of bones on the right and left side of the anterior face; the "cheekbones." (**Chapter 6.4**)

Zygomatic process(es): A long, slender protrusion off of the temporal bone that forms part of the cheek. (**Chapter 6.4**)

PART VII

CHAPTER 7 MUSCULAR SYSTEM

7.1 Introduction to the Muscular System

Chapter Competency

Analyze how components of the muscular system function in the body.

Learning Objectives

- Identify the gross and microscopic structural components of the muscular system.
- Correlate the structural components of the muscular system with their functions.
- Identify the major muscles and their functions.
- Summarize the functions of the muscular system.

Imagine you are working as a fitness and wellness specialist helping a client improve strength, flexibility, posture, and overall physical performance. As the client moves through exercises, you observe how muscles contract, relax, stabilize joints, maintain posture, and generate force. You also consider how muscle fatigue, injury, or disease can affect movement and daily activities. To support safe and effective exercise, you must understand how muscle tissue is structured and how the muscular system functions in the body.

Muscle tissue is one of the four primary tissue types and is responsible for the active movement of the body and the movement of materials within the body. The muscular system supports movement, posture, heat production, and the transport and storage of substances. The body contains three types of muscle tissue: skeletal muscle, cardiac muscle, and smooth muscle. Although all three types share some common properties, each has specialized structures and functions.

In this chapter, you will explore the structure and function of the muscular system.

You will learn how skeletal muscle attaches to bones and produces voluntary movement, how cardiac muscle contracts to pump blood through the heart, and how smooth muscle moves substances through internal organs, blood vessels, and passageways. You will also examine the microscopic structure of muscle tissue, the process of skeletal muscle contraction, the organization and actions of major muscles, and common muscular system disorders.

By mastering these concepts, you will gain a deeper understanding of how muscles produce movement, maintain posture, generate heat, and support essential body functions. This foundation will help you connect muscle structure to movement, exercise, injury prevention, rehabilitation, and disorders that affect strength, coordination, and mobility.

7.2 Muscle Tissue

Types of Muscle Tissue

Muscle tissue is classified into three types according to its structure and function: skeletal, cardiac, and smooth. See Table 7.2 for a brief description of the three types of muscle tissue.[1]

Table 7.2 Comparison of Structure and Properties of Types of Muscle[2]

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Tissue	Structure	Function	Location
Skeletal	Long cylindrical fibers, striated, many peripherally located nuclei	Under voluntary control; produces heat and protects organs	Attached to bones and around body openings (e.g., mouth, anus)
Cardiac	Short, branched fibers, striated, single central nucleus, intercalated discs	Under involuntary control; contracts to pump blood	Heart
Smooth	Short, spindle-shaped, no striations, single nucleus per cell	Under involuntary control; moves substances through organs and tubes	Walls of major organs and passageways

Functions of Muscle Tissue

The primary function of muscle tissue is to contract and produce movement of the body. Some muscle movement is **voluntary**, which means it is under conscious control. For example, when you want to move your arm or any other part of the body, you can choose to do so. Other movements are **involuntary**, meaning they are not under conscious control, such as the contraction of your pupil in bright light.

Skeletal muscles act not only to produce voluntary movement of the body but also to stop movement, such as resisting gravity to maintain posture. It is a complex job to balance the body on two feet and walk upright. The muscles of the vertebral column, thorax, and abdominal wall extend, flex, and stabilize different parts of the body's trunk. The deep muscles in the core of the body help maintain posture. Muscles also prevent excess movement of the bones and joints, maintaining skeletal stability and preventing skeletal structure damage or deformation.

Additionally, skeletal muscles contribute to the maintenance of homeostasis in the body by generating heat. Muscle contraction requires energy, and when ATP is broken down, heat is produced. This heat is very noticeable during exercise, when sustained muscle movement causes body temperature to rise, and in cases of extreme cold, when shivering produces random skeletal muscle contractions to generate heat. Shivering is an involuntary contraction of skeletal muscles in response to a lower-than-normal body temperature.

Muscles are also responsible for the transport and storage of substances. While most skeletal muscles are attached to bones, some skeletal muscles are also located throughout the body at the openings of internal tracts to control the movement of various substances. These muscles allow functions, such as swallowing, urination, and defecation, to be under voluntary control. Smooth muscle allows the movement of substances through passageways such as the blood vessels and intestines. Cardiac muscle pumps blood throughout the body.[3]

3. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Properties of Muscle Tissue

All types of muscle tissue have four unique properties that include electrical excitability, contractility, extensibility, and elasticity.

Muscle cells are **excitable** in response to nervous system stimulation. While the nervous system can influence the excitability of cardiac and smooth muscle to some degree, skeletal muscle completely depends on signaling from the nervous system to work properly. On the other hand, both cardiac muscle and smooth muscle can respond to other stimuli, such as hormones and local stimuli. A muscle can return to its original length when relaxed due to a quality of muscle tissue called **elasticity**. It can recoil back to its original length due to elastic fibers. **Contractility** allows muscle tissue to pull on its attachment points and shorten with force. Muscle tissue also has **extensibility**, meaning it can stretch or extend and still contract.

Differences among the three muscle types include the microscopic organization of their contractile proteins—actin and myosin. The actin and myosin proteins are arranged in an alternating pattern in the cytoplasm of individual muscle fibers (cells are referred to as fibers in muscle) in both skeletal muscle and cardiac muscle. This pattern creates stripes called **striations**. The striations are visible with a light microscope under high magnification. **Skeletal muscle** fibers are multinucleated (containing up to 100 or more nuclei). **Cardiac muscle** fibers each have one to two nuclei and are physically and electrically connected to each other by special structures called intercalated discs so that the entire heart contracts as one unit (called a syncytium).

Because the actin and myosin are not arranged in such a regular fashion in **smooth muscle**, the cytoplasm of a smooth muscle fiber (which has only a single nucleus) has a uniform, non-striated appearance (resulting in the name smooth muscle). However, the less organized appearance of smooth muscle should not be interpreted as less efficient. Smooth muscle in the walls of arteries is a critical component that regulates blood pressure necessary to push blood through the circulatory system. Smooth muscle in the skin, visceral organs, and internal passageways is essential for moving all materials through the body.[4]

See Figure 7.1 [5] for microscopic images of the three types of muscle tissue.

4. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

5. ScientificAnimations.com. (2018). *Types_Of_Muscle* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Types_Of_Muscle.jpg

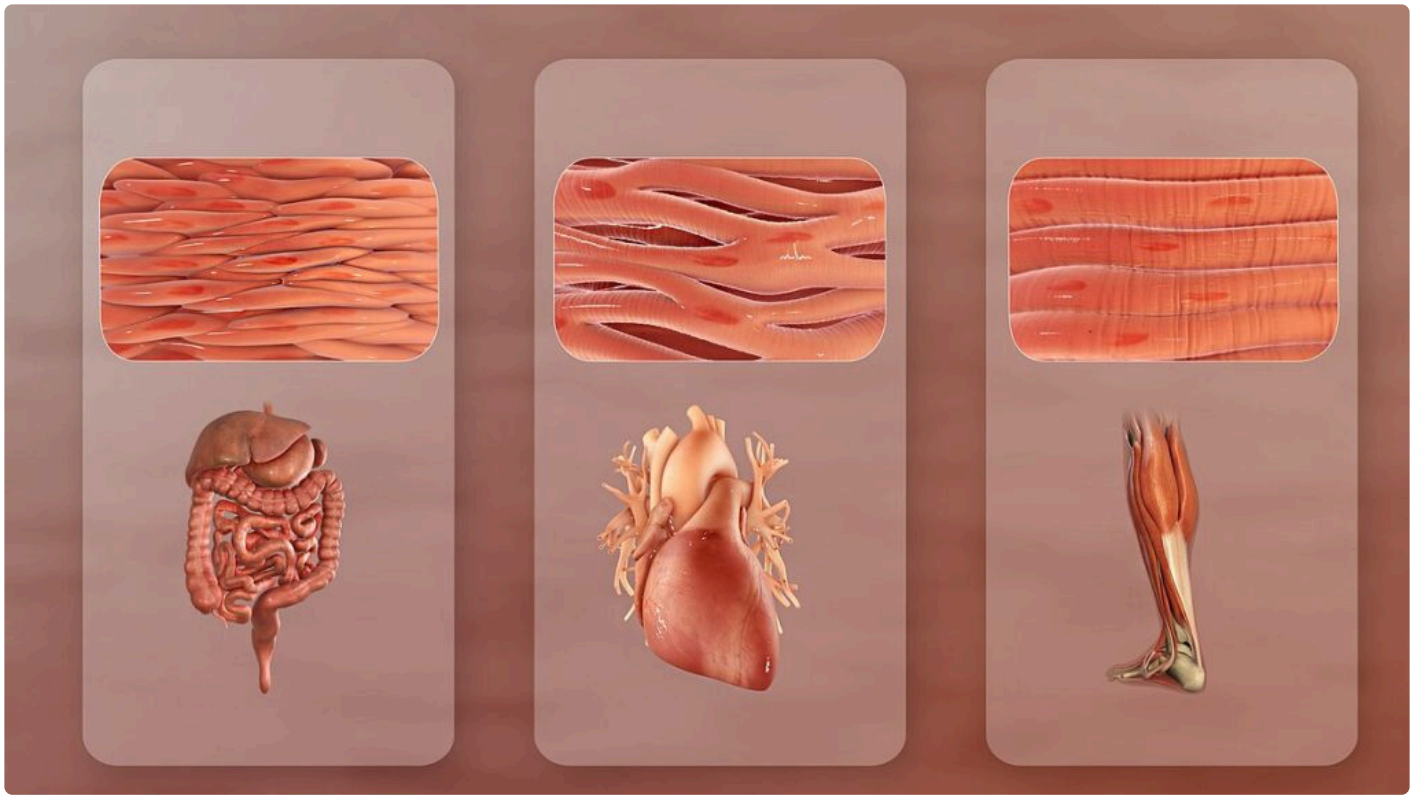


Figure 7.1 Types of Muscle: Smooth, Cardiac, and Skeletal

The remaining sections of this chapter will further describe each type of muscle tissue.

7.3 Skeletal Muscle

Skeletal muscle is attached to bones, so its contraction makes facial expressions, posture, and other voluntary movements of the body possible. Forty percent of your body mass is made up of skeletal muscle.[1]

Skeletal Muscle Organization

Each skeletal muscle is an organ that consists of various integrated tissues. These tissues include the skeletal muscle fibers (muscle cells or myocytes), blood vessels, nerve fibers, and connective tissue. Every skeletal muscle is richly supplied by blood vessels for nourishment, oxygen delivery, and waste removal. Inside each skeletal muscle, muscle fibers are organized into individual bundles or groups of fibers called **fascicles**.

Each skeletal muscle has three layers of connective tissue (called "mysia") that enclose it, provide structure to the muscle as a whole, and also bundle the muscle fibers within the muscle. See Figure 7.2[2] for an illustration of the structure of skeletal muscle tissue. The three layers of connective tissue are the epimysium, the perimysium, and the endomysium:

- **Epimysium**. The epimysium is a sheath of dense, irregular connective tissue that wraps around the outside of the entire muscle. It allows the muscle to contract and move powerfully while maintaining its structure. The epimysium separates the muscle from other tissues and organs in the area, allowing the muscle to move independently.
- **Perimysium**. The perimysium is a layer of connective tissue that surrounds each fascicle (bundle of muscle fibers).
- **Endomysium**. The endomysium is a thin connective tissue layer of collagen and reticular fibers covering each individual muscle fiber. The endomysium contains the extracellular fluid and nutrients to support the muscle fiber. These nutrients are

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. National Cancer Institute. *Human Biology fig. 1.20 – Structure of a skeletal muscle – English labels* [Diagram]. Anatomytool.com. Public Domain. https://anatomytool.org/content/human-biology-fig-120-structure-skeletal-muscle-english-labels

supplied via blood to the muscle tissue.

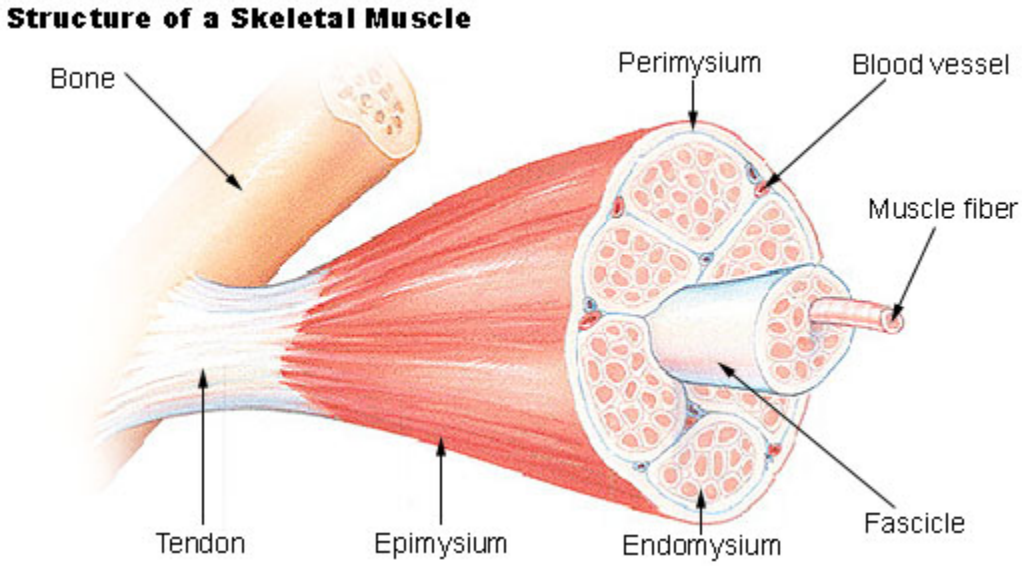


Figure 7.2 Muscle Structure

To move the skeleton, the tension created by the contraction of the fibers in most skeletal muscles is transferred to tendons. **Tendons** are strong bands of dense, regular connective tissue that connect muscles to bones. This bone connection is why this muscle tissue is called skeletal muscle.

The collagen of the three mysia layers (epimysium, perimysium, and endomysium) intertwine with the collagen of the tendon, and the other end of the tendon is connected to the periosteum (outer covering) of the bone. The tension created by contraction of the muscle fibers is then transferred through the mysia, to the tendon, and then to the periosteum to pull on the bone for movement of the skeleton. In a way, your body is like a sophisticated marionette inside. Skeletal muscles contract and pull on tendons, which then pull on bones to create movement.

In other places, the mysia may fuse with a broad, flat tendon-like sheet called an **aponeurosis**, or to **fascia**, the connective tissue between skin and bones. The broad sheet of connective tissue in the lower back that the latissimus dorsi muscles (the "lats") fuse into is an example of an aponeurosis.[3]

3. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Skeletal Muscle Fibers

Skeletal muscle cells are long and cylindrical and are commonly referred to as **muscle fibers**. Skeletal muscle fibers can be quite large for human cells, with diameters up to 100 µm and lengths up to 30 cm (11.8 in) in the sartorius muscle of the upper leg. Muscle fibers have up to 100 nuclei in each fiber. Multiple nuclei mean multiple copies of genes, which allows the production of large amounts of proteins and enzymes needed for muscle contraction.

The plasma membrane of a muscle fiber is called the **sarcolemma**. The cytoplasm is referred to as **sarcoplasm**, and the specialized smooth endoplasmic reticulum, which stores, releases, and retrieves calcium ions (Ca^{2+}), is called the **sarcoplasmic reticulum (SR)**.

Inside the muscle fiber are **myofibrils**, long, cylindrical organelles that run parallel within the muscle fiber and contain the sarcomeres, the basic unit of muscle contraction. See Figure 7.3[4] for an illustration of the organization of a skeletal muscle fiber.

4. OpenStax College. (2016). *1002_Organization_of_Muscle_Fiber* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1002_Organization_of_Muscle_Fiber.jpg

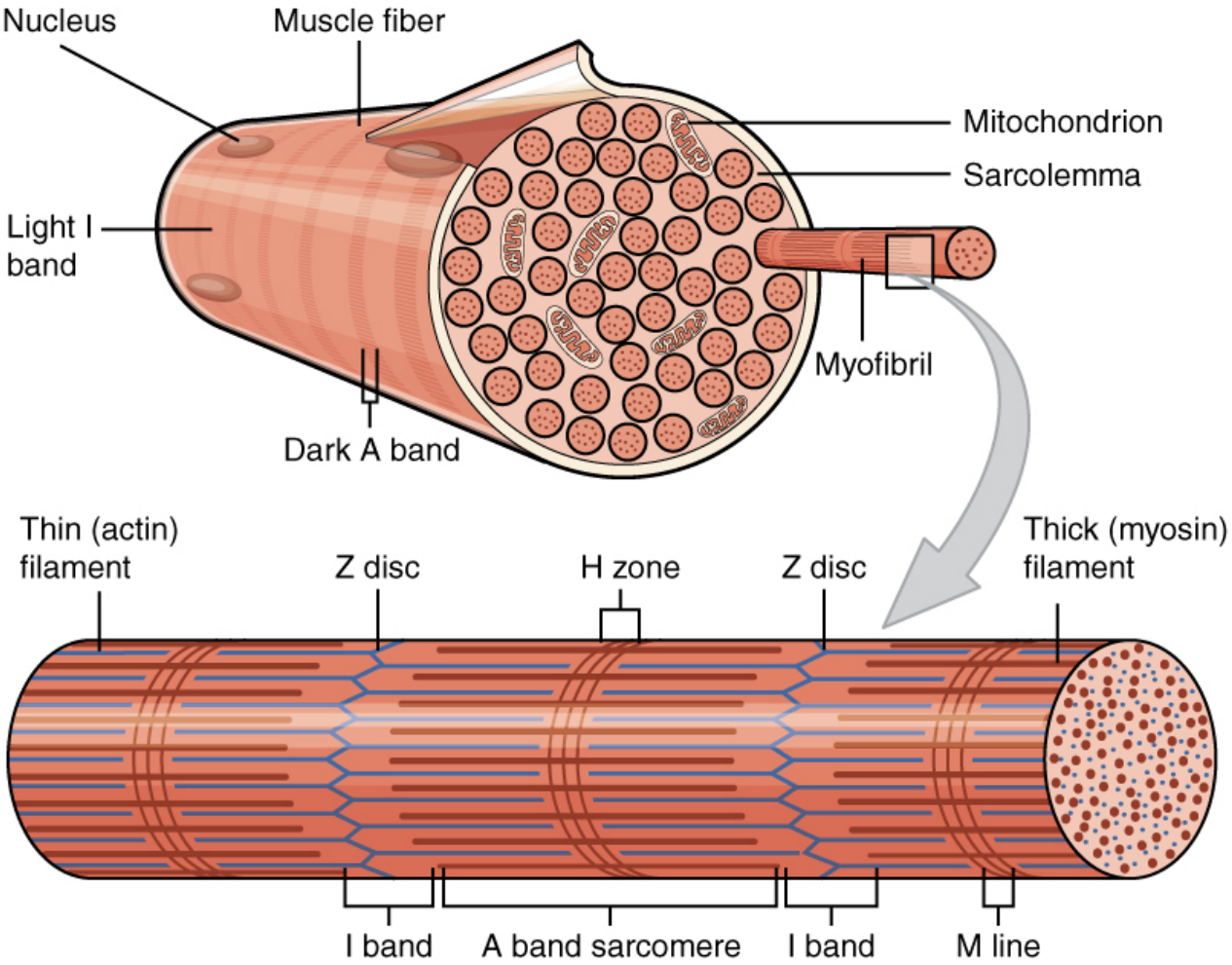


Figure 7.3 Organization of a Skeletal Muscle Fiber

Sarcomere

The smallest functioning or basic unit of a skeletal muscle fiber is the **sarcomere**, a highly organized arrangement of the contractile proteins **actin** (thin filament) and **myosin** (thick filament), along with other regulatory and support proteins. The arrangement of actin and myosin in the sarcoplasm of individual muscle fibers creates a pattern, or stripes, called striations when viewed under a microscope.

The sarcomere is bundled within the myofibril that runs the entire length of the muscle fiber and attaches to the sarcolemma at its end. As myofibrils contract, the entire muscle cell contracts. Because myofibrils are only approximately 1.2 µm in diameter, hundreds to thousands (each with thousands of sarcomeres) can be found inside one muscle fiber. Each sarcomere is approximately 2 µm in length and is bordered by structures called Z-discs (also called Z-lines) to which the actin myofilaments are anchored. Because the actin forms strands that are thinner than the myosin, they are

called the **thin filaments** of the sarcomere. Likewise, because the myosin strands have more mass and are thicker, they are called the **thick filaments** of the sarcomere[5]. See Figure 7.4[6] for an illustration of a sarcomere, and Figure 7.5[7] for a microscopic image of a sarcomere.

5. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

6. OpenStax College. (2016). *1003_Thick_and_Thin_Filament* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1003_Thick_and_Thin_Filaments.jpg

7. Sameerb. (2006). *Sarcomere* [Diagram]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Sarcomere.gif

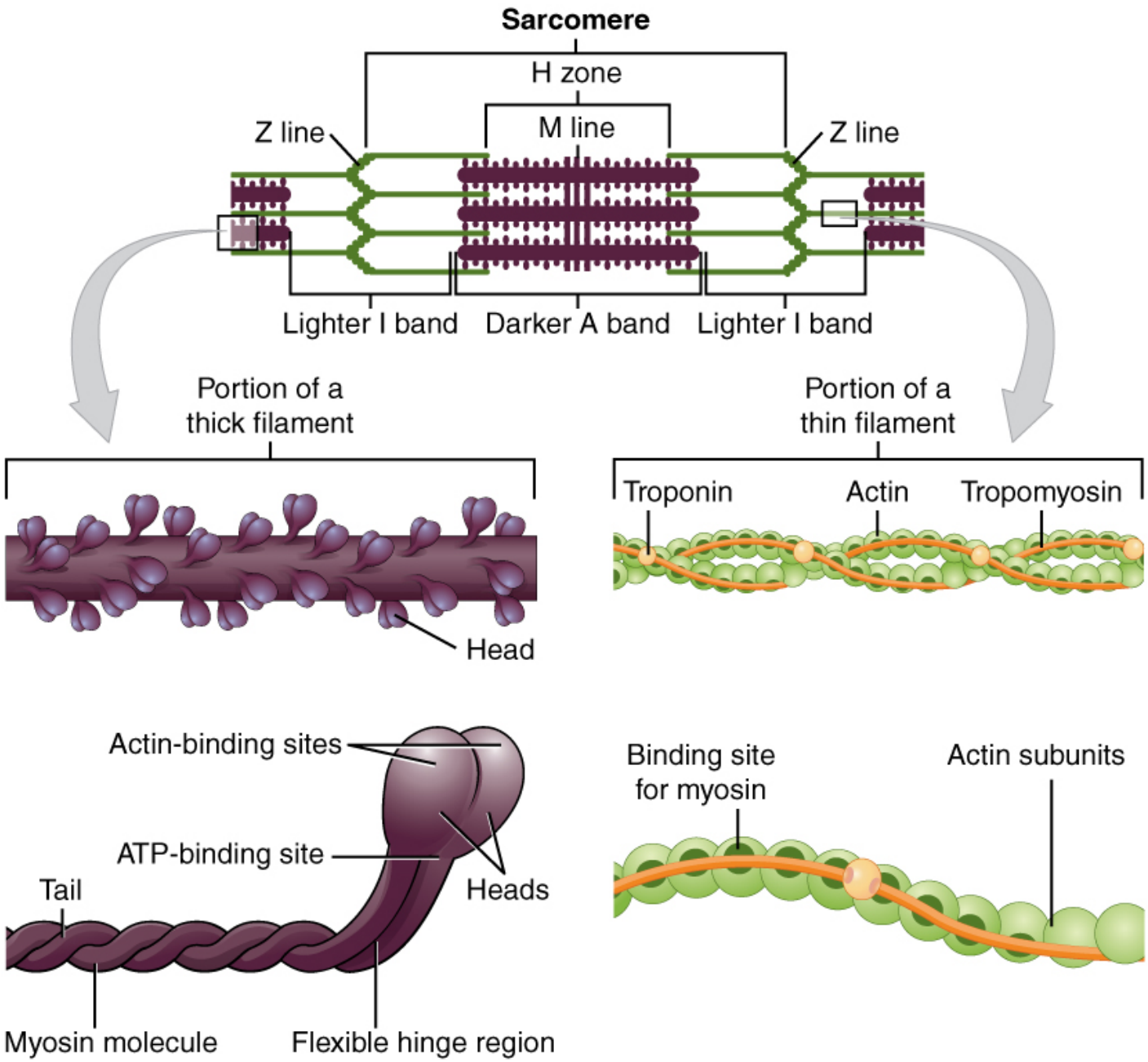


Figure 7.4 Sarcomere

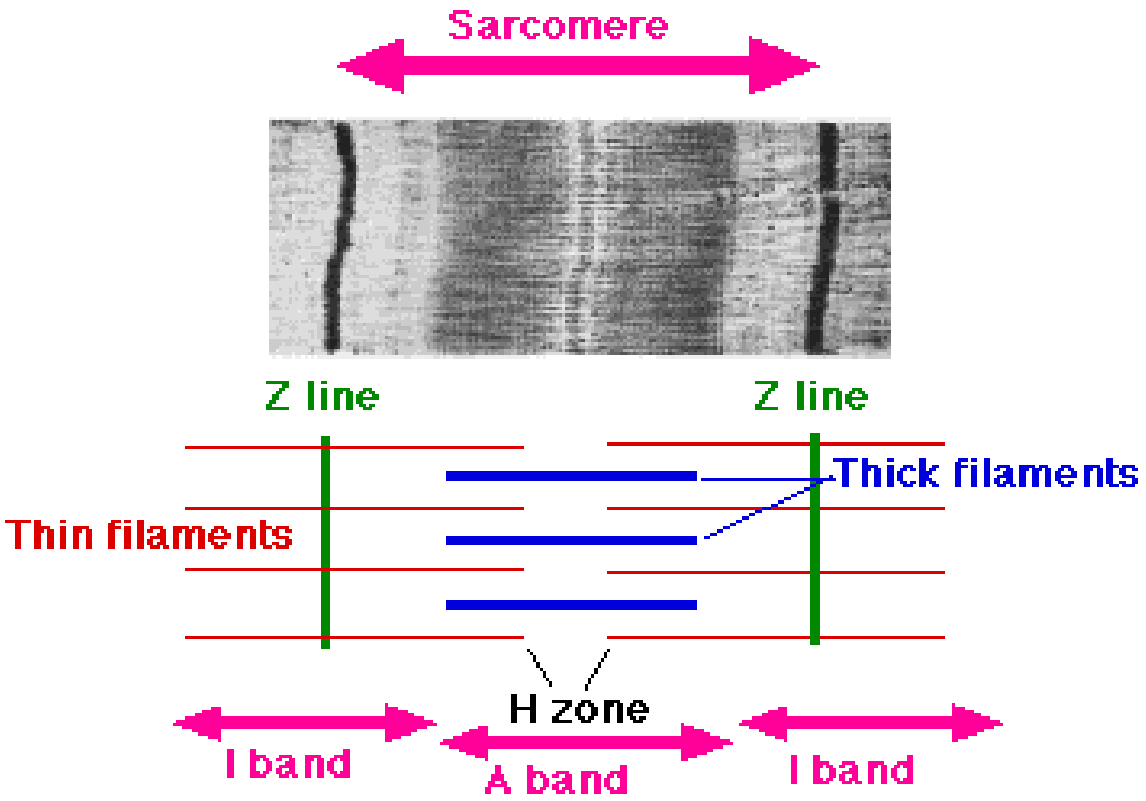


Figure 7.5 Microscopic Image of a Sarcomere

Skeletal Muscle Contraction

Motor Units

Every skeletal muscle fiber must be innervated by a motor neuron in order to contract. One motor neuron and the number of fibers it controls is called a **motor unit**. The size of a motor unit varies depending on the nature of the muscle.

A small motor unit is an arrangement where a single motor neuron controls a small number of muscle fibers in a muscle. Small motor units allow very fine motor control of the muscle. The best example in humans is the small motor units of the extraocular eye muscles that move the eyeballs. There are thousands of muscle fibers in each muscle, but every six or so fibers are stimulated by a single motor neuron. This allows for precise control of eye movements so that both eyes can quickly focus on the same object. Small motor units are also involved in the many fine motor movements of the fingers and thumb of the hand for grasping, texting, etc.

A large motor unit is an arrangement where a single motor neuron controls a large

number of muscle fibers in a muscle. Large motor units are concerned with simple, or "gross," movements, such as powerfully extending the knee joint. The best example is the large motor units of the thigh muscles or back muscles, where a single motor neuron will supply thousands of muscle fibers in a muscle.

There is a wide range of motor units within many skeletal muscles, which gives the nervous system a wide range of control over the muscle. The small motor units in the muscle will have smaller motor neurons that are more excitable, firing first to their skeletal muscle fibers, which also tend to be the smallest. Activation of these smaller motor units results in a relatively small degree of contractile strength (tension) generated in the muscle. As more strength is needed, larger motor units with bigger motor neurons are enlisted to activate larger muscle fibers. This increase in the number of active motor units produces an increase in muscle contraction known as **recruitment**. As more motor units are recruited, the muscle contraction grows progressively stronger. In some muscles, the largest motor units may generate a contractile force of 50 times more than the smallest motor units in the muscle. This allows a feather to be picked up using the biceps brachii arm muscle with minimal force, and a heavy weight to be lifted by the same muscle by recruiting the largest motor units.

When necessary, the maximal number of motor units in a muscle can be recruited simultaneously, producing the maximum force of contraction for that muscle, but this cannot last for very long because of the energy requirements to sustain the contraction. To prevent complete muscle fatigue, motor units are generally not all simultaneously active. Instead, some motor units rest while others are active, which allows for longer muscle contractions.[8]

See Figure 7.6[9] for an illustration of motor units.

8. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

9. Daniel Walsh and Alan Sved. (2019). *Motor_unit* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. *https://commons.wikimedia.org/wiki/File:Motor_unit.png*

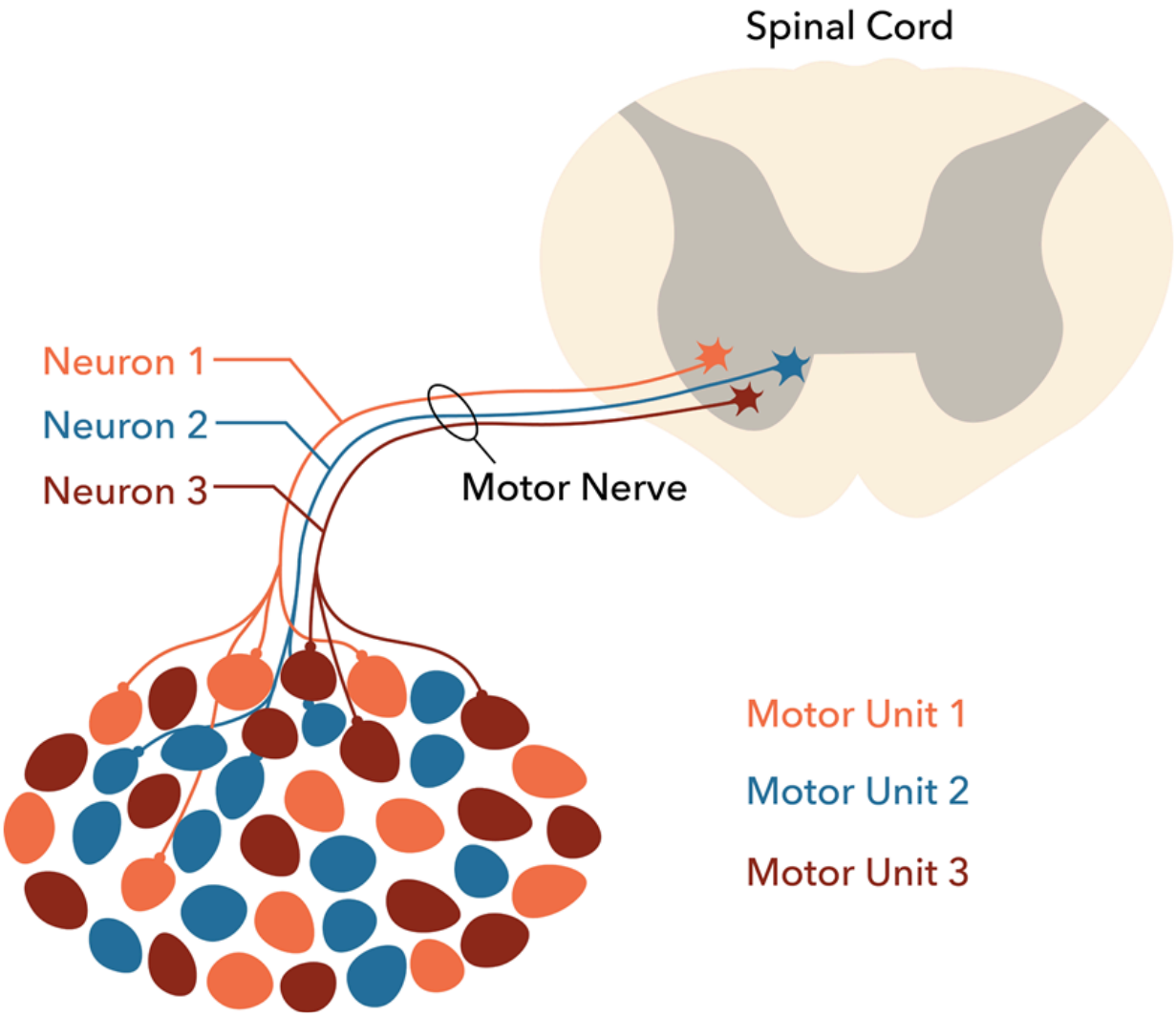


Figure 7.6 Motor Units

The Neuromuscular Junction

The **neuromuscular junction (NMJ)** is the region where a neuron meets and communicates with a skeletal muscle fiber. The two structures are very close together but don't physically touch. There is a small gap of space between them called a synaptic cleft. The neuron will release many molecules of a neurotransmitter or chemical called acetylcholine that will stimulate the skeletal muscle to contract. This is where the muscle fiber first responds to signaling by the motor neuron. Every skeletal muscle fiber in every skeletal muscle is innervated by a motor neuron at the NMJ. Excitation signals from the neuron are the only way to activate the muscle fiber to contract.[10]

10. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young,

Excitation-Contraction Coupling

All living cells have membrane potentials, or electrical gradients across their cell membranes. Additional information about the electrical activity of excitable cells is discussed in the "**Nervous System**" chapter. The inside of the membrane is usually around -60 to -90 mV compared to the outside of the cell. This is referred to as a cell's membrane potential. Neurons and muscle cells can use their membrane potentials to generate electrical signals. They do this by controlling the movement of charged particles, called **ions**, across their membranes to create electrical currents. This is achieved by opening and closing specialized protein channels in the membrane called ion channels.

The term **excitation-contraction coupling** refers to what must happen for a skeletal muscle fiber to contract. First, the sarcolemma must be "excited"— it must be stimulated to create an action potential. The muscle fiber action potential travels along the sarcolemma and is "coupled" to the actual contraction of the muscle fiber.

The brain initiates skeletal muscle contraction. To do so, it sends a signal down the spinal cord. From there, a motor neuron "tells" the muscle to contract. These neurons have long axons that transmit **action potentials** (electrical signals) all the way from the spinal cord to the muscle itself (which may be up to three feet away).

Signaling begins when an action potential travels along the axon of a motor neuron to the neuromuscular junction (NMJ). At the NMJ, the motor axon terminal releases a **neurotransmitter** (a chemical messenger) called **acetylcholine (ACh)**. The ACh molecules diffuse across the space between the motor neuron and the sarcolemma, called the **synaptic** cleft and bind to ACh receptors located on the other side of the synapse. The ACh receptors are found on the **motor end plate** of the sarcolemma. See Figure 7.7[11] for an illustration of the neuromuscular junction, and Figure 7.8[12] for a microscopic image of a neuromuscular junction.

K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

11. Paul Hege. (2020). *Neuromuscular_junction* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Neuromuscular_junction.svg

12. Hlij55567516. (2015). *运动终板* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:%E8%BF%90%E5%8A%A8%E7%BB%88%E6%9D%BF.JPG

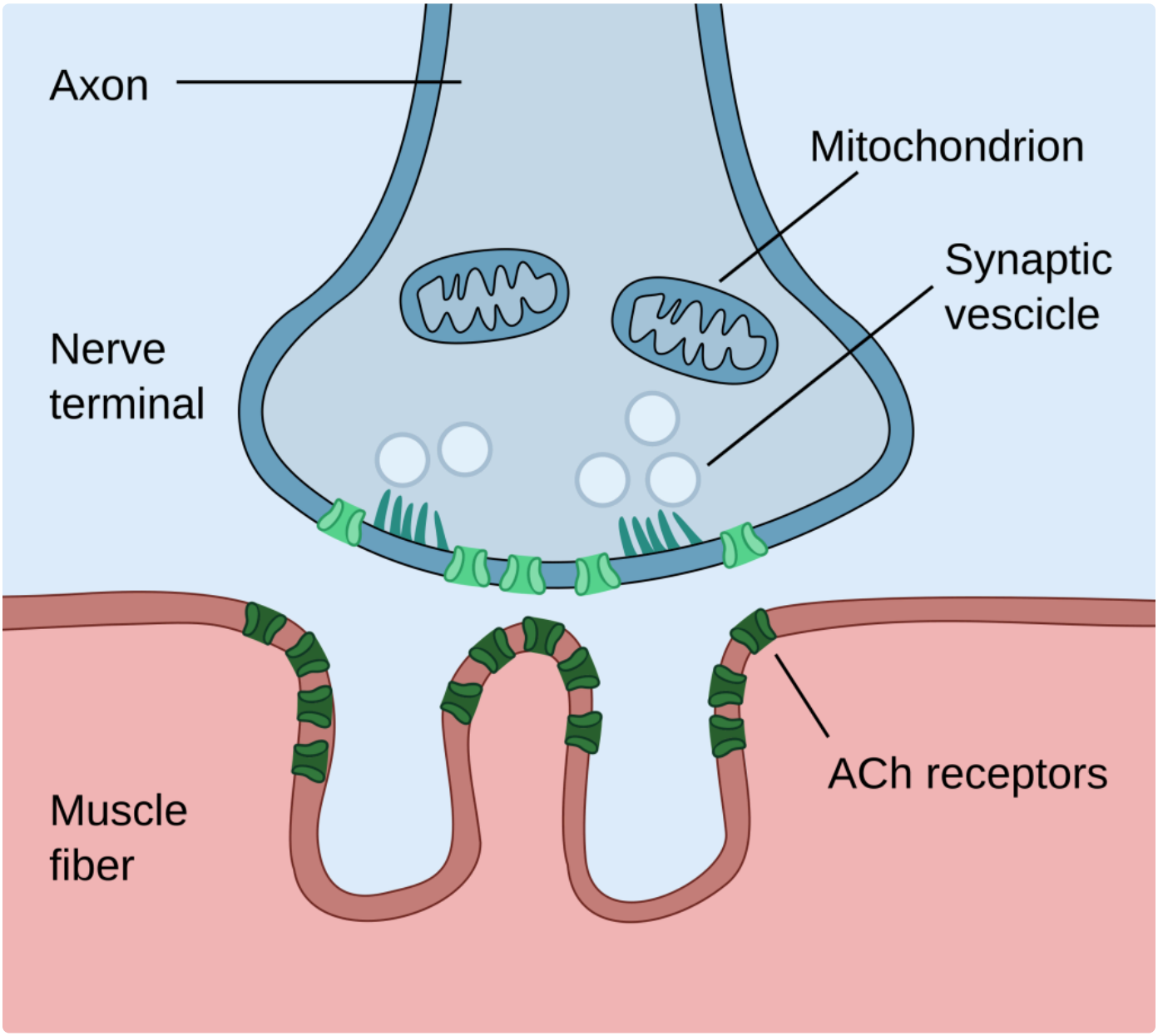


Figure 7.7 Neuromuscular Junction

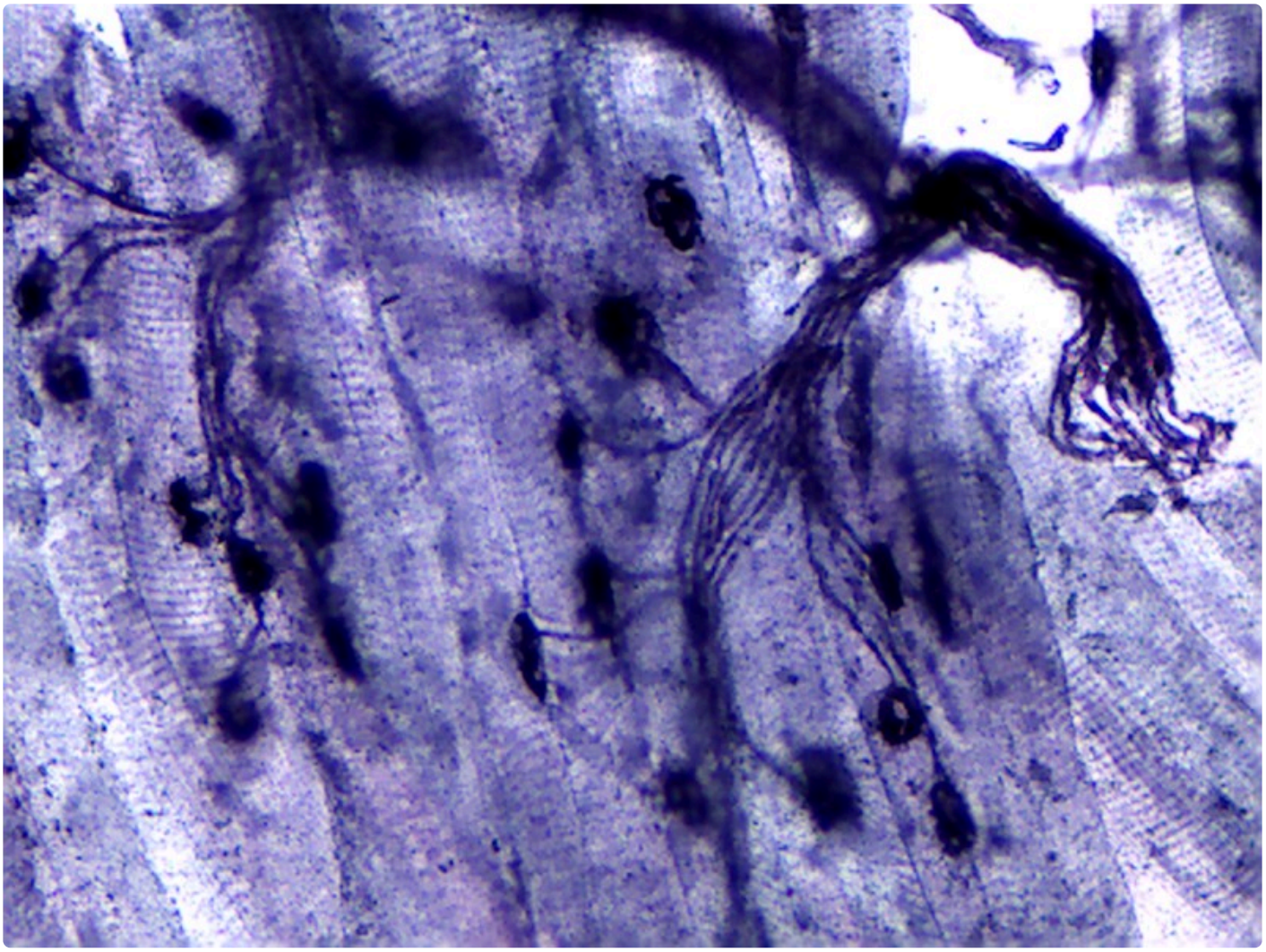


Figure 7.8 Microscopic Image of a Neuromuscular Junction

Once ACh binds to the ACh receptors on the motor end plate, a channel opens and positively charged sodium ions pass through into the muscle fiber. This causes the muscle fiber to **depolarize**, meaning that the membrane potential inside the muscle fiber becomes less negative. As the membrane depolarizes, another set of ion channels called **voltage-gated sodium channels** are triggered to open. Sodium ions enter the muscle fiber, and an action potential rapidly spreads (or "fires") along the entire membrane to initiate excitation-contraction coupling. See Figure 7.9[13] for an illustration of the steps in muscle fiber contraction.

13. OpenStax College. (2016). *1010a_Contraction_new* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1010a_Contraction_new.jpg

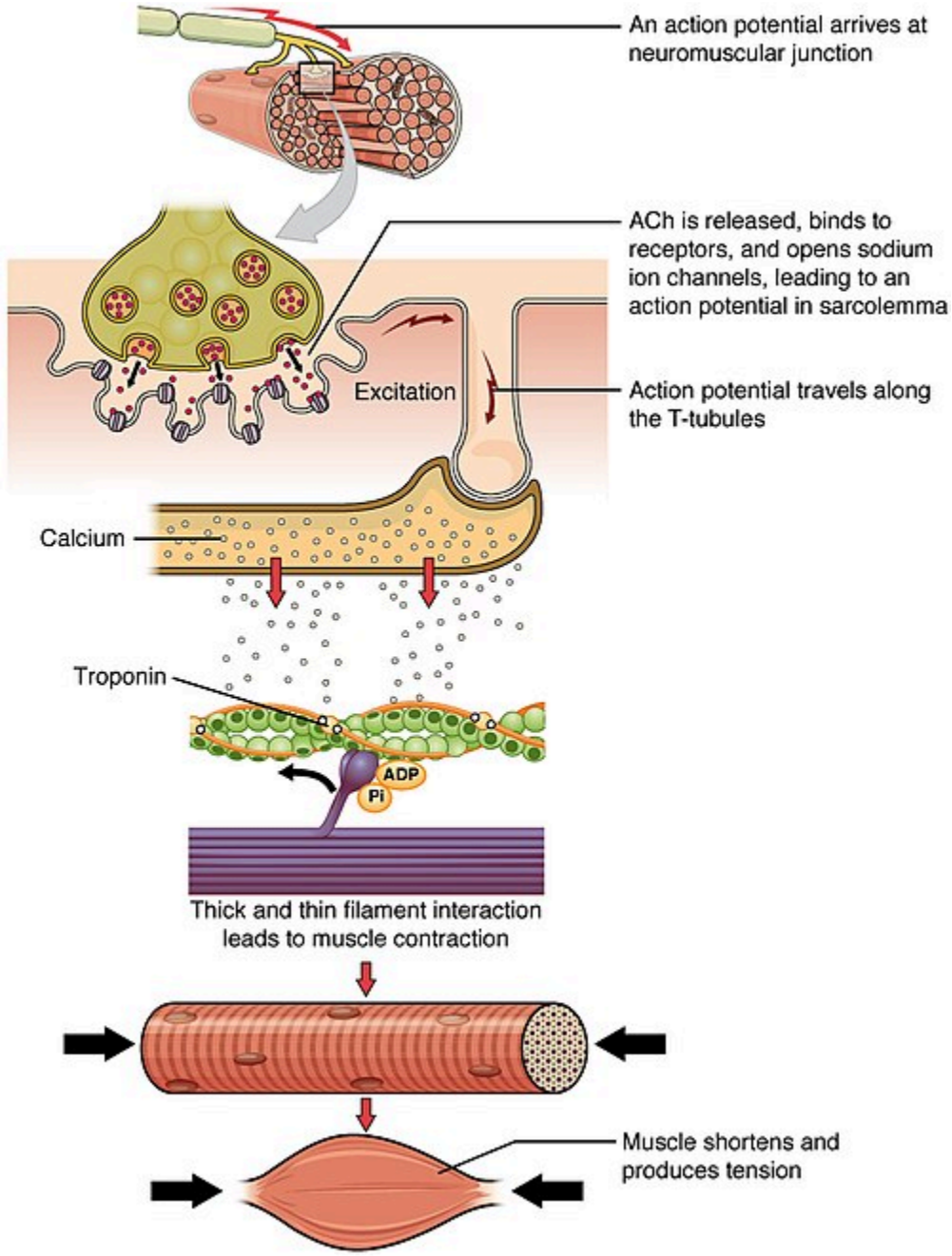


Figure 7.9 Contraction of a Muscle Fiber

Things happen very quickly in the world of excitable membranes (just think about how quickly you can snap your fingers as soon as you decide to do it). Immediately following depolarization of the membrane, it **repolarizes**. In repolarization, voltage-gated potassium channels open and potassium ions leave the cell, re-establishing the negative membrane potential. Muscle contraction usually stops when signaling from

the motor neuron ends. A muscle will also stop contracting when it runs out of ATP and becomes fatigued.[14]

The Sliding Filament Model of Contraction

When signaled by a motor neuron, a skeletal muscle fiber contracts as the thin filaments (actin) are pulled by and then slide past the thick filaments (myosin) inside the sarcomeres. This process is known as the **sliding filament model of muscle contraction**. See Figure 7.10[15] for an illustration of the sliding filament of muscle contraction.

14. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

15. OpenStax College. (2016). *1006_Sliding_Filament_Model_of_Muscle_Contraction* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1006_Sliding_Filament_Model_of_Muscle_Contraction.jpg

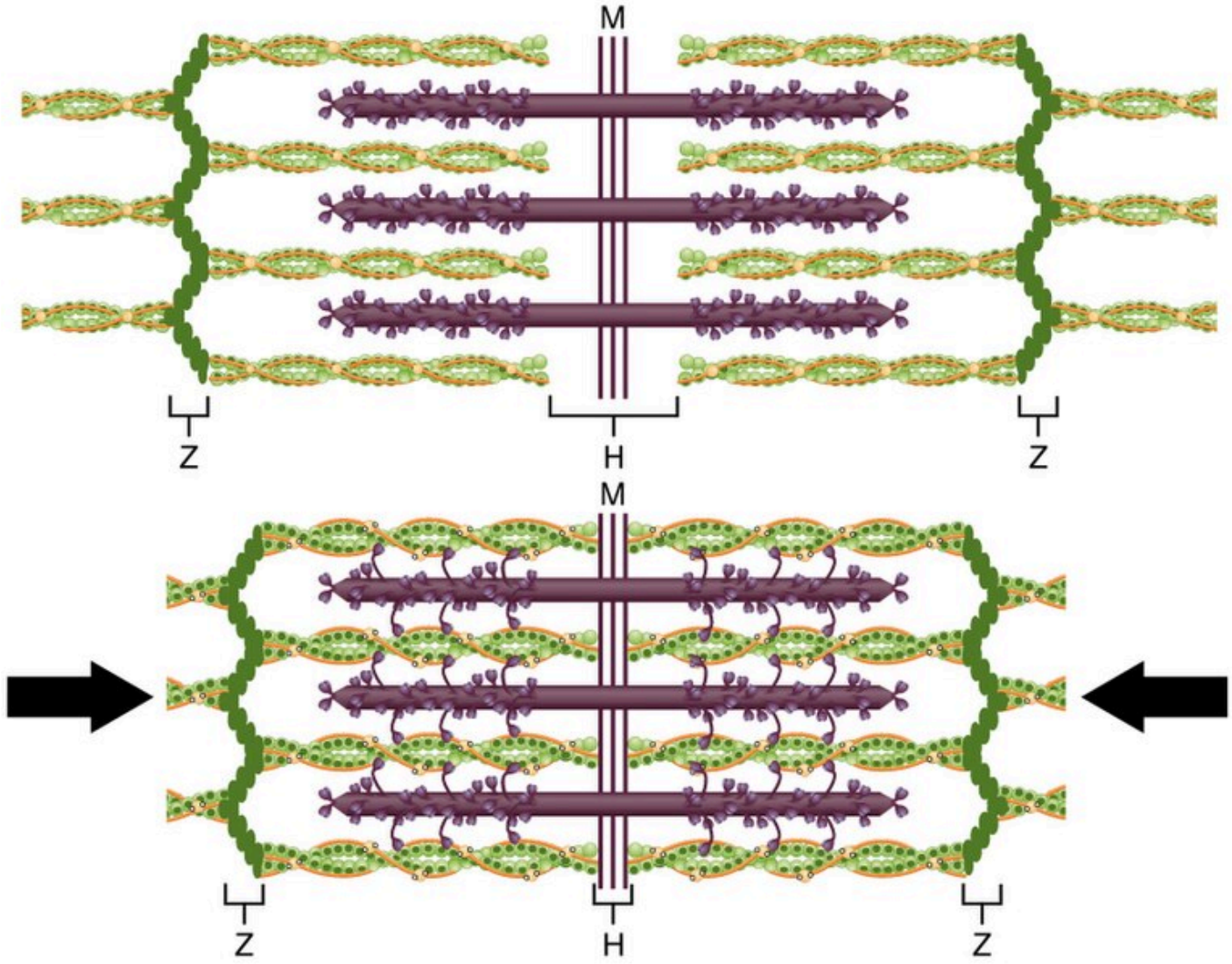


Figure 7.10 The Sliding Filament of Muscle Contraction

Muscle contraction is regulated by proteins and calcium ions. The actin filaments contain myosin-binding sites. These binding sites are the only places that the myosin heads can attach to the actin to pull it during contraction. When a muscle is relaxed, these binding sites are covered by a ribbon-like protein called tropomyosin that winds around the actin filaments. Another regulatory protein called troponin is attached to tropomyosin. For a muscle to contract, these binding sites have to be uncovered.

When a muscle has an action potential, calcium ions are released from the sarcoplasmic reticulum inside the muscle fiber, where they are stored. Calcium ions then attach to the troponin molecules and change its shape, much like a key unlocking a lock.

This allows the myosin heads to attach to actin. The thin filaments are then pulled by the myosin heads and slide toward the center of the sarcomere.[16]

Video

Watch the video "Muscle Tissues and Sliding Filament Model" below to learn about the different types of muscle tissue and how the sliding filament model explains muscle contraction.[17]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

ATP and Muscle Contraction

A huge amount of ATP is needed to power the muscle contraction cycle and keep skeletal muscles working. In fact, it is the loss of ATP that results in the rigor mortis observed soon after death. With no further ATP production possible, myosin cannot detach from actin, causing the rigidity seen in skeletal muscles.[18]

16. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

17. Amoeba Sisters. (2022, May 5). *Muscle tissues and sliding filament model* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=dpxalWACO7k

18. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Relaxation of a Skeletal Muscle

Relaxing skeletal muscle fibers, and ultimately, the skeletal muscle, begins with the motor neuron, which stops releasing its chemical signal, ACh, into the synapse at the NMJ. Because the skeletal muscle fiber has now "lost" its signal to contract, it no longer generates an action potential, and calcium ions are pumped back into the sarcoplasmic reticulum. When calcium ions are removed from troponin, the troponin-tropomyosin complex recovers the binding sites on actin so that myosin can no longer "grab" and slide it. As a result, the muscle relaxes.[19]

Muscle Strength

The number of skeletal muscle fibers in a given muscle is genetically determined and does not change. Muscle strength is directly related to the number of myofibrils and sarcomeres within each fiber. Factors, such as hormones and stress (and artificial anabolic steroids), acting on the muscle can increase the production of sarcomeres and myofibrils within the muscle fibers, a change called **hypertrophy**, which results in the increased mass and bulk in a skeletal muscle. Likewise, decreased use of a skeletal muscle results in **atrophy**, where the number of sarcomeres and myofibrils disappear (but not the number of muscle fibers). It is common for a broken limb in a cast to show atrophied muscles when the cast is removed. This effect is temporary, and the muscle regains strength when the limb is used again. Certain diseases, such as polio, also lead to atrophied muscles.

To move an object, referred to as a load, the sarcomeres in the muscle fibers of the skeletal muscle must shorten. The force generated by the contraction of the muscle (or shortening of the sarcomeres) is called **muscle tension**. Muscle tension is also generated when the muscle is contracting against a load that does not move, resulting in two main types of skeletal muscle contractions: isotonic contractions and isometric contractions. All these muscle activities are under the control of the nervous system.[20]

19. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

20. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Isotonic and Isometric Contractions

In **isotonic contractions**, the tension in the muscle stays constant, and movement occurs as the length of the muscle changes (shortens). There are two types of isotonic contractions: concentric and eccentric. A **concentric contraction** involves the muscle shortening to move a load. An example of this is the biceps brachii muscle contracting to bend the elbow when a hand weight is brought upward with increasing muscle tension. As the biceps brachii contracts, the angle of the elbow joint decreases as the forearm is brought toward the body. An **eccentric contraction** occurs as the muscle tension diminishes and the muscle lengthens. In this case, the hand weight is lowered in a slow and controlled manner. The tension is released from the biceps brachii, and the angle of the elbow joint increases.

An **isometric contraction** occurs as the muscle produces tension without producing movement. For example, if one attempts to lift a hand weight that is too heavy, there will be sarcomere activation and shortening to a point, and ever-increasing muscle tension, but no change in the angle of the elbow joint. In everyday living, isometric contractions are active in maintaining posture and bone and joint stability. However, holding your head in an upright position does not occur because the muscles cannot move the head, but because the goal is to remain stationary and not produce movement. Most actions of the body are the result of a combination of isotonic and isometric contractions working together.[21] See Figure 7.11[22] for an illustration of the isometric and isotonic contractions.

21. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

22. OpenStax Collge. (2016). *1015_Types_of_Contraction_new* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1015_Types_of_Contraction_new.jpg

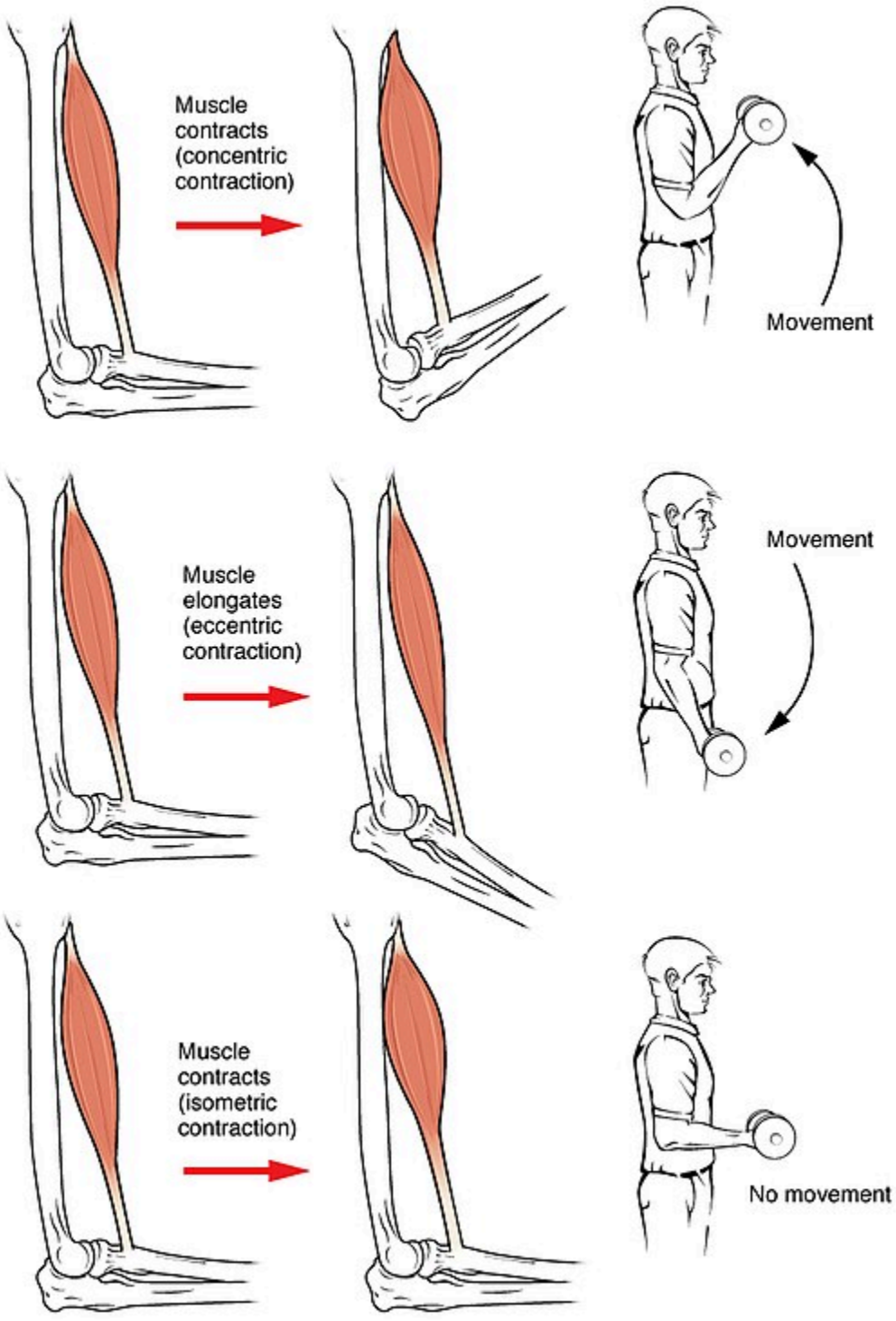


Figure 7.11 Types of Muscle Contractions

Muscle Tone

Skeletal muscles are rarely completely relaxed (flaccid). Even if a muscle is not

producing movement, it contracts a small amount to produce **muscle tone**. The tension produced by muscle tone allows muscles to stabilize joints and maintain posture. Muscle tone is accomplished by a complex interaction between the nervous system and skeletal muscles that results in the activation of a few motor units at a time. In this manner, muscles never fatigue completely, as some motor units can recover while others are active.[23]

Hypotonia

The absence of the low-level contractions that lead to muscle tone is referred to as **hypotonia** and can result from damage to parts of the brain, such as the cerebellum, the spinal cord, or from loss of innervation to a skeletal muscle, as in poliomyelitis. Hypotonic muscles have a flaccid (limp) appearance and display functional impairments, such as weak reflexes.[24]

Hypertonia

Excessive muscle tone is referred to as **hypertonia**, accompanied by hyperreflexia (excessive reflex responses), and it is often the result of damage to upper motor neurons in the brain or spinal cord. Hypertonia can present with muscle rigidity (as seen in Parkinson's disease) or **spasticity**, an increase in muscle tone and stiffness.[25]

Performance-Enhancing Substances

Some athletes attempt to boost their performance by using various agents that may enhance muscle performance. Anabolic steroids are a well-known method to boost muscle mass and increase power output. Anabolic steroids are a form

23. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

24. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

25. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

of testosterone, a male sex hormone that stimulates muscle formation, leading to increased muscle mass.

Endurance athletes may also try to boost the availability of oxygen to muscles by using substances such as erythropoietin (EPO), a hormone normally produced by the kidneys, which triggers the production of red blood cells. The extra oxygen carried by these blood cells can then be used by muscles. Human growth hormone (hGH) is another supplement, and although it can facilitate building muscle mass, its main role is to promote the healing of muscle and other tissues after strenuous exercise. Increased hGH may allow for faster recovery after muscle damage, reducing the rest required after exercise, and allowing for more sustained high-level performance.

Although performance-enhancing substances often do improve performance, most are banned by governing bodies in sports and are illegal for nonmedical purposes. Their use to enhance performance raises ethical issues of cheating because they give users an unfair advantage over nonusers. A greater concern, however, is that their use carries serious health risks. The side effects of these substances are often significant, irreversible, and in some cases fatal. The physiological strain caused by these substances is often greater than what the body can handle, leading to effects that are unpredictable and dangerous. Anabolic steroid use has been linked to infertility, aggressive behavior, cardiovascular disease, and brain cancer.

Similarly, some athletes have used creatine to increase power output. Creatine phosphate provides quick bursts of ATP to muscles in the initial stages of contraction. Increasing the amount of creatine available to cells is thought to produce more ATP and, therefore, increase explosive power output, although its effectiveness as a supplement has been questioned.

Interactions of Skeletal Muscles in the Body

Muscles are usually connected to bones by tendons. Some muscles are connected by an aponeurosis instead. Muscles have at least two attachment points. To pull on a bone and move the skeleton, a skeletal muscle must also be attached to a fixed part of the skeleton. The movable end of a muscle that attaches to the bone being pulled is called the muscle's **insertion**, and the end of the muscle attached to a fixed (stabilized) bone is called the **origin**. During forearm flexion—bending the elbow—the brachioradialis assists the brachialis.

Although a number of muscles may be involved in an action, the primary muscle involved is called the **prime mover**, or **agonist**. To lift a cup, a muscle called the biceps brachii is the prime mover; however, because it is assisted by the brachialis, the brachialis is called a **synergist**. A synergist can also be a **fixator** that stabilizes the bone attached to the prime mover's origin. See Figure 7.12[26] for an illustration of prime movers and synergists.

26. OpenStax College. (2013). *Biceps_Muscle_CNX* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Biceps_Muscle_CNX.jpg

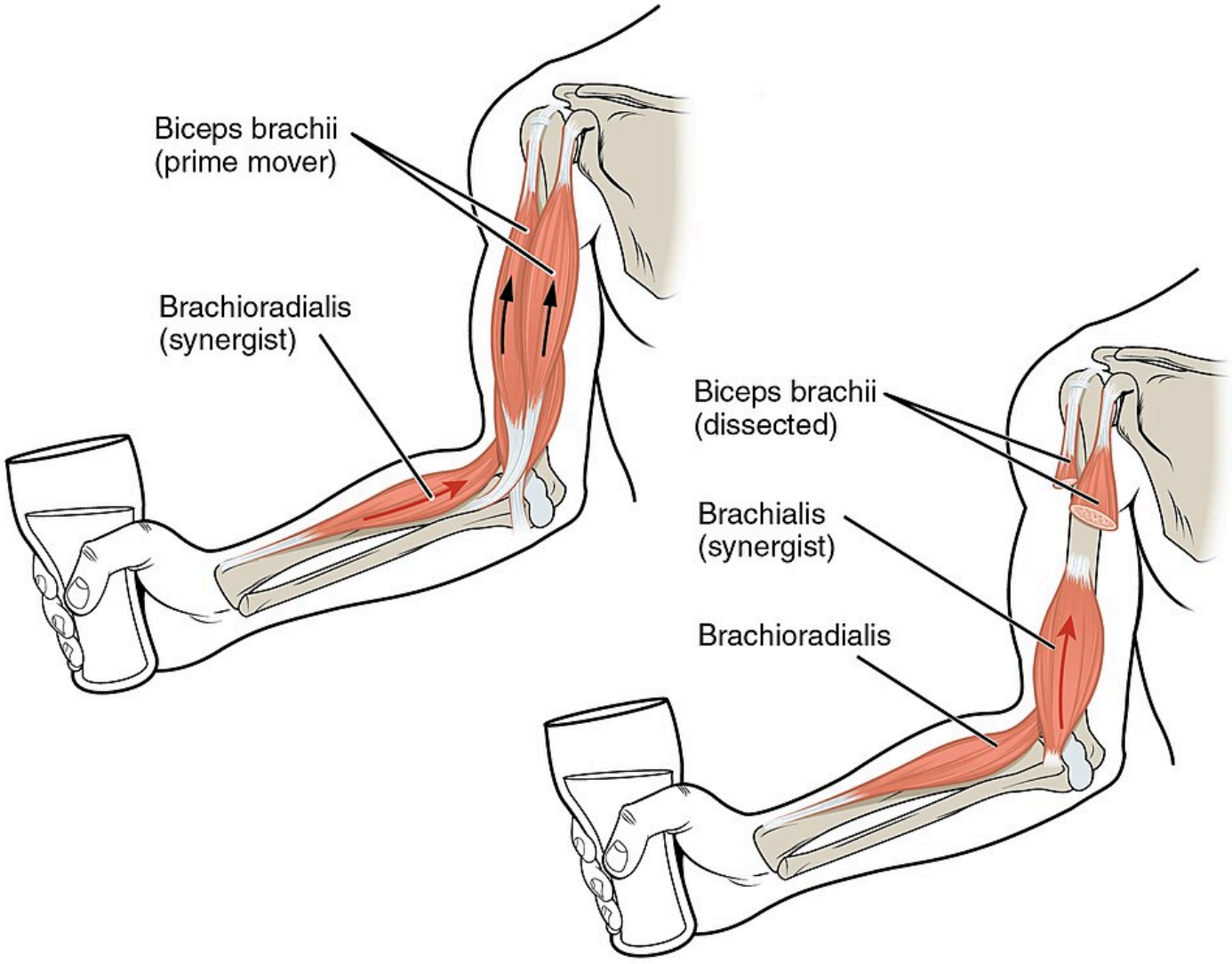


Figure 7.12 Prime Movers and Synergists

A muscle with the opposite action of the prime mover is called an **antagonist**. Antagonists play two important roles in muscle function: (1) they maintain body or limb position, such as holding the arm out or standing erect; and (2) they control rapid movement, as in shadow boxing without landing a punch or the ability to check the motion of a limb.

For example, to extend the knee, a group of four muscles called the quadriceps femoris in the anterior compartment of the thigh is activated (and would be called the agonists of knee extension). However, to flex the knee joint, an opposite or antagonistic set of muscles called the hamstrings is activated.

As you can see, these terms would also be reversed for the opposing action. If you consider the first action as the knee bending, the hamstrings would be called the

agonists, and the quadriceps femoris would then be called the antagonists. See Table 7.3a for an example of some agonists and antagonists.

Table 7.3a. Examples of Agonist and Antagonist Skeletal Muscle Pairs[27]

Agonist	Antagonist	Action(s)
Biceps brachii: anterior upper arm	Triceps brachii: posterior upper arm	The biceps brachii flexes the forearm, whereas the triceps brachii extends it
Hamstrings: posterior thigh (group of three muscles)	Quadriceps femoris: anterior thigh (group of four muscles)	The hamstrings flex the lower leg, whereas the quadriceps femoris extend it

There are also skeletal muscles that do not pull against the skeleton for movements. For example, there are the muscles that produce facial expressions. The insertions and origins of facial muscles are in the skin, allowing muscles to contract to form a smile or frown, form sounds or words, and raise the eyebrows. There are also skeletal muscles in the tongue and the external urinary and anal sphincters that allow for voluntary control of urination and defecation. In addition, the diaphragm contracts and relaxes to change the volume of the thoracic cavity during breathing, but it does not move the skeleton to do this.[28]

Exercise and Stretching

When exercising, it is important to first warm up the muscles. Stretching pulls on the muscle fibers and results in an increased blood flow to the muscles being worked. Without a proper warm-up, it is possible to damage some of the muscle fibers or pull a tendon. A pulled tendon, regardless of location, results in pain, swelling, and diminished function.

Most of the joints used during exercise are synovial joints, which have synovial fluid in

27. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

28. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

the joint space between two bones. Exercise and stretching may have a beneficial effect on synovial joints. Synovial fluid is a thin, but viscous film with the consistency of egg whites. After proper stretching and warm-up, the synovial fluid may become less viscous, allowing for better joint function.[29]

Skeletal Muscle Actions

There are many types of actions that are caused by the contraction of muscles, such as flexion, extension, abduction, adduction, rotation, dorsiflexion, plantar flexion, supination, and pronation. These muscle actions are summarized in Table 7.3b.

Table 7.3b. Muscle Actions[30]

29. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

30. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Action	Description
Flexion	Movement that decreases the angle between two bones, such as bending the arm at the elbow.
Extension	Movement that increases the angle between two bones, such as straightening the arm at the elbow.
Abduction	Movement of a limb away from the midline of the body.
Adduction	Movement of a limb toward the midline of the body.
Rotation	Circular movement around a central point. Internal rotation is toward the center of the body, and external rotation is away from the center of the body.
Dorsiflexion	Decreasing the angle between the foot and the lower leg at the ankle (i.e., the foot moves upward towards the shin).
Plantar Flexion	Increasing the angle between the foot and the lower leg at the ankle (i.e., the foot moves downward toward the ground, such as when pressing down on a gas pedal in a car).
Supination	Movement of the hand or foot turning upward. When applied to the hand, it is the act of turning the palm upwards. When applied to the foot, it is the outward roll of the foot/ankle during normal movement.
Pronation	Movement of the hand or foot turning downward. When applied to the hand, it is the act of turning the palm downward. When applied to the foot, it is the inward roll of the foot/ankle during normal movement.
Eversion	Excessive movement turning the sole of the foot away from the midline of the body; a common cause of an ankle sprain.
Inversion	Excessive movement, turning the sole of the foot towards the midline; a common cause of an ankle sprain.
Elevation	Upward (superior) motion of the scapula or mandible.
Depression	Downward (inferior) motion of the scapula or mandible.
Hyperextension	Abnormal or excessive extension of a joint beyond its normal range of motion.

Action	Description
Circumduction	Movement of the limb, hand, or fingers in a circular pattern, in which one end of the body region being moved stays relatively stationary while the other end describes a circle.
Opposition	Thumb movement that brings the tip of the thumb in contact with the tip of a finger.

See Figures 7.13[31] and 7.14[32] for illustrations of muscle actions.

31. Tonye Ogele CNX. (2013). *Body_Movements_I* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Body_Movements_I.jpg

32. Tonye Ogele CNX. (2013). *Body_Movements_II* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Body_Movements_II.jpg

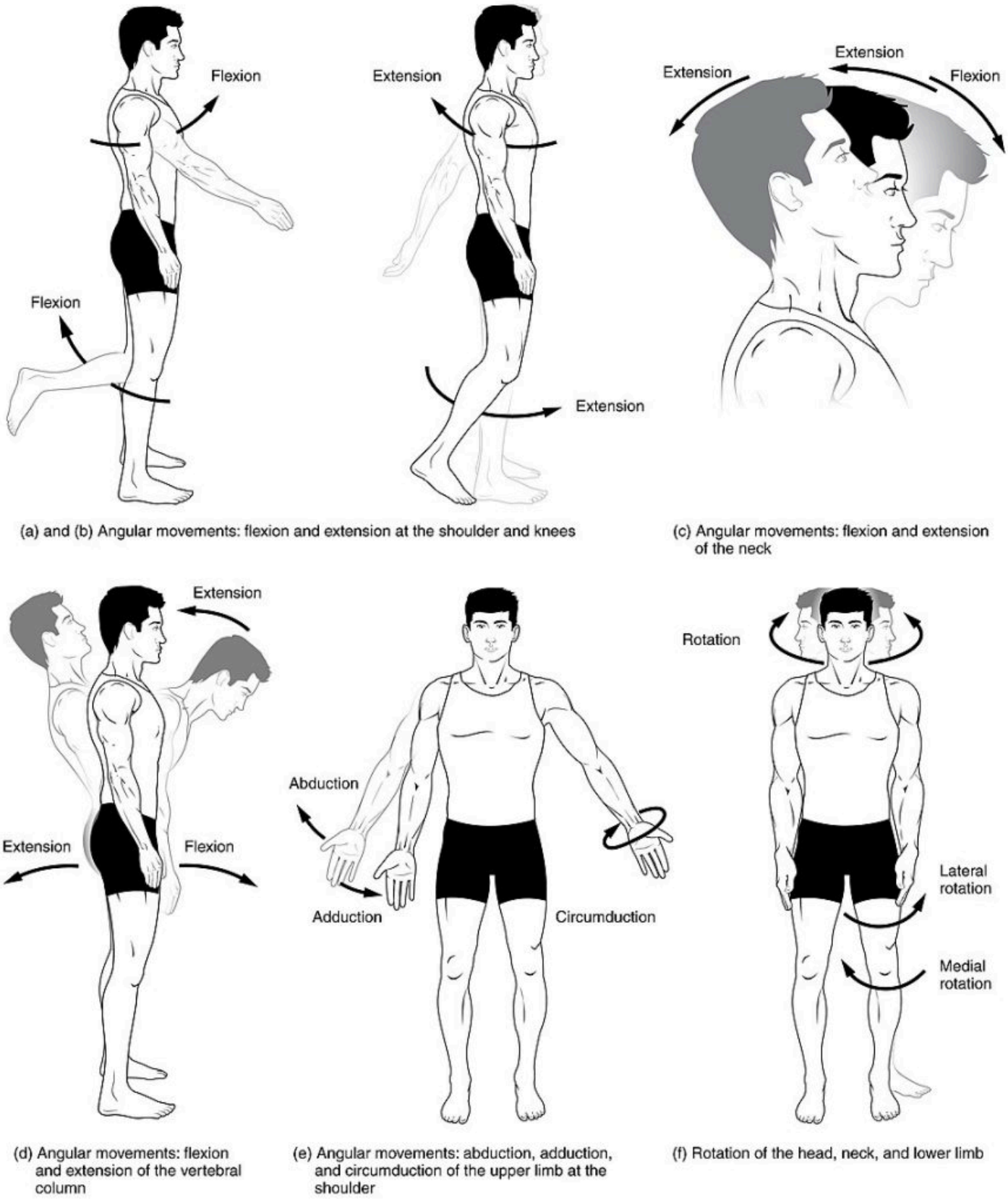


Figure 7.13 Flexion, Extension, Adduction, Abduction, Circumduction, and Rotation

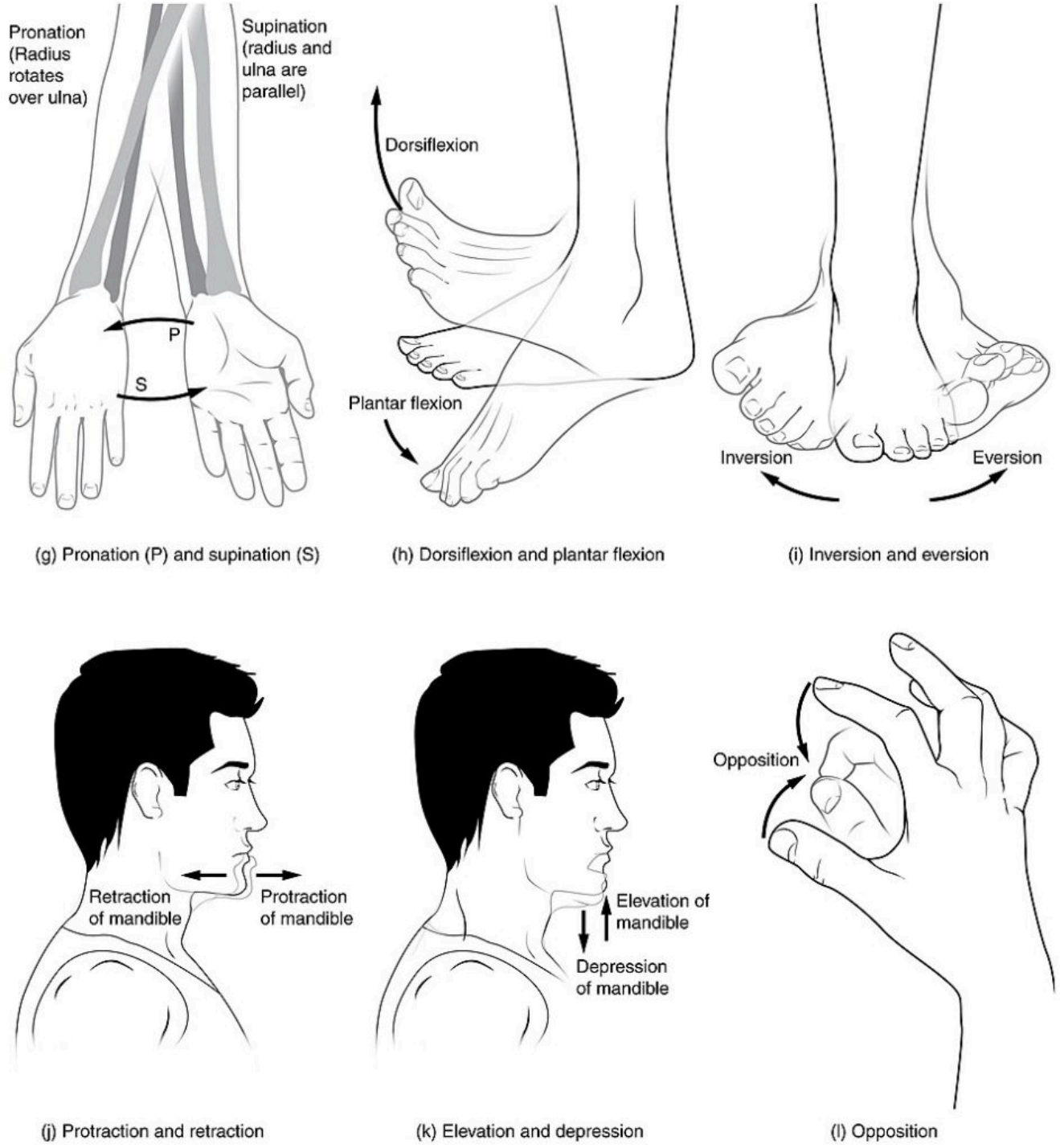


Figure 7.14 Pronation, Supination, Dorsiflexion, Plantar Flexion, Inversion, Eversion, Protraction, Retraction, Elevation, Depression, and Opposition

Patterns of Fascicle Organization

As previously discussed in this chapter, skeletal muscle is surrounded by connective

tissue at three levels. Each muscle fiber (cell) is covered by endomysium, and the entire muscle is covered by epimysium. Groups of muscle fibers are "bundled" into **fascicles** and covered by connective tissue called perimysium. Fascicle arrangement by perimysium is correlated to the force generated by a muscle; it also affects the range of motion of the muscle. Based on the patterns of fascicle arrangement, skeletal muscles can be classified in several ways. The following are the most common fascicle arrangements.[33]

Parallel muscles have fascicles that are arranged in the same direction as the long axis of the muscle. The majority of skeletal muscles in the body have this type of organization. Some parallel muscles are flat sheets that expand at the ends to make broad attachments. Other parallel muscles are rounder with tendons at one or both ends. Muscles that seem to be plump have a large mass of tissue located in the middle of the muscle, between the insertion and the origin, which is known as the central body. A more common name for this is **belly**. When a muscle contracts, the contractile fibers shorten it to an even larger bulge. For example, extend and then flex your biceps brachii muscle; the large, middle section is the belly. See Figure 7.15[34] for an image of the biceps brachii muscle. When a parallel muscle has a central, large belly that is spindle-shaped, meaning it tapers as it extends to its origin and insertion, it is sometimes called **fusiform**.

33. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

34. OpenStax College. (2016). *Biceps_Brachii_Muscle_Contraction* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:1015_Types_of_Contraction_new.jpg

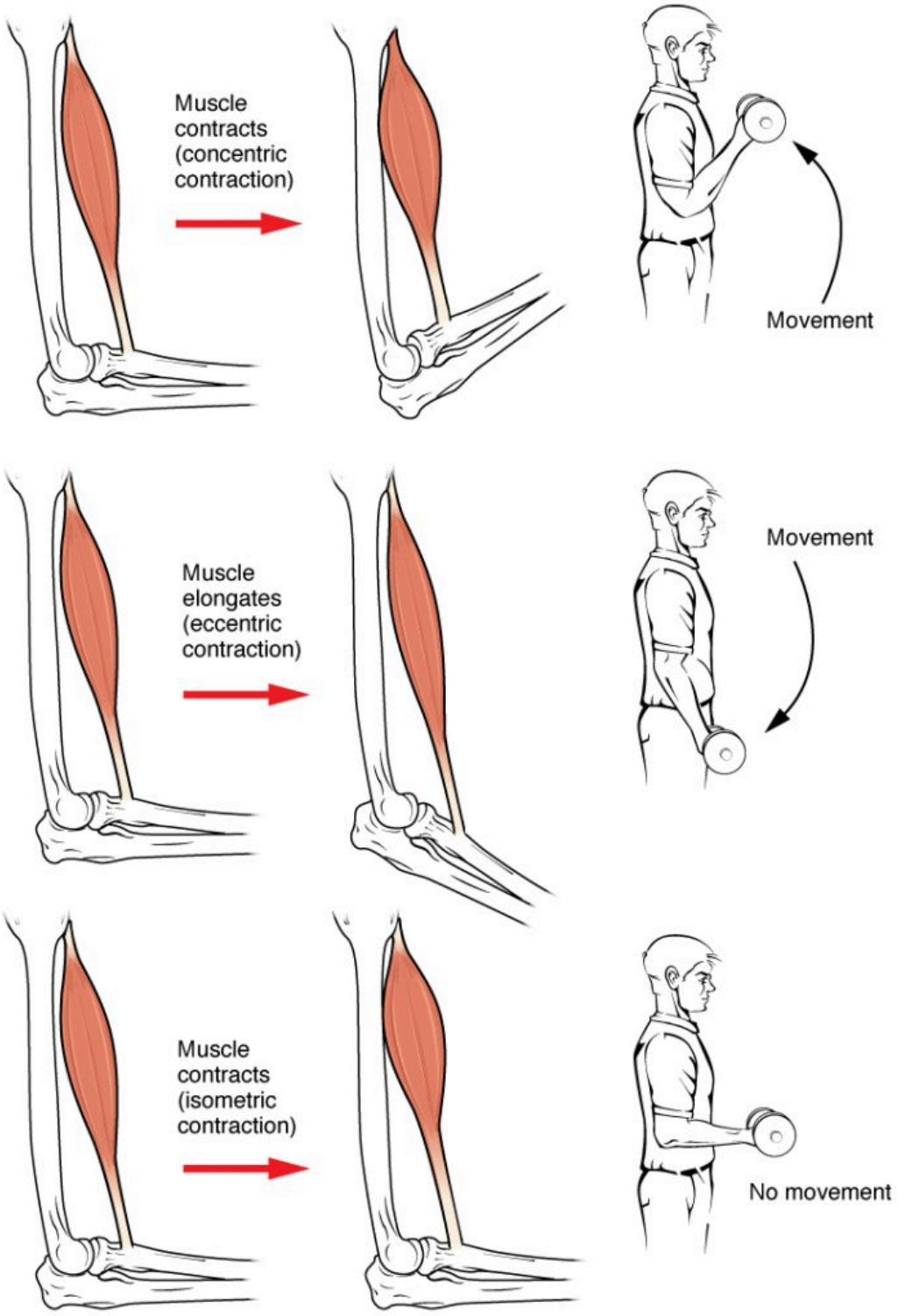


Figure 7.15 Biceps Brachii Muscle Contraction

Circular muscles are also called **sphincters**. When they relax, the sphincters' circularly arranged bundles of muscle fibers increase the size of the opening, and when they contract, the size of the opening shrinks to close. The orbicularis oris muscle is a circular

muscle that surrounds the mouth. When it contracts, the oral opening becomes smaller, as when puckering the lips for whistling. Another example is the orbicularis oculi, the muscles that surround each eye. Notice the names of the two orbicularis muscles (orbicularis oris and orbicularis oculi), where part of the first name of both muscles is the same. The first part of orbicularis, orb (*orb* = "circular"), is a reference to a round or circular structure; it may also make one think of orbit, such as the moon's path around the earth. The word oris (*oris* = "oral") refers to the oral cavity, or the mouth. The word oculi (*ocular* = "eye") refers to the eye.

There are other muscles throughout the body named by their shape or location. The deltoid is a large, triangular-shaped muscle that covers the shoulder. It is so named because the Greek letter delta looks like a triangle. The rectus abdominis (*rector* = "straight") is the straight muscle in the anterior wall of the abdomen, while the rectus femoris is the straight muscle in the anterior compartment of the thigh.

When a muscle has a widespread expansion over a sizable area, but then the fascicles come to a single, common attachment point, the muscle is called convergent. The attachment point for a **convergent muscle** could be a tendon, an aponeurosis (a flat, broad tendon), or a **raphe** (a very slender tendon). The large muscle on the chest, the pectoralis major, is an example of a convergent muscle because it converges on the greater tubercle of the humerus via a tendon. The temporalis muscle of the cranium is another. **Pennate muscles** (*penna* = "feathers") blend into a tendon that runs through the central region of the muscle for its whole length, somewhat like the quill of a feather, with the muscle arranged similar to the feathers. Due to this design, the muscle fibers in a pennate muscle can only pull at an angle, and as a result, contracting pennate muscles do not move their tendons very far. However, because a pennate muscle generally can hold more muscle fibers within it, it can produce relatively more tension for its size. In a **unipennate** muscle, the fascicles are located on one side of the tendon. The extensor digitorum of the forearm is an example of a unipennate muscle. A **bipennate** muscle has fascicles on both sides of the tendon. In some pennate muscles, the muscle fibers wrap around the tendon, sometimes forming individual fascicles in the process. This arrangement is referred to as **multipennate**. A common example is the deltoid muscle of the shoulder, which covers the shoulder but has a single tendon that inserts on the deltoid tuberosity of the humerus.

See Figure 7.16[35] for an illustration of the seven different muscle shapes.

35. OpenStax College. (2013). *Fascicle_Muscle_Shapes* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Fascicle_Muscle_Shapes.jpg

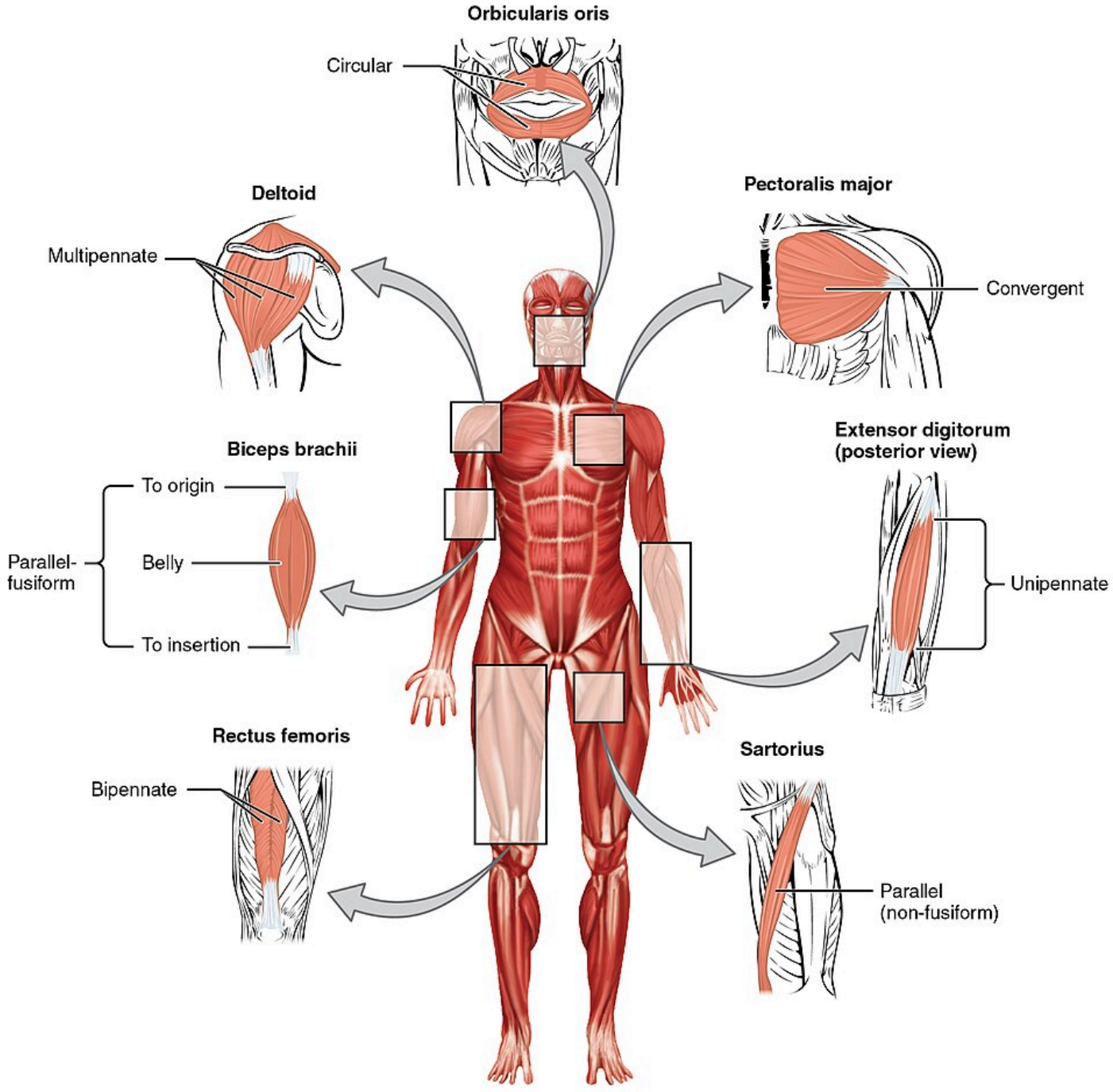


Figure 7.16 Muscle Shapes and Fiber Alignment

Naming Skeletal Muscles

The Greeks and Romans conducted the first studies on the human body in Western culture. Subsequent societies studied Latin and Greek, and, therefore, the early pioneers

of anatomy continued to apply Latin and Greek terminology or roots when they named the skeletal muscles.

The large number of muscles in the body and unfamiliar words can make learning the names of the muscles in the body seem daunting, but understanding the etymology can help. Etymology is the study of how the root of a particular word entered a language and how the use of the word evolved. Taking the time to learn the roots of the words is crucial to understanding the vocabulary of anatomy and physiology. When you understand the names of muscles, it will help you remember where the muscles are located and what they do. See Table 7.3c for some examples of Latin root words and their meanings related to muscles. Table 7.3d provides some mnemonic devices for common Latin roots found in muscle names. Pronunciation of words and terms will take a bit of time to master, but after some basic information, the correct names and pronunciations will become easier.[36]

Table 7.3c. Understanding a Muscle Name from the Latin[37]

36. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

37. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Example	Word	Latin Root 1	Latin Root 2	Meaning	Translation
abductor digiti minimi	**abductor**	ab = away from	duct = to move	A muscle that moves away from	A muscle that moves the little finger or toe away
	digiti	digitus = digit		Refers to a finger or toe	
	minimi	minimus = mini, tiny		Little	
adductor digiti minimi	**adductor**	ad = to, toward	duct = to move	A muscle that moves toward	A muscle that moves the little finger or toe toward
	digiti	digitus = digit		Refers to a finger or toe	
	minimi	minimus = mini, tiny		Little	

Table 7.3d. Memory Tips for Latin Roots[38]

38. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Example	Latin or Greek	Translation	Memory
ad	to; toward		ADvance toward your goal.
ab	away from		To be ABSent from class means being away.
sub	under		SUBmarines move underwater.
ductor	something that moves		A conDUCTOR makes a train move.
anti	against		If you are ANTIsocial, you are against engaging in social activities.
epi	on top of		The EPIdermis is the top layer of skin.
apo	to the side of		The APOstrophe sits next to the side of a word.
longissimus	longest		"Longissimus" is longer than the word "long."
longus	long		A longus muscle is relatively LONG.
brevis	short		A brevis muscle is relatively short, like a BRIEF meeting.
maximus	large		"I MAX out" can be used to remember that the gluteus maximus is a large muscle.
medius	medium		"Medius" and "medium" both begin with "med."
minimus	tiny; little		"Mini mouse" can help remember that minimus means tiny.
rectus	straight		To RECTify a situation is to straighten it out.
multi	many		If something is MULTIcolored, it has many colors.
uni	one		A UNIcorn has one horn.
bi/di	two		If a ring is DIcast, it is made of two metals.

Example	Latin or Greek	Translation	Memory
tri	three		TRIple the amount is three times as much.
quad	four		QUADruplets are four children born at one birth.
externus	outside		An EXTERNal temperature is taken outside the body.
internus	inside		An INTERNal temperature is taken inside the body.

Anatomists name the skeletal muscles according to a number of criteria, each describing the muscle in some way. These include naming the muscle after its shape, its size compared to other muscles in the area, its location in the body, or the location of its attachments to the skeleton, how many origins it has, or its action.

The skeletal muscle's anatomical location or its relationship to a particular bone often determines its name. For example, the frontalis muscle is located anterior to the frontal bone of the skull. Similarly, the shapes of some muscles are very distinctive, and the names, such as orbicularis, reflect the shape. For the buttocks, the size of the muscles influences the names: gluteus **maximus** (largest), gluteus **medius** (medium), and the gluteus **minimus** (smallest). Gluteus means buttocks. Names can indicate length—**brevis** (short) and **longus** (long)—and identify position relative to the midline—**lateralis** (away from the midline) and **medialis** (toward the midline). The direction of the muscle fibers and fascicles is used to describe muscles relative to the midline, such as the **rectus** (straight) abdominis or the **oblique** (at an angle) muscles of the abdomen.

Some muscle names indicate the number of muscles in a group. One example of this is the quadriceps femoris, a group of four muscles located on the anterior thigh. Other muscle names can provide information as to how many origins a particular muscle has, such as the biceps brachii. The prefix *bi* indicates that the muscle has two origins, and *tri*, as in triceps brachii, indicates three origins.

The location of a muscle's attachment can also appear in its name. When the name of a muscle is based on the attachments, the origin is always named first. For instance, the sternocleidomastoid muscle of the neck has a dual origin on the sternum (sterno) and clavicle (cleido), and it inserts on the mastoid process of the temporal bone.

The last feature by which a muscle is named is its action. When muscles are named

for the movement they produce, one can find action words in their name. Some examples are flexor (decreases the angle at the joint), extensor (increases the angle at the joint), abductor (moves the bone away from the midline), or adductor (moves the bone toward the midline).

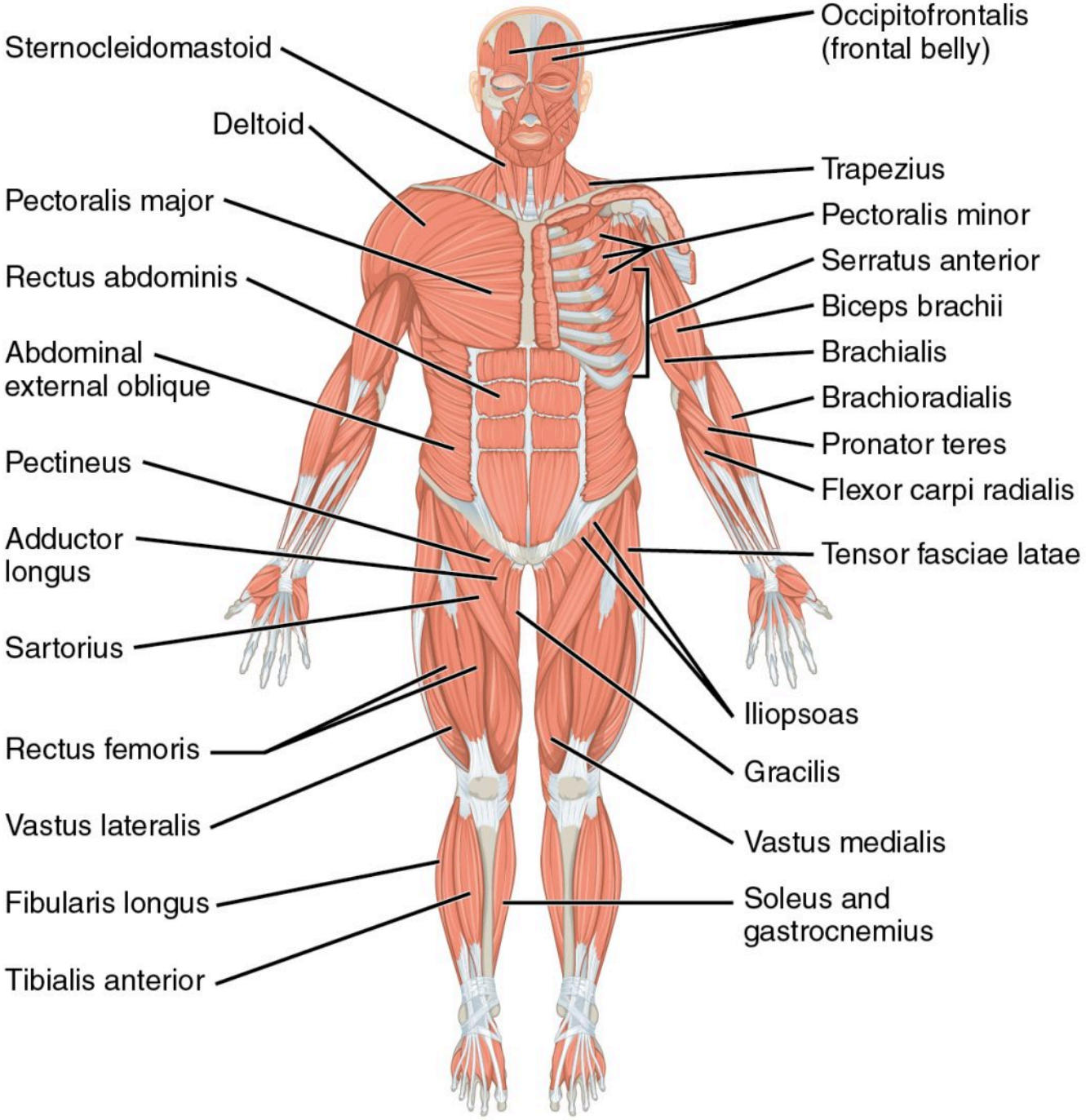
The skeletal muscles are divided into axial (muscles of the trunk and head) and appendicular (muscles of the arms and legs) categories. This system reflects the bones of the skeletal system, which are also arranged in this manner. The axial muscles are grouped based on location, function, or both.[39]

Major Skeletal Muscles

See Figure 7.17[40] for an illustration of the major skeletal muscles of the human body. Functions of muscles are further described in the following subsections.

39. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

40. OpenStax College. (2016). *1105_Anterior_and_Posterior_Views_of_Muscles* [Diagram]. Wikimedia Commons. CC BY 4.0. https://en.wikipedia.org/wiki/File:1105_Anterior_and_Posterior_Views_of_Muscles.jpg



Major muscles of the body. Right side: superficial; left side: deep (anterior view)



Figure 7.17 Major Skeletal Muscles

Muscles That Create Facial Expression

The origins of the muscles of facial expression are on the surface of the skull (remember, the origin of a muscle does not move). The insertions of these muscles have fibers intertwined with connective tissue and the dermis of the skin. Because the muscles insert in the skin rather than on bone, when they contract, the skin moves to create facial expression. See Figure 7.18[41] for an illustration of the muscles that create facial expressions.

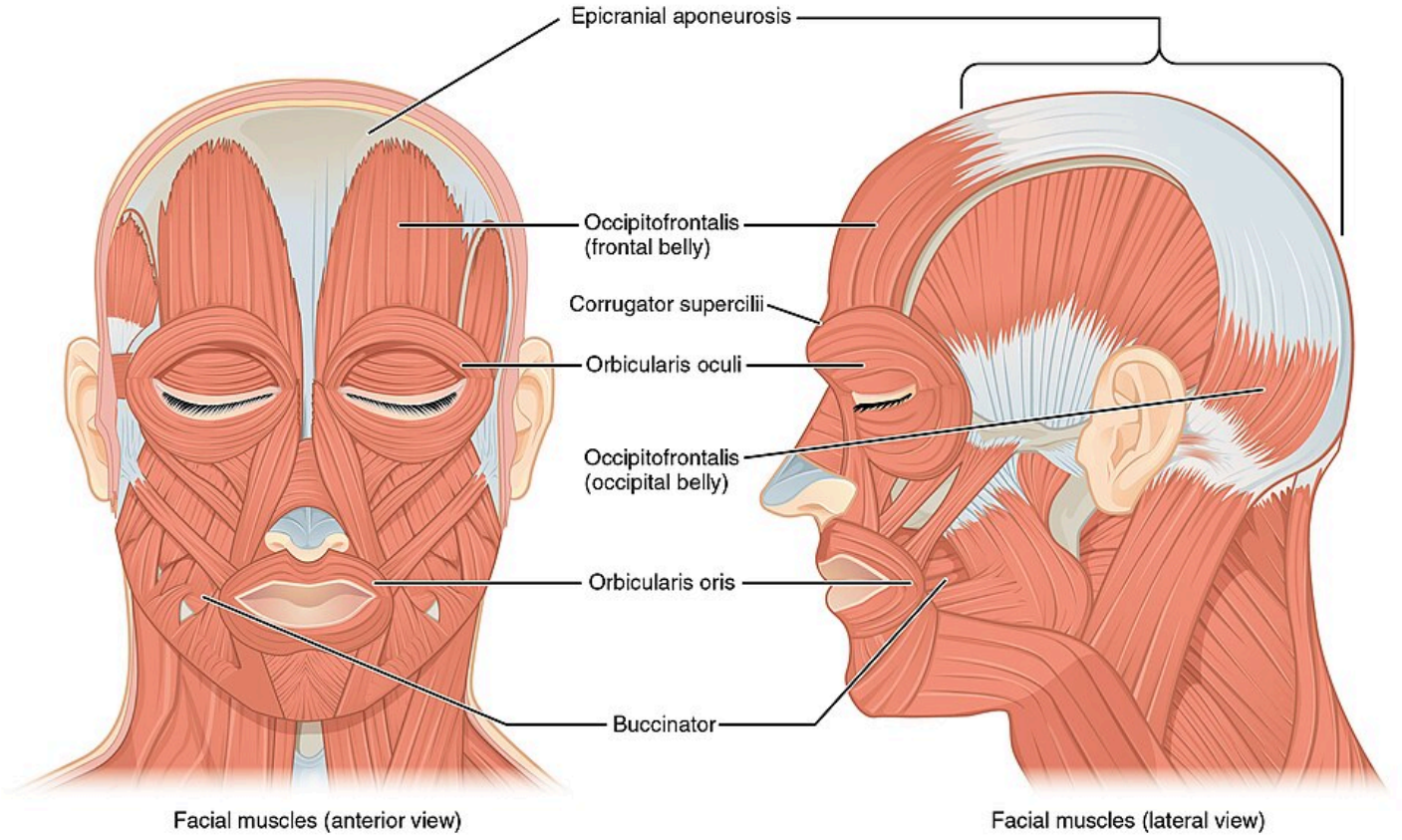


Figure 7.18 Muscles of Facial Expressions

41. OpenStax College. (2016). *1106_Front_and_Side_Views_of_the_Muscles_of_Facial_Expressions* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1106_Front_and_Side_Views_of_the_Muscles_of_Facial_Expressions.jpg

Muscles that create facial expressions include the following:[42]

- **Occipitofrontalis** (epicranius): Muscle that raises the eyebrows and wrinkles the forehead. The muscle has a frontal belly and an occipital belly (near the occipital bone on the posterior part of the skull). The muscle on the forehead is the **frontalis**, and the one on the back of the head is the occipitofrontalis, but there is no muscle across the top of the head. Instead, the two bellies are connected by a broad tendon called the **epicranial aponeurosis** or galea aponeurosis (*galea* = "helmet").
- **Orbicularis oris**: The circular muscle around the mouth that compresses and puckers the lips.
- **Orbicularis oculi**: The circular muscle around each eye that closes the eye(s).
- **Buccinator**: Muscle found in the cheeks that allows you to whistle, blow, and suck. It also contributes to the action of chewing.
- **Zygomaticus**: Muscle from the zygomatic bone to the mouth. It is the "smiling" muscle.

Muscles That Move the Eyes

- **Extrinsic Eye Muscles**: The movement of the eyeball is under the control of the extrinsic eye muscles, which originate outside the eye and insert onto the outer surface of the white of the eye. These muscles are located inside the eye socket and cannot be seen on any part of the visible eyeball.[43] See Figure 7.19[44] for an illustration of the extrinsic eye muscles.

42. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

43. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

44. OpenStax College. (2016). *1107_The_Extrinsic_Eye_Muscles* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1107_The_Extrinsic_Eye_Muscles.jpg

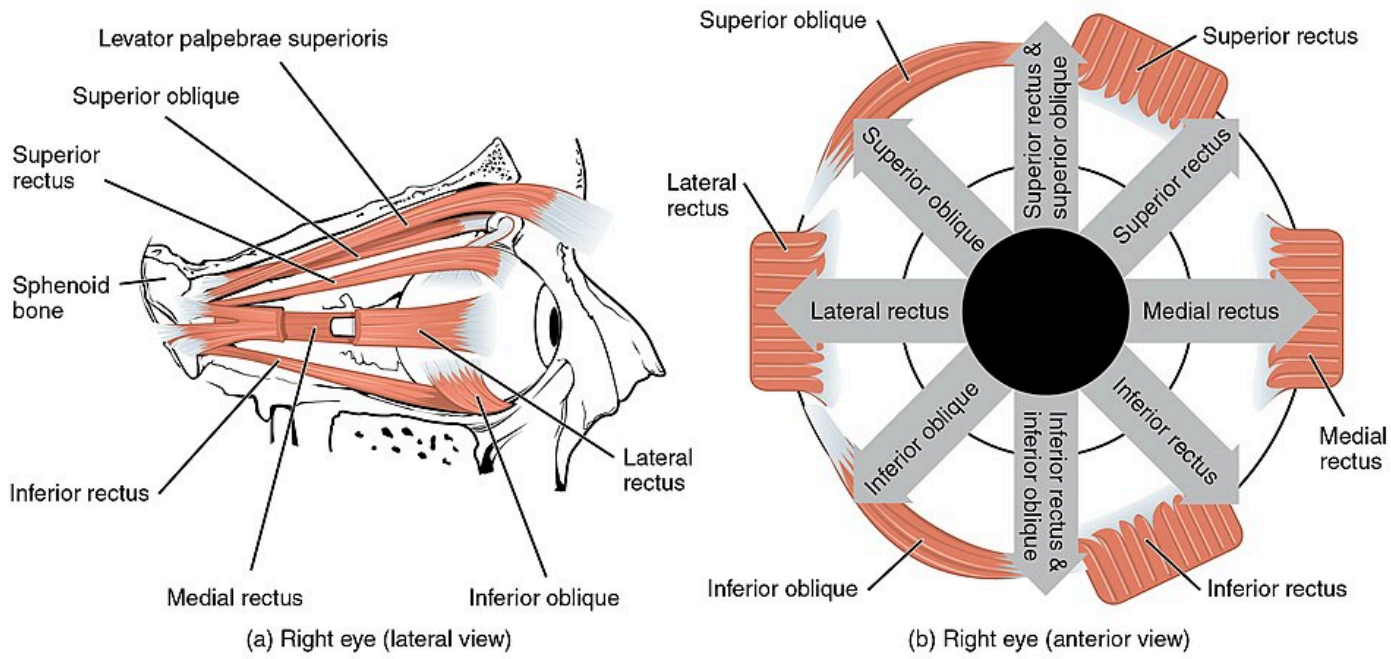


Figure 7.19 Muscles of the Eyes: (a) the Extrinsic Eye Muscles Originate Outside of the Eye on the Skull; (b) Each Muscle Inserts onto the Eyeball

Muscles That Move the Lower Jaw

In anatomical terminology, chewing is called **mastication**. Muscles involved in chewing must be able to exert enough pressure to bite through and then chew food before it is swallowed. The muscles of mastication include the masseter and the temporalis.[45]

- **Masseter**: The main muscle used for chewing because it lifts the mandible (lower jaw) to close the mouth.
- **Temporalis**: The muscle that lifts and pulls back the mandible. You can feel the temporalis move by putting your fingers to your temple as you chew.

See Figure 7.20[46] for an illustration of the masseter and temporalis muscles.

45. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

46. OpenStax College. (2016). *1108_Muscle_that_Move_the_Lower_Jaw* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1108_Muscle_that_Move_the_Lower_Jaw.jpg

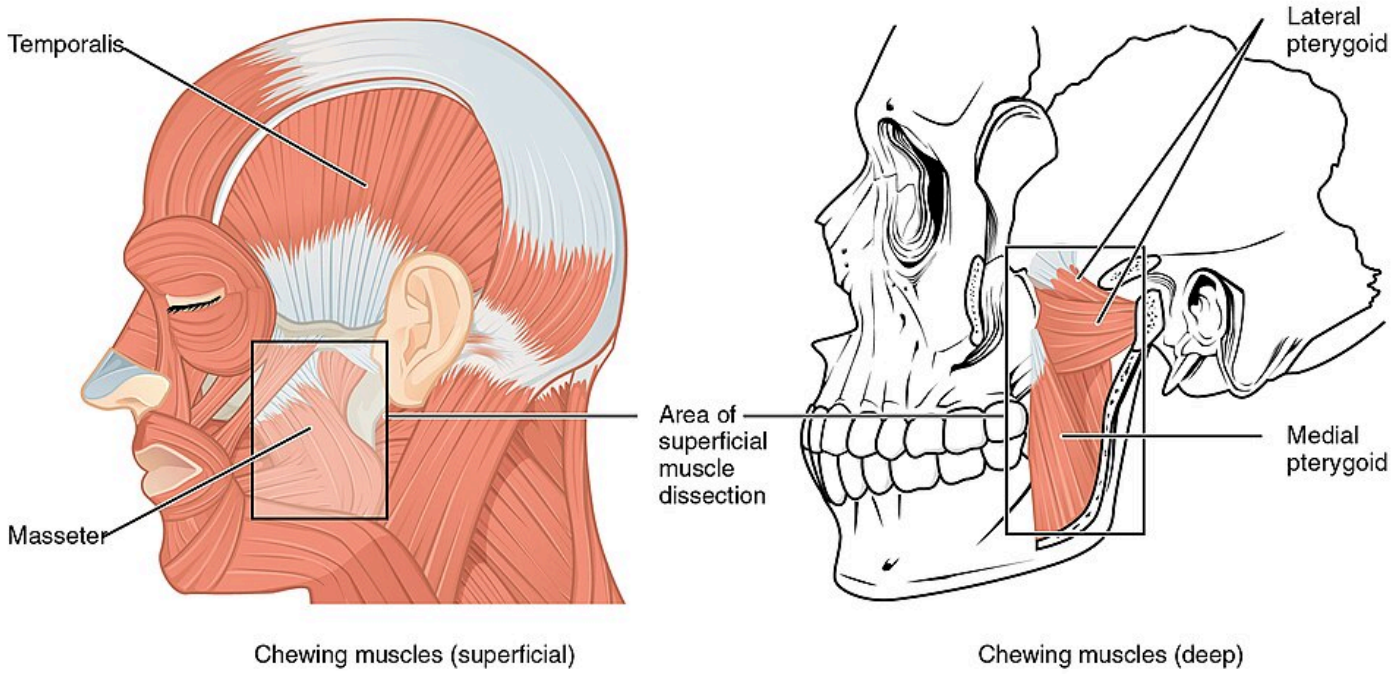


Figure 7.20 Masseter and Temporalis Muscles That Move the Lower Jaw

Muscles That Move the Head

The head, attached to the top of the vertebral column, is balanced, moved, and rotated by the neck muscles. When these muscles contract, they can rotate, flex, or extend. The major muscle that moves the head is the sternocleidomastoid.[47]

- **Sternocleidomastoid**: Major muscle that laterally flexes and rotates the head. When both of them contract, the head flexes at the neck. It has a dual origin on the sternum (stern/o) and clavicle (cleid/o) and inserts on the mastoid process of the temporal bone. Place your fingers on both sides of the neck and turn your head to the left and to the right to feel the movement of this muscle. See Figure 7.21[48] for an illustration of the sternocleidomastoid.

47. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

48. OpenStax College. (2016). *1111_Posterior_and_Side_Views_of_the_Neck* [Diagram]. Wikimedia Commons. CC BY 4.0.https://commons.wikimedia.org/wiki/File:1111_Posterior_and_Side_Views_of_the_Neck.jpg

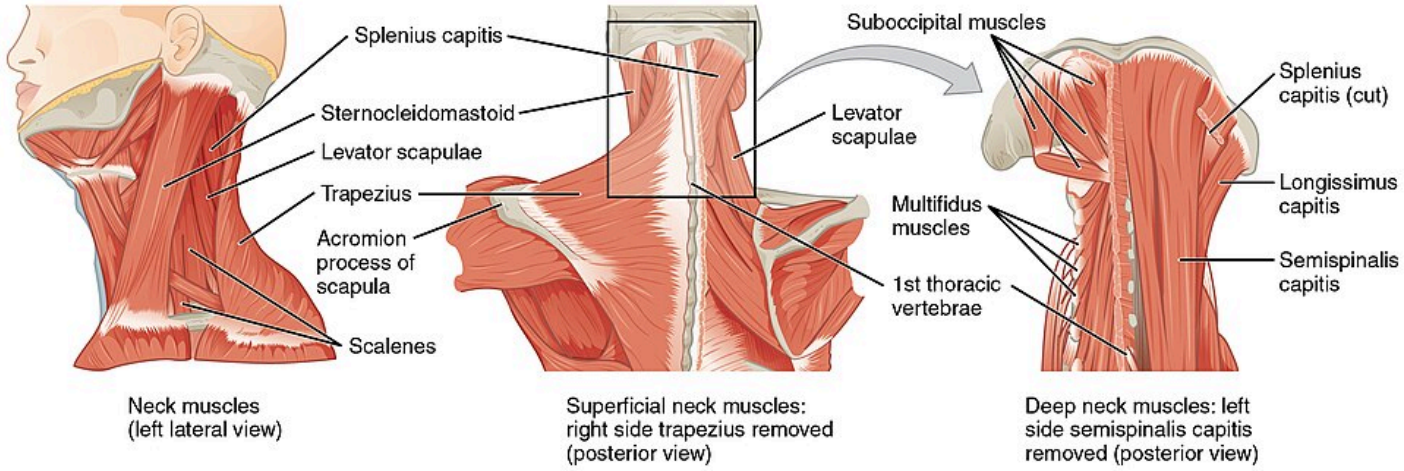


Figure 7.21 Posterior and Lateral Views of the Neck Showing the Sternocleidomastoid Muscle

See Table 7.3e in the "**Chapter Resources**" section for a description of the movements by the muscles that move the head.

Major Muscles of the Abdomen

There are four pairs of abdominal muscles that cover the anterior and lateral abdominal region and meet at the anterior midline. These paired muscles of the anterolateral abdominal wall can be divided into four groups: the external obliques, the internal obliques, the transversus abdominis, and the rectus abdominis. The different orientations of these muscles allow various movements and rotations of the trunk. The three layers of muscle also help to protect the internal abdominal organs in an area where there is no bone.[49]

- **External oblique(s)**: Flat superficial skeletal muscle in the antero-lateral wall of the abdomen. The external oblique is closest to the surface and extends inferiorly and medially, in the direction of sliding one's four fingers into pants pockets.
- **Internal oblique(s)**: Perpendicular to the external oblique is the intermediate internal oblique, extending superiorly and medially, the direction the thumbs usually go when the other fingers are in the pants pocket.
- **Transverse abdominis**: The deep muscle is the transversus abdominis. It is arranged

49. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

transversely around the abdomen, similar to the front of a belt on a pair of pants.

- **Rectus abdominis**: The straight muscle in the anterior wall of the abdomen, commonly called the "sit-up" muscle. It originates at the pubic crest and symphysis and extends the length of the body's trunk. The **linea alba** is a white, fibrous band that is made of the bilateral **rectus sheaths** that join at the anterior midline of the body. These enclose the rectus abdominis muscles. Each muscle is segmented by three transverse bands of collagen fibers called the **tendinous intersections**. This results in the look of "six-pack abs," as each segment hypertrophies in individuals at the gym who do many sit-ups.
- See Figure 7.22[50] for an illustration of the major abdominal muscles.

50. OpenStax College. (2016). *1112_Muscles_of_the_Abdomen* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1112_Muscles_of_the_Abdomen.jpg

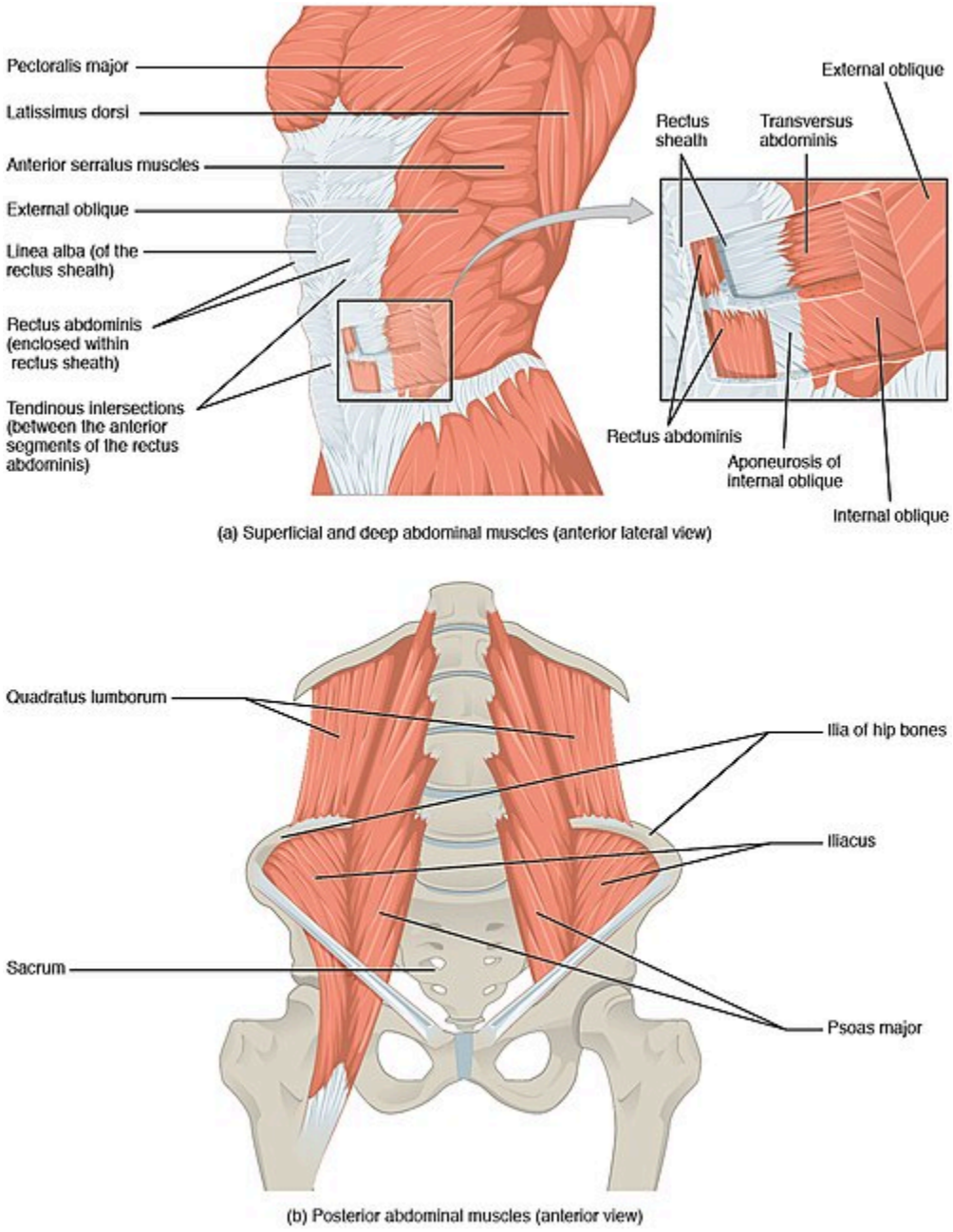


Figure 7.22 Abdominal Muscles: (a) Anterior and b) Posterior

See Table 7.3f in the "**Chapter Resources**" section for a description of the movements by the abdominal muscles.

Major Muscles of the Chest (Thorax)

The muscles of the chest serve to facilitate breathing by changing the size of the thoracic cavity. When you inhale, your chest rises because the cavity expands.

Alternatively, when you exhale, your chest falls because the thoracic cavity decreases in size.[51]

Diaphragm

The change in volume of the thoracic cavity during breathing is due to the contraction and relaxation of the **diaphragm**. See Figure 7.23[52] for an illustration of the diaphragm muscle. The diaphragm separates the thoracic and abdominal cavities and is dome-shaped at rest. The diaphragm also has three openings for structures between the chest cavity and the abdomen. The inferior vena cava passes through the **caval opening**, and the esophagus and attached nerves pass through the **esophageal hiatus**. The aorta passes through the **aortic hiatus** of the posterior diaphragm.[53] See Figure 7.24[54] for an illustration of these openings in the diaphragm.

51. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

52. Anatomography. (2021). *Human_diaphragm* [Diagram]. Wikimedia Commons. CC BY-SA 2.1 Japan. https://commons.wikimedia.org/wiki/File:Human_diaphragm.png

53. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

54. OpenStax College. (2016). *1113_The_Diaphragm* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1112_Muscles_of_the_Abdomen.jpg

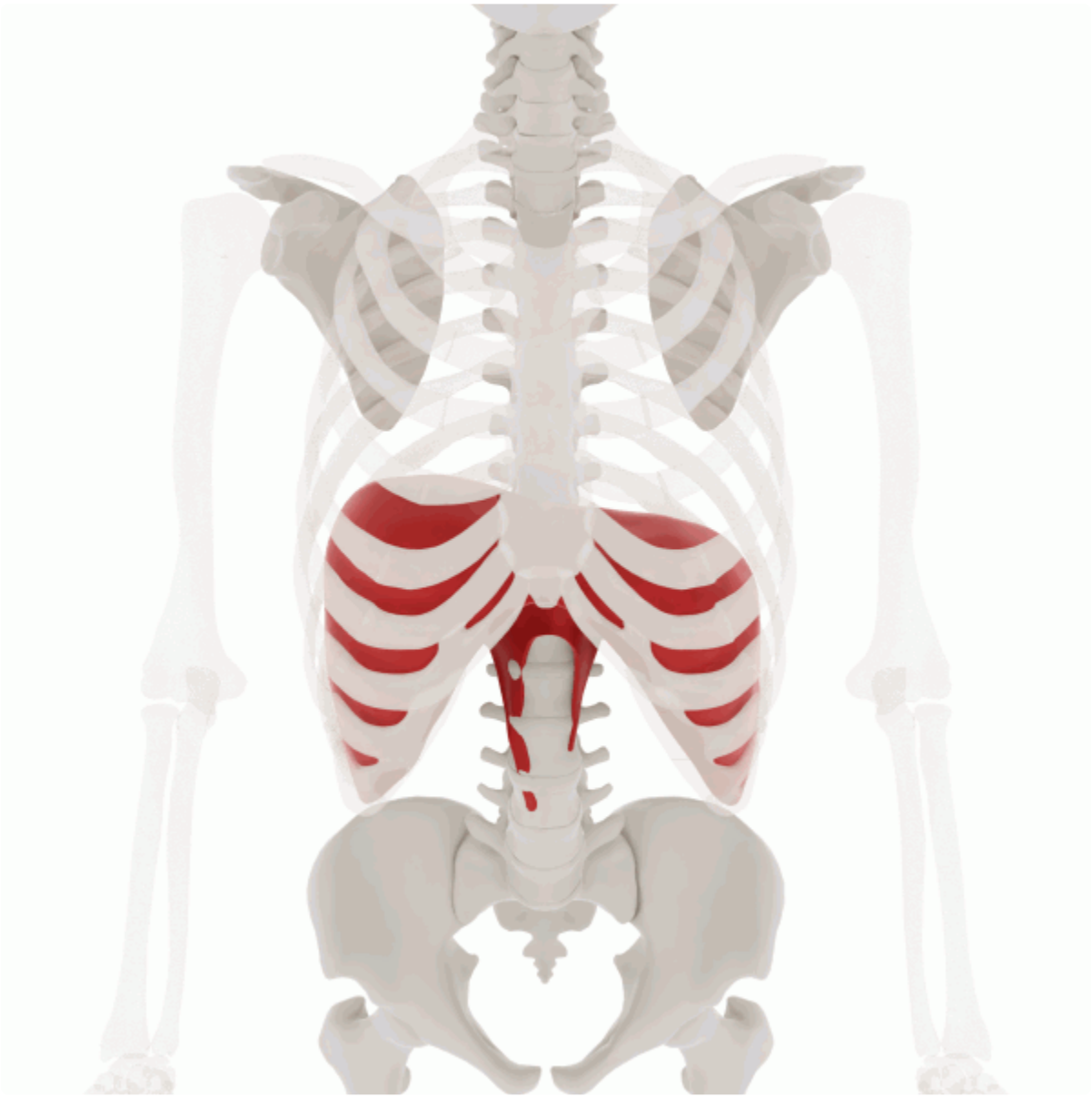


Figure 7.23 Rotating Diagram of the Diaphragm Muscle

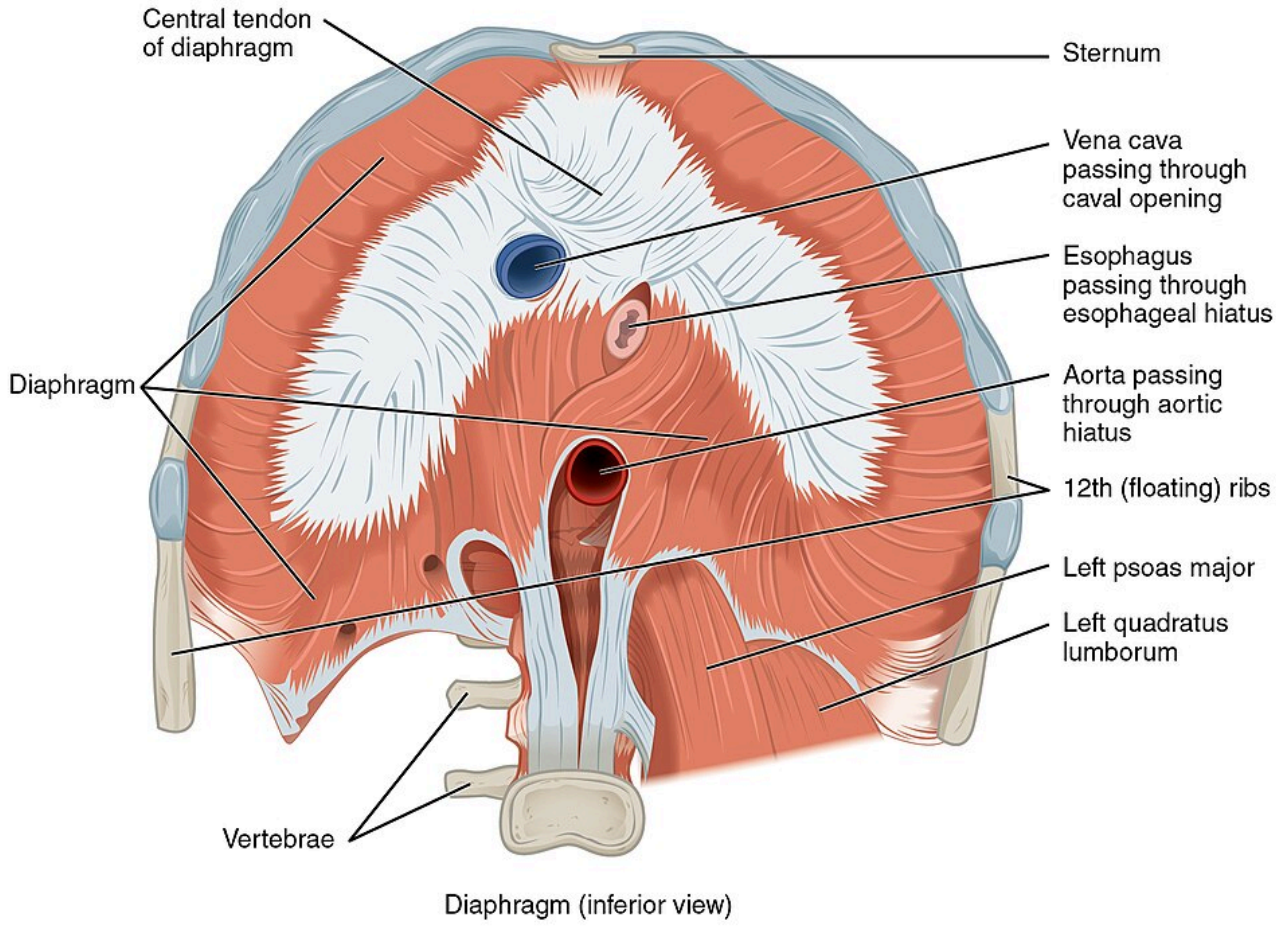


Figure 7.24 Openings in the Diaphragm

Intercostal Muscles

There are two primary sets of muscles called **intercostal muscles**, which are found in the intercostal spaces or spaces between the ribs (*cost/o* = "rib"). The main role of the intercostal muscles is to assist breathing by changing the dimensions of the rib cage. See Figure 7.25[55] for an illustration of the intercostal muscles.[56]

55. OpenStax College. (2016). *1114_Thorax* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1114_Thorax.jpg

56. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

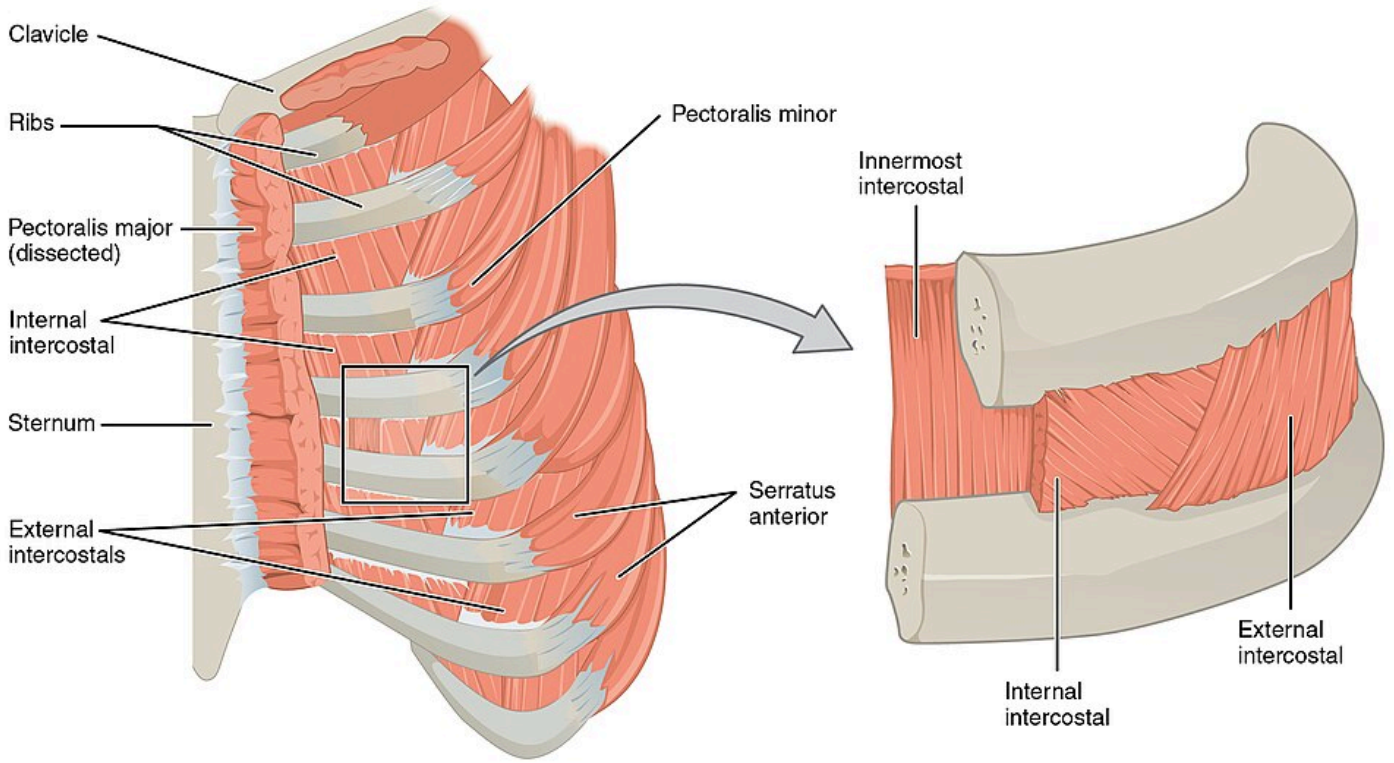


Figure 7.25 Intercostal Muscles

See Table 7.3g in the "**Chapter Resources**" section for a description of the movements by the thoracic muscles.

Major Muscles of the Shoulder and Upper Limbs

Muscles of the shoulder and upper limb can be divided into four groups: muscles that stabilize and position the pectoral girdle, muscles that move the arm, muscles that move the forearm, and muscles that move the wrists, hands, and fingers.

The **pectoral girdle**, or shoulder girdle, consists of the lateral ends of the clavicle and scapula, along with the proximal end of the humerus, and the muscles covering these three bones to stabilize the shoulder joint. The girdle creates a base from which the head of the humerus, in its ball-and-socket joint, can move the arm in multiple directions.[57]

57. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Major Muscles of the Pectoral (Shoulder) Girdle

- **Pectoralis minor**: Rotates shoulder anteriorly (throwing motion).
- **Serratus anterior**: Moves the arm from the side of the body to the front of the body.
- **Trapezius**: Elevates shoulders (shrugging), pulls shoulder blades together, and tilts head backwards. The trapezius stabilizes the upper part of the back.
- **Rhomboid major**: Attaches the vertebral border of the scapula to the spinous process of the thoracic vertebrae. It stabilizes the scapula during pectoral girdle movement.
- **Rhomboid minor**: Attaches the vertebral border of the scapula to the spinous process of the thoracic vertebrae. It stabilizes the scapula during pectoral girdle movement.

See Figure 7.26[58] for an illustration of the pectoral girdle muscles.

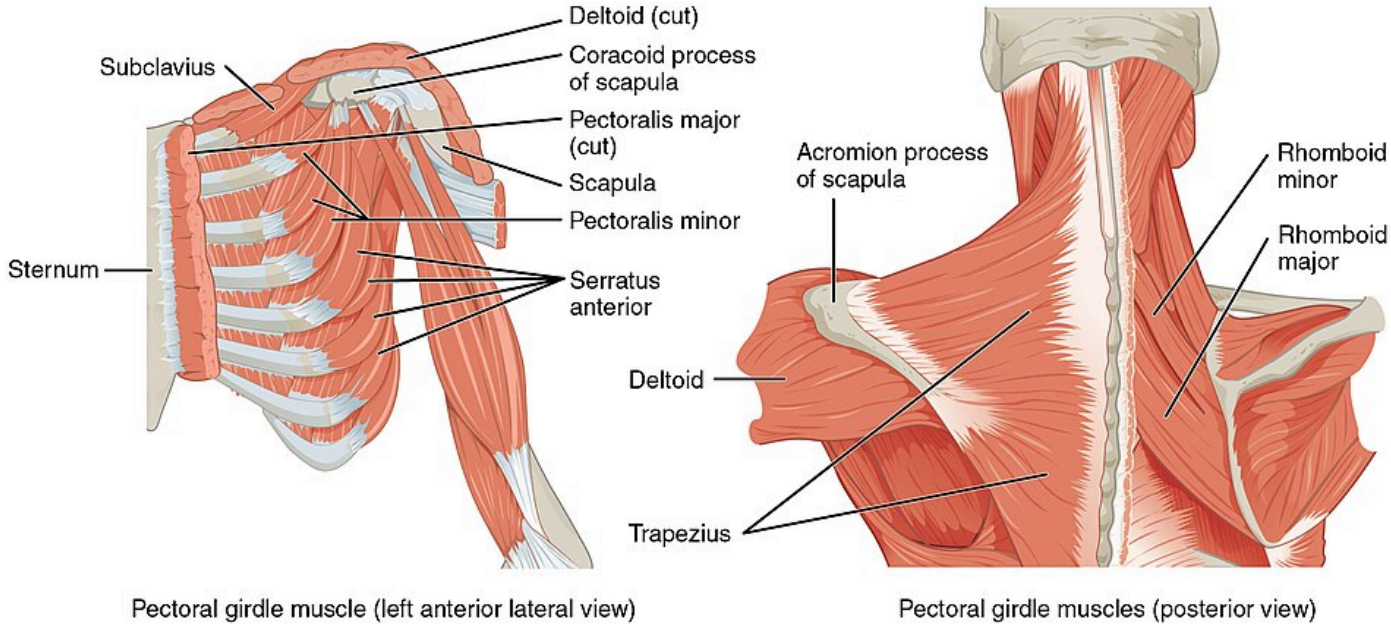


Figure 7.26 Pectoral Girdle Muscles

See Table 7.3h in the "**Chapter Resources**" section for a description of the movements by the muscles that position the pectoral girdle.

58. OpenStax. (2016). *1118_Muscles_that_Position_the_Pectoral_Girdle* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1118_Muscles_that_Position_the_Pectoral_Girdle.jpg

Muscles That Move the Humerus

Similar to the muscles that position the pectoral girdle, muscles that cross the shoulder joint and move the humerus bone of the arm include both axial and scapular muscles. The two axial muscles are the pectoralis major and the latissimus dorsi. The rest of the shoulder muscles originate on the scapula.

- **Pectoralis major**: The pectoralis major is thick and fan-shaped, covering much of the superior portion of the anterior thorax. It flexes the arm at the shoulder, adducts, and medially rotates the arm.
- **Latissimus dorsi**: The broad, triangular latissimus dorsi is located on the inferior part of the back, where it inserts into a thick connective tissue sheath called an aponeurosis. It extends the arm at the shoulder, adducts, and medially rotates the arm.
- **Deltoid**: The deltoid is the thick muscle that creates the rounded lines of the shoulder and is the major abductor of the arm, but it also facilitates flexing and medial rotation, as well as extension and lateral rotation.
- **Subscapularis**: The subscapularis originates on the anterior scapula and medially rotates the arm.
- **Supraspinatus**: The supraspinatus is superior to the spine of the scapula and abducts the arm.
- **Infraspinatus**: The infraspinatus is inferior to the spine of the scapula and laterally rotates the arm.
- **Teres major**: The thick and flat teres major is inferior to the teres minor and extends the arm and assists in adduction and medial rotation of the arm.
- **Teres minor**: The teres minor laterally rotates, adducts, and extends the arm.

See Figure 7.27[59] for an illustration of muscles that move the humerus.

59. OpenStax College. (2016). *1119_Muscles_that_Move_the_Humerus* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1119_Muscles_that_Move_the_Humerus.jpg

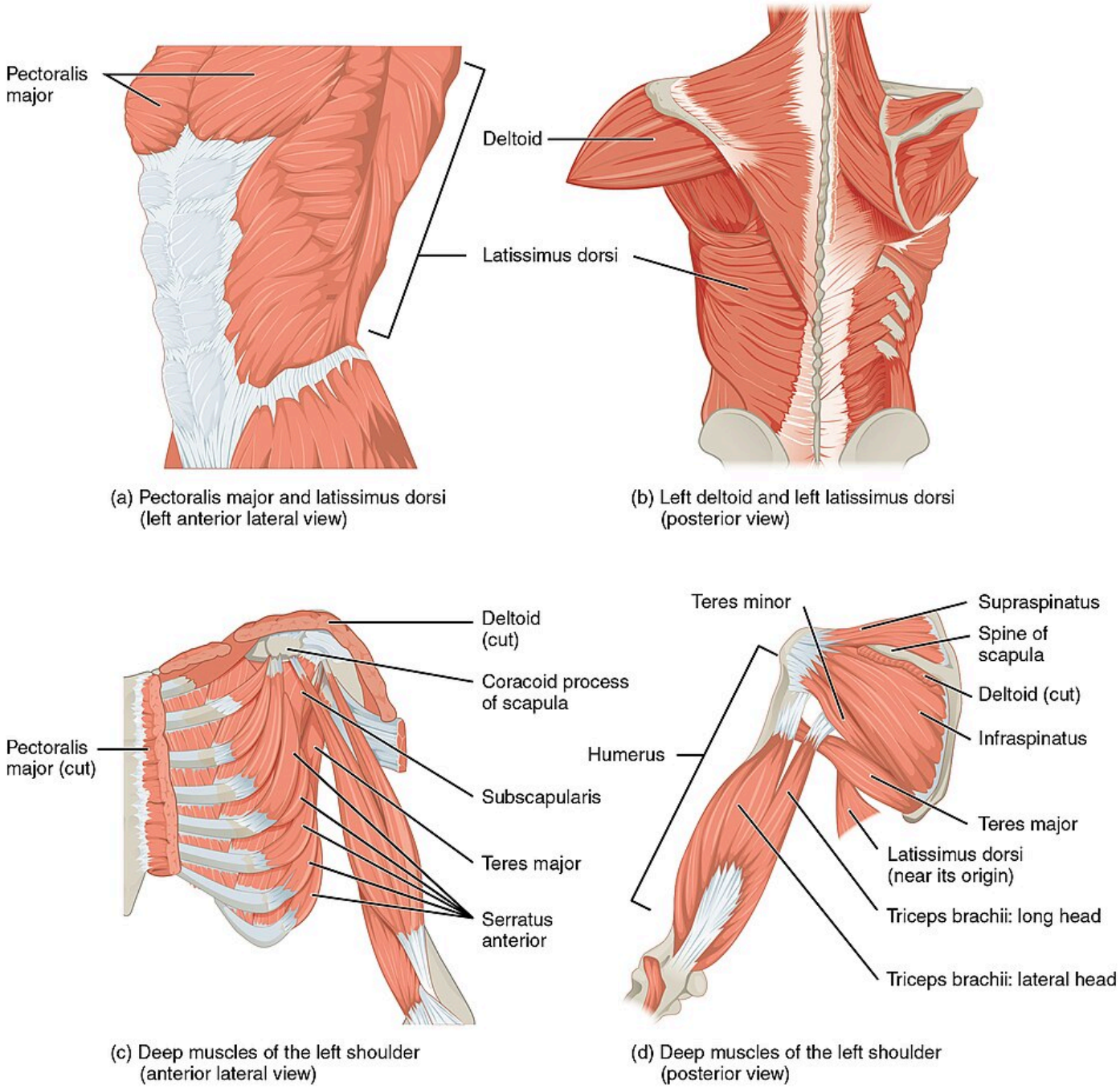


Figure 7.27 Muscles That Move the Humerus

Rotator Cuff

The tendons of the deep subscapularis, supraspinatus, infraspinatus, and teres minor

connect the scapula to the humerus, forming the **rotator cuff** (musculotendinous cuff), the circle of tendons around the shoulder joint. When baseball pitchers undergo shoulder surgery, it is usually on the rotator cuff, which becomes pinched and inflamed and may tear away from the bone due to the repetitive motion of bringing the arm overhead to throw a fast pitch.

See Table 7.3i in the "**Chapter Resources**" section for a description of the movements by the axial and scapular muscles.

Major Muscles That Move the Forearm

The forearm, made of the radius and ulna bones, has four main types of action at the elbow joint: flexion, extension, pronation, and supination. The major muscles here are as follows:

- **Biceps brachii**: The two-headed biceps brachii crosses the shoulder and elbow joints to flex the forearm, also taking part in supinating the forearm at the radioulnar joints and flexing the arm at the elbow joint. It performs a biceps curl and also allows the palm of the hand to point toward the body while flexing.
- **Brachialis**: Deep to the biceps brachii, the brachialis provides additional power in flexing the forearm at the elbow.
- **Brachioradialis**: The brachioradialis can flex the forearm quickly or help lift a load slowly. When bending the elbow (flexing), the brachioradialis assists the brachialis. The brachioradialis also supinates and pronates the forearm.
- **Triceps brachii**: The three-headed triceps brachii muscle extends the arm at both the elbow and shoulder joints. Part of it also helps adduct the arm.

See Figure 7.28[60] for an illustration of muscles that move the forearm.

60. OpenStax College. (2016). *1120_Muscles_that_Move_the_Forearm* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1119_Muscles_that_Move_the_Humerus.jpg

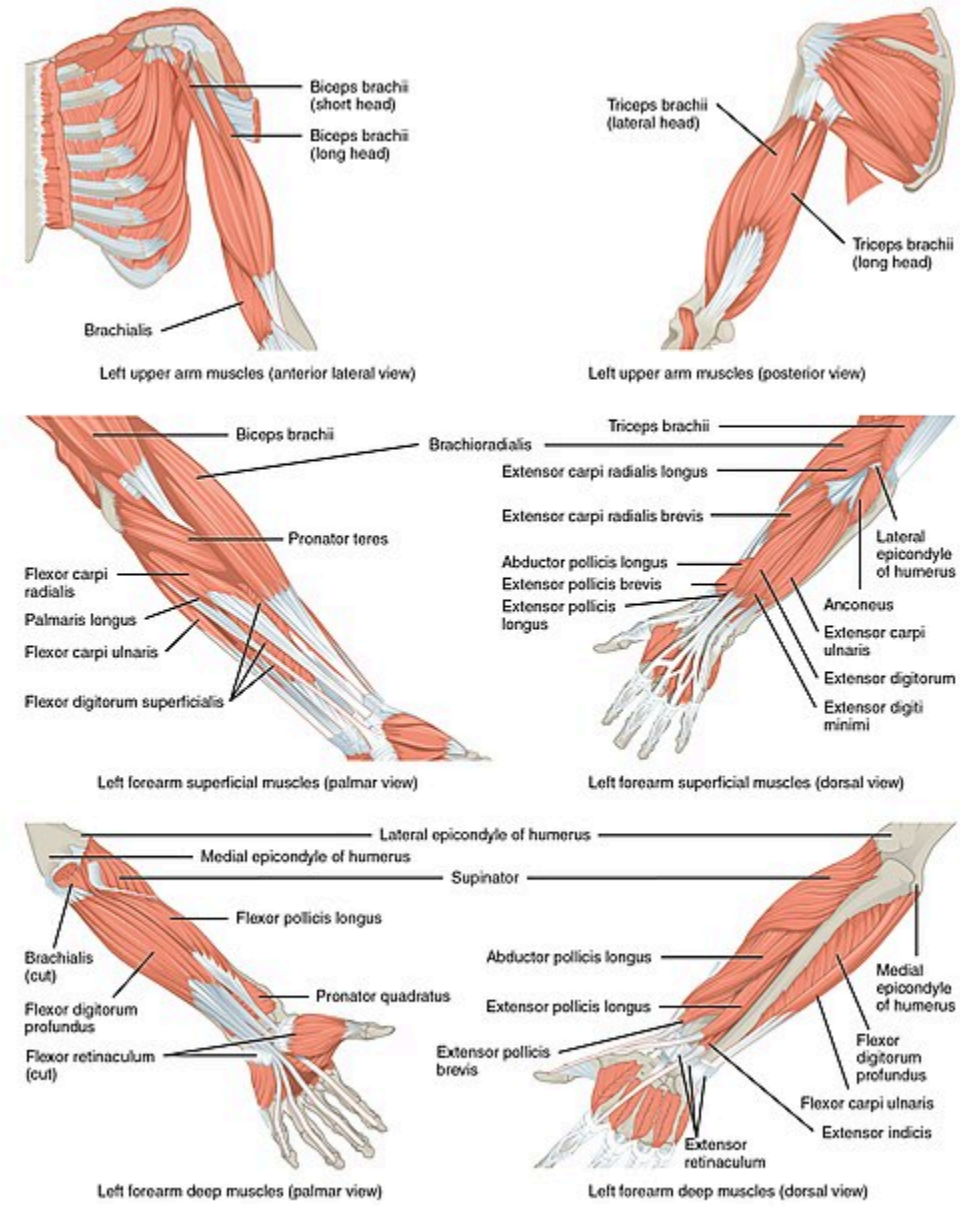


Figure 7.28 Muscles That Move the Forearm

See Table 7.3j in the "**Chapter Resources**" section for a description of the movements of the muscles that move the forearm.

Major Muscles That Move the Hand

Intrinsic Hand Muscles:

Intrinsic hand muscles move the wrists, hands, and fingers and originate in the palm. These muscles allow the fingers to make precise movements, such as typing and writing. They both originate and insert within the hand. They include the:

- **Thenar Muscle Group**: Group of muscles on the lateral aspect of the palm.
- **Hypothenar Muscle Group**: Group of muscles on the medial aspect of the palm.
- **Lumbricals**: Muscles that flex each finger at the metacarpophalangeal joints and extend each finger at the interphalangeal joints.
- **Dorsal interossei**: Muscles that abduct and flex the three middle fingers at the metacarpophalangeal joints and extend them at the interphalangeal joints.
- **Palmar interossei**: Muscles that abduct and flex each finger at the metacarpophalangeal joints and extend each finger at the interphalangeal joints.

Extrinsic Hand Muscles:

Extrinsic muscles of the hand move the wrists, hands, and fingers and originate on the arm. They are inserted into the hand in order to facilitate crude movements of the wrists, hands, and fingers. They include the:

- **Extrinsic flexors**: Located primarily on the anterior (palmar) side of the forearm. They flex the wrist and fingers, allowing movements such as gripping and making a fist.
- **Extrinsic extensors**: Located primarily on the posterior (dorsal) side of the forearm. They extend the wrist and fingers to help control the release of objects and stabilize the wrist during fine motor movements.

See Table 7.3k in the "Chapter Resources" section for a description of the movements by the muscles that move the wrist, hands, and forearm.

See Table 7.3l in the "Chapter Resources" section for a description of the movements by the hand muscles.

Muscles of the Pelvis and Lower Limbs

The appendicular muscles of the lower body position and stabilize the **pelvic or hip girdle**, which serves as a foundation for the lower limbs. The pelvic girdle has less range of motion because it stabilizes and supports the body. The body's center of gravity is in the area of the pelvis. If the center of gravity were not to remain fixed, standing up would be difficult. Therefore, what the leg muscles lack in range of motion and versatility, they make up for in size and power, facilitating the body's stabilization, posture, and movement.[61]

Major Muscles of the Upper Leg (Thigh)

Most muscles that insert on and move the femur originate on the pelvic girdle. The muscles found in the hip and thigh include the following:

- **Iliopsoas**: Muscle group consisting of the iliacus and psoas major muscles, flexing the thigh at the hip, rotating it laterally, and flexing the trunk of the body onto the hip when sitting up from a supine position.
- **Gluteus maximus**: The largest of the gluteus muscles that extends the femur and laterally rotates the thigh.
- **Gluteus medius**: The muscle deep to the gluteus maximus that abducts the femur at the hip and medially rotates the thigh.
- **Gluteus minimus**: Smallest of the gluteal muscles and deep to the gluteus medius. It abducts the hip and medially rotates the thigh.
- **Gracilis**: The gracilis muscle adducts the thigh in addition to flexing the leg at the knee.
- **Quadriceps femoris group**: A group of muscles often referred to as the "quads." It consists of four muscles that extend and stabilize the knee. They move the lower leg out in front of the body, as when kicking. The tendon common to all four is the **quadriceps tendon** (patellar tendon), which inserts into the proximal part of the patella and continues at the distal area as the **patellar ligament**. The patellar ligament attaches to the tibial tuberosity.
    - **Rectus femoris**: The rectus femoris is on the anterior aspect of the thigh.

61. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

- **Vastus lateralis**: Found on the lateral aspect of the thigh.
- **Vastus medialis**: Located on the medial aspect of the thigh.
- **Vastus intermedius**: Found between vastus lateralis and vastus medialis and deep to the rectus femoris.

- **Sartorius**: A band-like muscle that extends from the anterior superior iliac spine of the pelvis to the medial side of the proximal tibia. This versatile muscle flexes the leg at the knee and flexes, abducts, and laterally rotates the leg at the hip. This muscle allows us to sit cross-legged.
- **Hamstring group**: Group of three muscles that flex the knee, extend the hip, and rotate the thigh. The tendons of these muscles form the **popliteal fossa**, the diamond-shaped space at the back of the knee. You can feel the hamstring tendons behind your knee. The three hamstring muscles include the following:
  - **Biceps femoris**: Muscle located on the lateral side of the posterior thigh.
  - **Semitendinosus**: Muscle located medially next to the biceps femoris.
  - **Semimembranosus**: The most medial muscle of the three from mid-thigh to medial knee. Part of it is deep to the semitendinosus.

  See Figure 7.29[62] for an illustration of the hip and thigh muscles.

62. OpenStax College. (2016). *1122_Gluteal_Muscles_that_Move_the_Femur* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1122_Gluteal_Muscles_that_Move_the_Femur.jpg

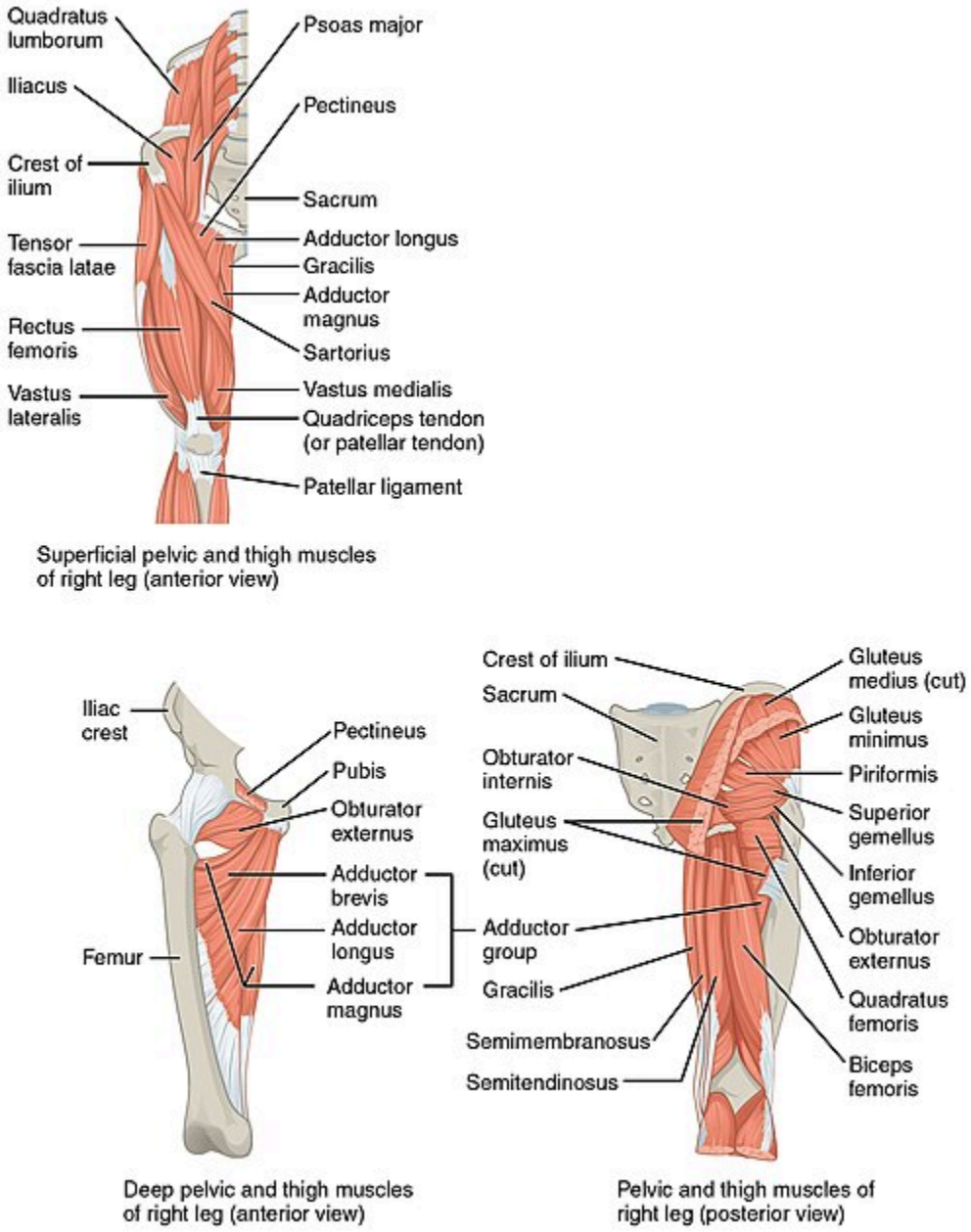


Figure 7.29 Hip and Thigh Muscles

See Table 7.3m in the "**Chapter Resources**" section for a description of the movements by the gluteal muscles that move the femur.

See Table 7.3n in the "**Chapter Resources**" section for a description of the movements by the thigh muscles that move the femur, tibia, and fibula.

Major Muscles of the Lower Leg

The lateral and medial muscles of the lower leg invert, evert, and rotate the foot and include the following:

- **Tibialis anterior**: A long and thick muscle on the anterolateral surface of the tibia. It dorsiflexes and inverts the foot.
- Tibialis posterior: A muscle that plantar flexes and inverts the foot.
- **Calcaneal tendon**: The calcaneal tendon, also referred to as the Achilles tendon, is a strong tendon that inserts on the calcaneal bone.
- **Gastrocnemius**: The most superficial and visible muscle of the calf is the gastrocnemius. It plantar flexes the foot and assists in flexing the knee.
- **Soleus**: Deep to the gastrocnemius is the wide, flat soleus. This muscle also plantar flexes the foot.
- **Lateral Peroneal Muscles**: The lateral side of the leg includes two muscles (Fibularis longus and Fibularis brevis). They evert the foot, assist with plantar flexion, and help stabilize the foot and ankle while walking and standing.

See Figure 7.30[63] for an illustration of muscles of the lower leg.

63. OpenStax College. (2016). *1123_Muscles_of_the_Leg_that_Move_the_Foot_and_Toes* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1123_Muscles_of_the_Leg_that_Move_the_Foot_and_Toes.jpg

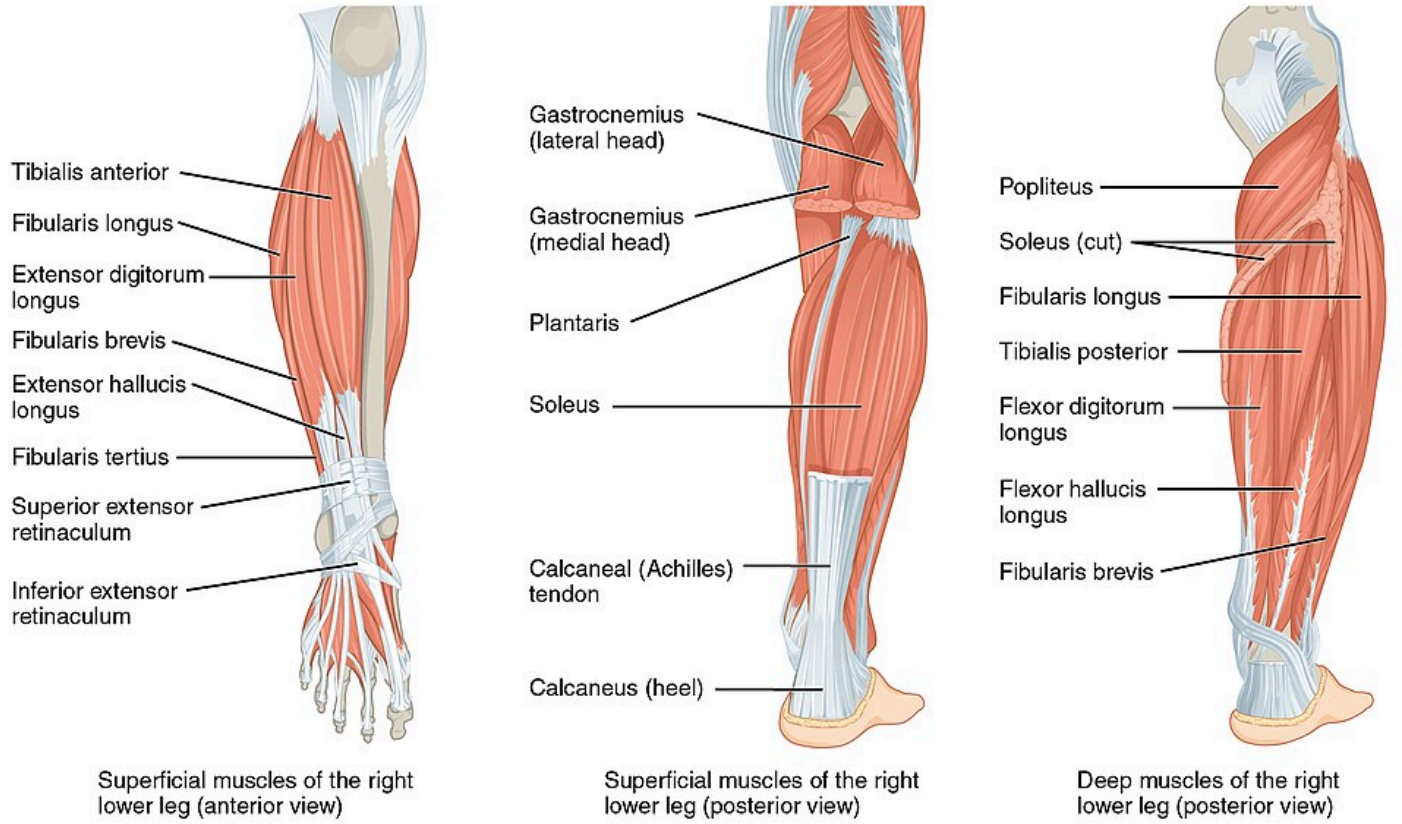


Figure 7.30 Muscles of the Lower Leg

See Figure 7.31[64] for an illustration of the gastrocnemius and soleus.

64. InjuryMap. (2019). *Lower_leg_muscles* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Lower_leg_muscles.svg

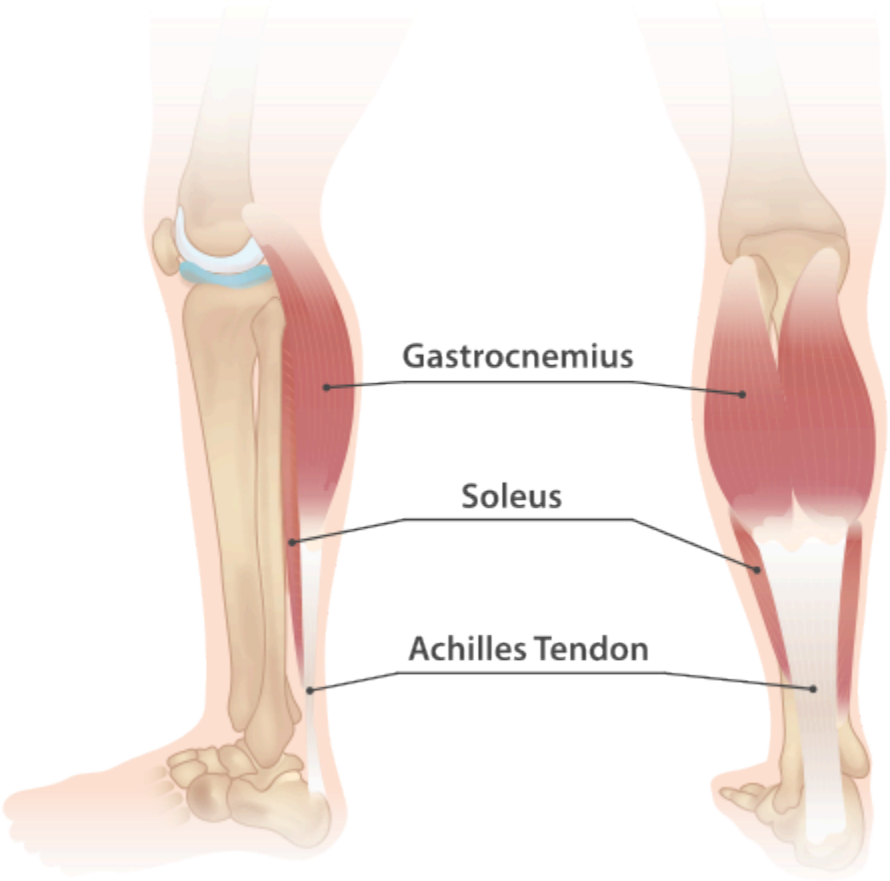
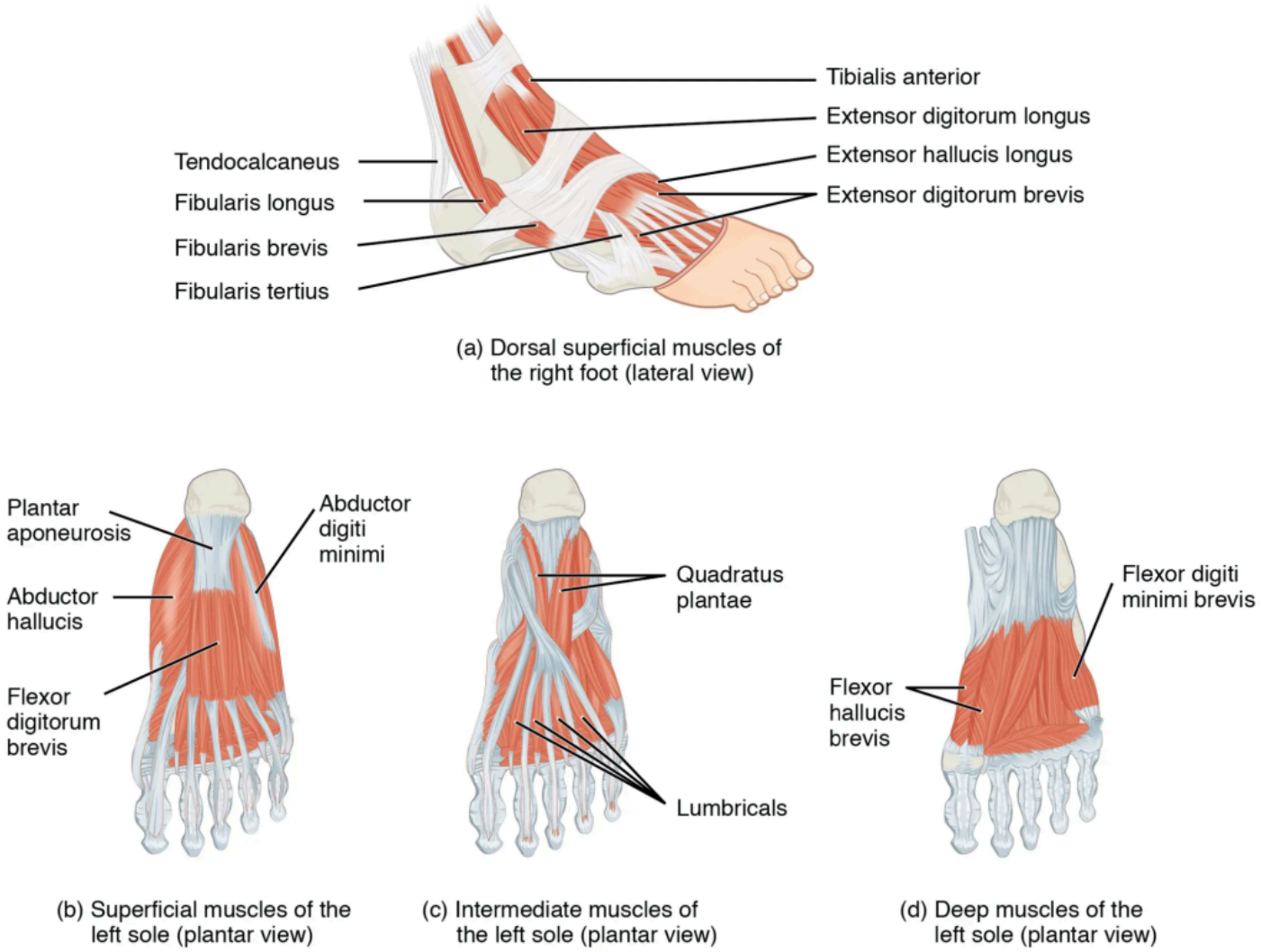


Figure 7.31 Gastrocnemius and Soleus

Intrinsic Muscles of the Foot

The foot also has intrinsic muscles, which originate and insert within it. These muscles primarily provide support for the foot and its arch, and contribute to the movements of the toes. The principal support for the longitudinal arch of the foot is a deep fascia called **plantar aponeurosis**, which runs from the calcaneus bone to the toes (inflammation of this tissue is the cause of "plantar fasciitis," which can affect runners. The intrinsic muscles of the foot consist of two groups. The dorsal group includes only one muscle, the extensor digitorum brevis. The second group is the plantar group, which consists of

four layers, starting with the most superficial. See Figure 7.32[65] for an illustration of the Intrinsic Muscles of the Foot.



7.32 Intrinsic Muscles of the Foot

See Table 7.3o in the "**Chapter Resources**" section for a description of the movements by the muscles that move the feet and toes.

65. OpenStax College. (2016). *1124 Intrinsic muscles of the foot* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1124_Intrinsic_Muscles_of_the_Foot.jpg

7.4 Cardiac Muscle

Cardiac muscle is an involuntary muscle that forms the walls of the heart. The cells of cardiac muscle, known as cardiomyocytes, are striated, and they contain sarcomeres. The fibers are shorter than skeletal muscle fibers and typically have just one centrally located nucleus. Special cardiomyocytes called pacemaker cells stimulate the heart to contract on its own without any nerve impulse. Cardiomyocytes also possess many mitochondria to provide the energy needed for contraction. Cardiac muscle fibers are extensively branched and connect to one another at their ends by intercalated discs. An **intercalated disc** allows the cardiac muscle cells to coordinate contraction so that the heart can work as a pump.[1]

See Figure 7.33[2] for an image of cardiac muscle tissue.

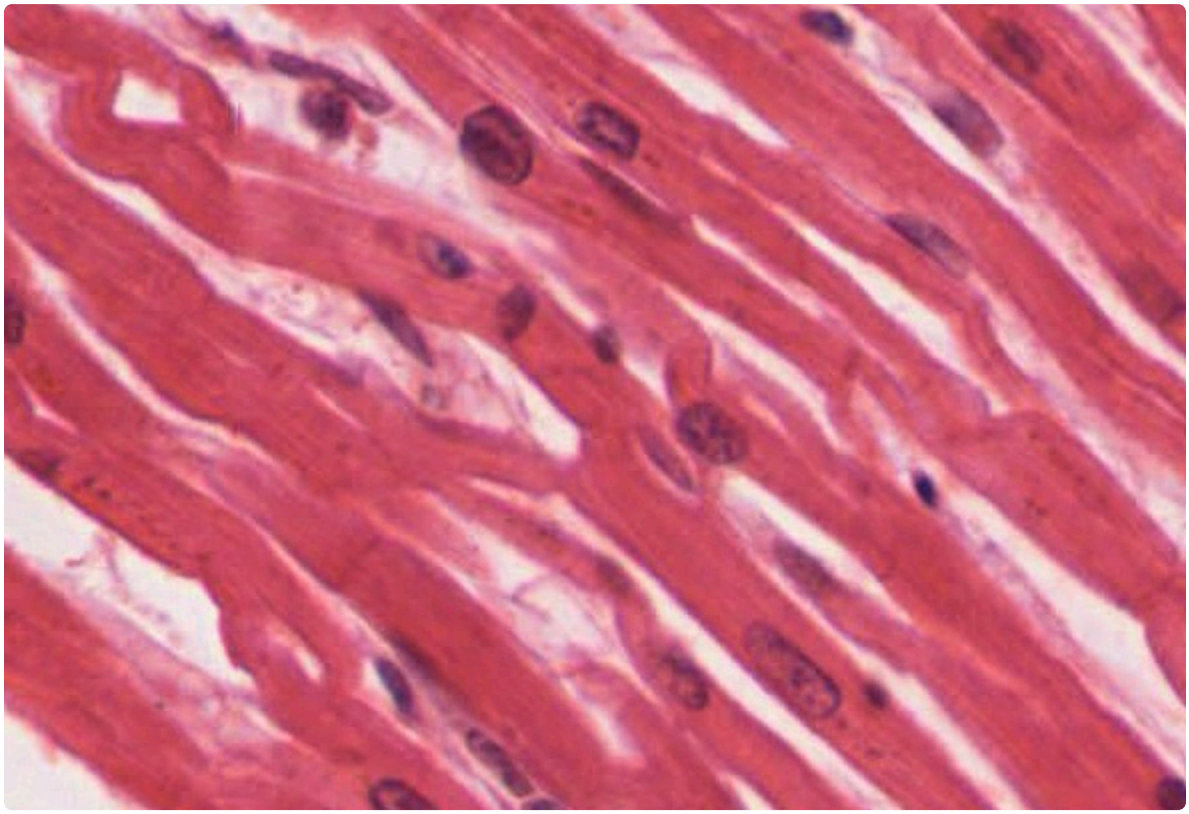


Figure 7.33 Cardiac Muscle Tissue

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. OpenStax College. (2013). *414c_Cardiacmuscle* [Photograph]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:414c_Cardiacmuscle.jpg

Take a Closer Look

Examine this cardiovascular tissue sample on the University of Michigan's histology slide viewer website.

- Open the cardiac muscle histology slide

Intercalated discs are part of the sarcolemma and contain two structures important in cardiac muscle contraction: gap junctions and desmosomes. A **gap junction** forms channels between cardiac muscle fibers to allow the depolarizing current to flow from one cardiac muscle cell to the next. This joining is called electric coupling, and in cardiac muscle, it allows the coordinated contraction of the entire heart. The remainder of the intercalated disc is composed of desmosomes. A **desmosome** is a cell structure that anchors the ends of cardiac muscle fibers together, so the cells do not pull apart during the stress of individual fibers contracting. See Figure 7.34[3] for an illustration of a desmosome in cardiac muscle.

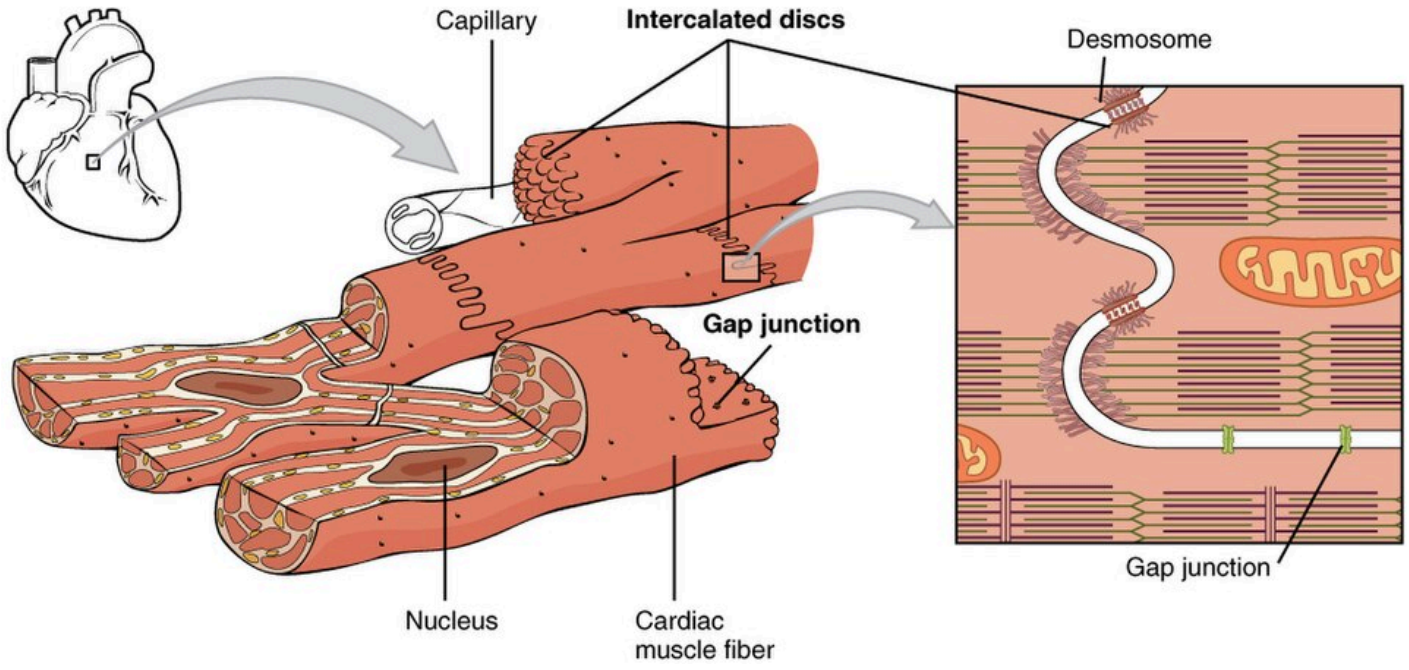


Figure 7.34 Desmosome in Cardiac Muscle

3. OpenStax College. (2016). *1020_Cardiac_Muscle* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1020_Cardiac_Muscle.jpg

Contractions of the heart (heartbeats) are controlled by specialized cardiac muscle cells called pacemaker cells that directly control heart rate. Although cardiac muscle is involuntary and cannot be consciously controlled, the pacemaker cells respond to signals from the autonomic nervous system (ANS) to speed up or slow down the heart rate. The pacemaker cells can also respond to various hormones that adjust the heart rate to control blood pressure.

7.5 Smooth Muscle

Smooth muscle contraction produces involuntary movements in the walls of hollow organs like the urinary bladder, uterus, stomach, intestines, and in the walls of passageways, such as the arteries and veins of the circulatory system, and the tracts of the respiratory, urinary, and reproductive systems. Smooth muscle in the walls of arteries is important to regulate blood pressure, and smooth muscle in the skin, visceral organs, and internal passageways is essential for moving materials through the body. Smooth muscle is also found in the eyes, where it changes the size of the iris and pupil and alters the shape of the lens. It is also in the skin, where it causes goosebumps in response to cold temperatures or fear.

Smooth muscle fibers are spindle-shaped (wide in the middle and tapered at both ends, somewhat like a football) and have a single nucleus; they range from about 30 to 200 μm (thousands of times shorter than skeletal muscle fibers), and they produce their own connective tissue, endomysium. See Figure 7.34[1] for an illustration of smooth muscle.

1. OpenStax College. (2016). *1021_Smooth_Muscle_new* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1021_Smooth_Muscle_new.jpg

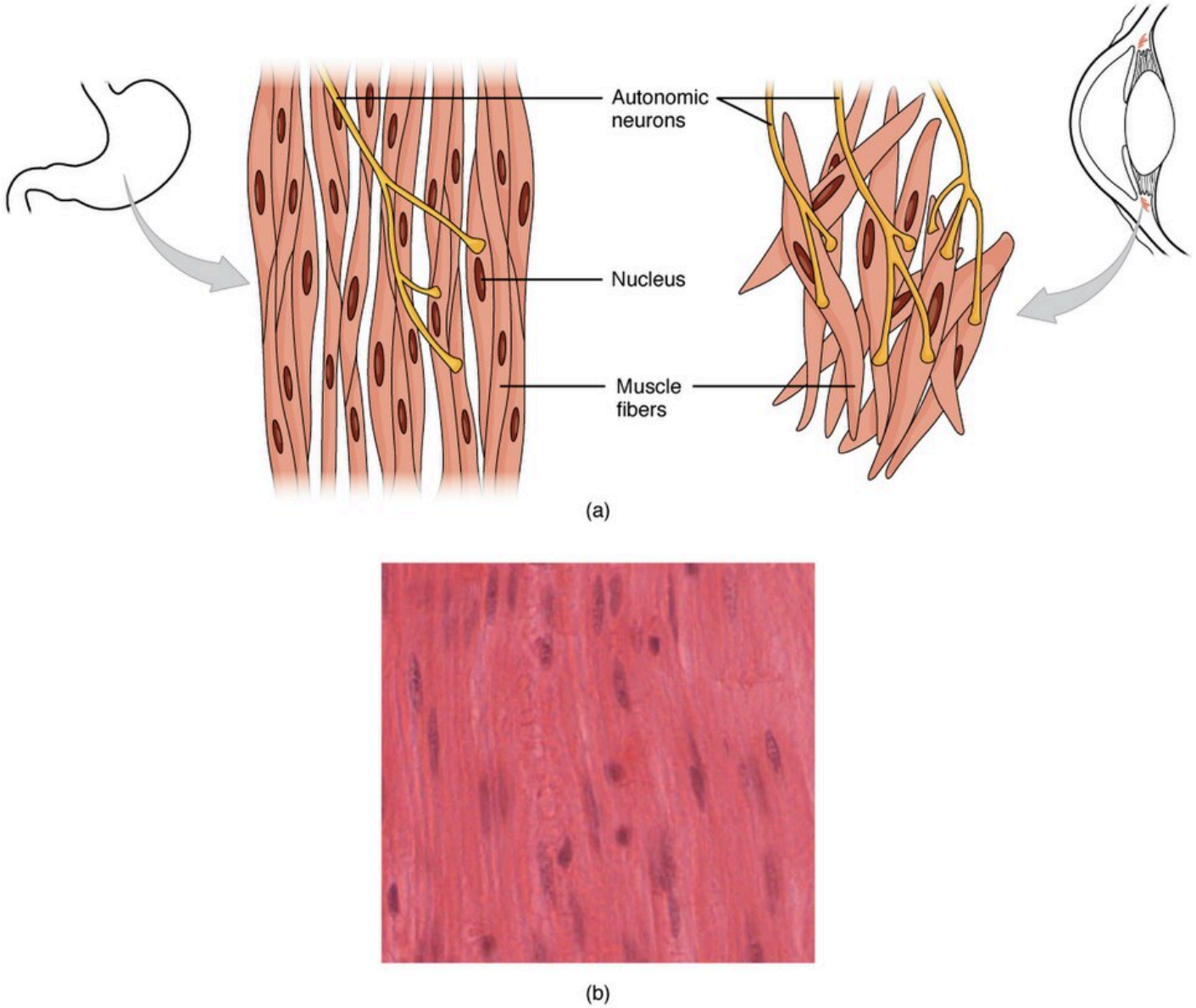


Figure 7.34 Smooth Muscle Tissue

Although they do not have striations and sarcomeres, smooth muscle fibers do have actin and myosin contractile proteins. Because the actin and myosin are not arranged in a regular pattern in smooth muscle, the cytoplasm of a smooth muscle fiber has a nonstriated appearance, resulting in the name smooth muscle.

Smooth muscle is under involuntary control; thus, it cannot be consciously controlled. The triggers for smooth muscle contraction include hormones and nervous system stimulation by the ANS (autonomic nervous system). In certain locations, such as the

walls of visceral organs, stretching the muscle can trigger its contraction (the myogenic response).[2]

Take a Closer Look

Examine this smooth muscle tissue sample on the University of Michigan's histology slide viewer website.

- **Open the smooth muscle histology slide**

2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

7.6 Muscular System Disorders

Amyotrophic Lateral Sclerosis (Lou Gehrig's Disease)

Amyotrophic lateral sclerosis (ALS), also called Lou Gehrig's disease, is a disease that causes the nerve cells in both the upper and lower parts of the body to stop working and die. The nerves lose the ability to stimulate specific muscles, which causes the muscles to become weak and leads to paralysis. No one knows what causes most cases of ALS, but scientists have been studying factors such as heredity, environmental exposures, diet, and injuries that could be linked with ALS. Although the actual number of cases is unknown, reports suggest fewer than 30,000 people in the United States have ALS. Every year, about 5,000 people are diagnosed with the disease.[1]

Cerebral Palsy

Cerebral palsy is a group of conditions that affect movement and posture caused by damage to the developing brain, most often before or right after birth. Symptoms appear during infancy or the preschool years and vary from very mild to severe. Children with cerebral palsy may have exaggerated reflexes. The arms, legs, and trunk may appear floppy, or they may have stiff muscles, known as spasticity. Symptoms also can include irregular posture, uncontrolled movements, a walk that's not steady, or some combination of these. Cerebral palsy may make it hard to swallow. It can also cause eye muscle imbalance, in which the eyes don't focus on the same object. Epilepsy, blindness, or deafness also might affect some people with cerebral palsy. There is no cure, but treatments can help improve function. The symptoms of cerebral palsy may vary during the child's development, but the condition generally stays the same over time.[2]

1. Centers for Disease Control and Prevention. (2024). *About amyotrophic lateral sclerosis.* https://www.cdc.gov/als/abouttheregistrymain/about-amyotrophic-lateral-sclerosis-als.html
2. Mayo Clinic. (2023). *Cerebral palsy*. https://www.mayoclinic.org/diseases-conditions/cerebral-palsy/symptoms-causes/syc-20353999

Fibromyalgia

Fibromyalgia is a disorder characterized by widespread musculoskeletal pain accompanied by fatigue, sleep, memory, and mood issues. Researchers believe that fibromyalgia amplifies pain sensations by affecting the way the brain and spinal cord process pain signals. Symptoms often begin after an event, such as physical trauma, surgery, infection, or significant psychological stress. In other cases, symptoms gradually develop over time with no single triggering event. Women are more likely to develop fibromyalgia than men. Many people who have fibromyalgia also have tension headaches, temporomandibular joint (TMJ) disorders, irritable bowel syndrome, anxiety, and depression. While there is no cure for fibromyalgia, a variety of medications can help control symptoms. Exercise, relaxation, and stress-reduction measures also may help.[3]

Muscular Dystrophy

Duchenne muscular dystrophy (DMD) is a progressive weakening of the skeletal muscles. It is one of several diseases collectively referred to as "muscular dystrophy." DMD is caused by a lack of the protein dystrophin, which helps the thin filaments of myofibrils bind to the sarcolemma. Over time, as muscle damage accumulates, muscle mass is lost, and greater functional impairments develop. DMD is an inherited disorder primarily affecting males. It is usually diagnosed in early childhood. DMD usually first appears as difficulty with balance and movement and then progresses to an inability to walk. It continues progressing upward in the body from the lower extremities to the upper body, where it affects the muscles responsible for breathing and circulation.[4]

Myasthenia Gravis

Myasthenia gravis is a chronic neuromuscular disease that causes weakness in the skeletal muscles. Myasthenia gravis is an autoimmune disease, which means that the body's immune system mistakenly attacks healthy cells or proteins needed for normal

3. Mayo Clinic. (2021). *Fibromyalgia*. https://www.mayoclinic.org/diseases-conditions/fibromyalgia/symptoms-causes/syc-20354780

4. Muscular Dystrophy Association. (n.d.). *Duchenne muscular dystrophy*. https://www.mda.org/disease/duchenne-muscular-dystrophy

functioning. Symptoms commonly associated with myasthenia gravis include weakness of the eye muscles (ocular myasthenia), drooping of one or both eyelids (ptosis), blurred or double vision (diplopia), changes in facial expressions, difficulty swallowing, shortness of breath, impaired speech (dysarthria), and weakness in the arms, hands, fingers, legs, and neck. Myasthenia gravis affects both men and women and occurs across all racial and ethnic groups. It most commonly impacts young adult women (under 40) and older men (over 60), but it can occur at any age, including childhood. Myasthenia gravis is not inherited or contagious. Occasionally, the disease may occur in more than one member of the same family. Myasthenia gravis is caused by an error in how nerve signals are sent to muscles, specifically when communication between the nerve and muscle is interrupted at the neuromuscular junction. Currently, there is no known cure for myasthenia gravis. Most people with myasthenia gravis live an average life expectancy. There are some treatments available to help reduce and improve muscle weakness.[5]

Figure 7.35 shows an example of myasthenia gravis.[6]



Figure 7.35 Myasthenia Gravis

Poliomyelitis (Polio)

Polio is a highly infectious disease caused by a virus. It invades the nervous system and can cause total paralysis in a matter of hours. The virus is transmitted by person-to-person spread mainly through the fecal-oral route or, less frequently, by a common source (for example, contaminated water or food) and multiplies in the intestine. Initial

5. National Institute of Neurological Disorders and Stroke. (2024). *Myasthenia gravis.* https://www.ninds.nih.gov/health-information/disorders/myasthenia-gravis

6. Cumulus at Dutch Wikipedia. (2007). *Myasthenia* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Myasthenia.jpg

symptoms are fever, fatigue, headache, vomiting, stiffness of the neck, and pain in the limbs. One in 200 infections leads to irreversible paralysis (usually in the legs). Among those paralyzed, 5–10% die when their breathing muscles become immobilized. Polio mainly affects children under 5 years of age. However, anyone of any age who is unvaccinated can contract the disease. There is no cure for polio; it can only be prevented. The polio vaccine, given multiple times, can protect a child for life. There are two vaccines available: the **oral polio vaccine and the inactivated polio vaccine**. Both are effective and safe.[7]

Tendinitis

Tendinitis is the inflammation of a tendon, the thick band of fibrous connective tissue that attaches a muscle to a bone. The condition causes pain and tenderness in the area around a joint. Most often, the condition results from repetitive motions over time that strain the tendons, but on rare occasions, a sudden injury can cause tendinitis. Individuals who perform the same movements over and over again are often at the greatest risk of tendinitis. Some examples of this include tennis and golfer's elbow, jumper's knee, and swimmer's shoulder. In all cases, overuse of the joint causes a microtrauma that initiates the inflammatory response and causes pain. Because connective tissue in the tendon does not have an abundant blood supply, tendinitis heals slowly.[8]

Tetanus

Tetanus is a serious disease of the nervous system caused by a toxin-producing bacterium. The bacteria affect the neuromuscular junction and cause muscle contractions, particularly of the jaw and neck muscles. Tetanus is commonly known as lockjaw. Severe complications of tetanus can be life-threatening. There's no cure for tetanus. Treatment focuses on managing symptoms and complications until the effects of the tetanus toxin resolve. Because of the widespread use of vaccines, cases of tetanus are rare in the United States and other parts of the developed world. The disease remains a threat to people who aren't up-to-date on their vaccinations. It's more common in developing countries.[9]

7. World Health Organization. (2025). *Poliomyelitis.* https://www.who.int/news-room/fact-sheets/detail/poliomyelitis
8. MedlinePlus [Internet]. (2022). *Tendinitis.* https://medlineplus.gov/tendinitis.html
9. Mayo Clinic. (2023). *Tetanus*. https://www.mayoclinic.org/diseases-conditions/tetanus/symptoms-causes/syc-20351625

Read more about muscular system disorders in the **"Other Musculoskeletal Disorders" section of the Open RN *Health Alterations* textbook**.



7.7 Career Connections Related to the Muscular System

Every time a person walks, lifts an object, smiles, exercises, or even sits upright, the muscular system is at work. When muscles are injured, weakened, painful, or affected by disease, many different professionals may help a person recover and improve their quality of life. Careers related to the muscular system can include massage therapists, physical therapist assistants, occupational therapy assistants, fitness professionals, and personal trainers.

Massage Therapist

Massage therapists treat clients by applying pressure to manipulate the body's soft tissues and joints. They may help clients with relaxation, pain management, muscle tension, injury recovery, and overall wellness. Massage therapists use knowledge of anatomy, muscle groups, body mechanics, and safety practices while providing care.

Physical Therapist Assistant

Physical therapist assistants work under the direction and supervision of physical therapists to help patients improve movement, reduce pain, and regain function. They may assist with therapeutic exercises, mobility training, hands-on treatments, special equipment, and tracking a patient's response to treatment. This career is closely connected to the muscular system because many patients receive physical therapy after muscle injuries, surgeries, weakness, or movement-related conditions.

Occupational Therapy Assistant

Occupational therapy assistants work with occupational therapists to help people participate in daily activities after injury, illness, disability, or age-related changes. They may help patients build strength, coordination, endurance, and safe movement patterns

needed for activities such as dressing, bathing, working, cooking, or returning to school. This career connects to the muscular system because muscles are needed for movement, posture, balance, and daily function.

Fitness Professional

Fitness professionals help individuals or groups improve their health, strength, flexibility, endurance, and overall physical activity. They may work in fitness centers, community programs, wellness centers, schools, or recreational settings. Fitness professionals use knowledge of the muscular system to plan safe activities, demonstrate exercises, support injury prevention, and encourage lifelong wellness.

Personal Trainer

Personal trainers work with clients to develop and guide exercise programs based on their goals, fitness levels, and needs. They may help clients improve muscle strength, flexibility, balance, posture, and cardiovascular fitness. Personal trainers use knowledge of muscles, movement, exercise safety, and proper technique to help clients exercise effectively and reduce the risk of injury.

Take a Closer Look

Explore careers related to the human body's muscular system on these websites.

- Massage therapist from the American Massage Therapy Association
- Massage therapists from the U.S. Bureau of Labor Statistics
- Physical therapist assistant from the American Physical Therapy Association
- Occupational therapy assistant from the American Occupational Therapy Association
- Personal trainer from the American College of Sports Medicine

7.8 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

7.9 Chapter Resources: Movements by Muscle

The following tables provides details on movements by muscles.[1]

Head

Table 7.3e Movements of the Muscles That Move the Head[2]

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Rotates and tilts head to the side; tilts head forward	Skull; vertebrae	Individually: rotates head to opposite side, lateral flexion; bilaterally: flexion	Sternocleidomastoid	Sternum; clavicle	Temporal bone (mastoid process)
Rotates and tilts head backward	Skull; vertebrae	Individually: laterally flexes and rotates head to the same side; bilaterally: extension	Semispinalis capitis	Transverse and articular processes of cervical and thoracic vertebrae	Occipital bone
Rotates and tilts head to the side; tilts head backward	Skull; vertebrae	Individually: laterally flexes and rotates head to the same side; bilaterally: extension	Splenius capitis	Spinous processes of cervical and thoracic vertebrae	Temporal bone (mastoid process); occipital bone
Rotates and tilts head to the side; tilts head backward	Skull; vertebrae	Individually: laterally flexes and rotates head to the same side; bilaterally: extension	Longissimus capitis	Transverse and articular processes of cervical and thoracic vertebrae	Temporal bone (mastoid process)

Abdomen

Table 7.3f Movements of the Abdominal Muscles[3]

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Twisting at the waist and bending to the side, bending forward at the waist	Vertebral column	Flexion, lateral flexion, and rotation of the vertebral column	External obliques; internal obliques	Ilium; ribs 5–12	Ribs 7–10; linea alba; ilium
Squeezing the abdomen during forceful exhalations, defecation, urination, and childbirth	Abdominal cavity	Compression	Transversus abdominis	Ilium; ribs 5–10	Sternum; linea alba; pubis
bending forward at the waist	Vertebral column	Flexion	Rectus abdominis	Pubis	Sternum; ribs 5 and 7
Bending to the side	Vertebral column	Lateral flexion	Quadratus lumborum	Ilium; ribs 5–10	Rib 12; vertebrae L1–L4

Thorax (Chest)

Table 7.3g Movements of the Thoracic Muscles[4]

3. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

4. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Inhalation; exhalation	Thoracic cavity	Compression; expansion	Diaphragm	Sternum; ribs 6–12; lumbar vertebrae	Central tendon
Inhalation; exhalation	Ribs	Elevation of the rib cage (expands the thoracic cavity)	External intercostals	Rib superior to each intercostal muscle	Rib inferior to each intercostal muscle
Forced exhalation	Ribs	Depression of the rib cage	Internal intercostals	Rib inferior to each intercostal muscle	Rib superior to each intercostal muscle

Pectoral Girdle

Table 7.3h Muscles That Position the Pectoral Girdle[5]

5. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Position in the Thorax	Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Anterior thorax	Stabilizes clavicle during movement by depressing it	Clavicle	Depression	Subclavius	First rib	Inferior surface of the clavicle
Anterior thorax	Rotates shoulder anteriorly (throwing motion); assists with inhalation	Scapula; ribs	Scapula: depresses; ribs: elevates	Pectoralis minor	Anterior surfaces of certain ribs (2–4 or 3–5)	Coracoid process of scapula
Anterior thorax	Moves arm from the side of the body to the front of the body; assists with inhalation	Scapula; ribs	Scapula: protracts; ribs: elevates	Serratus anterior	Ribs (1–8 or 1–9)	Anterior surface of the vertebral border of the scapula
Posterior thorax	Elevates shoulders (shrugging); pulls shoulder blades together; tilts head backwards	Scapula; cervical spine	Scapula: rotates superiorly, retracts, elevates, and depresses; spine: extends	Trapezius	Skull; vertebral column	Acromion and spine of scapula; clavicle

Position in the Thorax	Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Posterior thorax	Stabilizes the scapula during pectoral girdle movement	Scapula	Retracts; rotates inferiorly	Rhomboid major	Thoracic vertebrae (T2–T5)	Medial border of scapula
Posterior thorax	Stabilizes the scapula during pectoral girdle movement	Scapula	Retracts; rotates inferiorly	Rhomboid minor	Cervical and thoracic vertebrae (C7 and T1)	Medial border of scapula

Humerus

Table 7.3i Movements of the Axial Muscles and Scapular Muscles[6]

6. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Axial muscles					
Brings elbows together; moves elbows up (as during an uppercut punch)	Humerus	Flexion; adduction; medial rotation	Pectoralis major	Clavicle; sternum; cartilage of certain ribs (1–6 or 1–7); aponeurosis of the external oblique muscle	Greater tubercle of the humerus
Moves elbows back (as in elbowing someone standing behind you); spreads elbows apart	Humerus scapula	Humerus: extension, adduction, and medial rotation; scapula: depression	Latissimus dorsi	Thoracic vertebae (T7–T12); lumbar vertebrae; lower ribs (9–12); iliac crest	Intertubercular sulcus of the humerus
Scapular muscles					
Lifts arms at the shoulder	Humerus	Abduction; flexion; extension; medial and lateral rotation	Deltoid	Trapezius; clavicle; acromion; spine of scapula	Deltoid tuberosity of the humerus

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Assists pectoralis major in bringing elbows together and stabilizes the shoulder joint during movement of the pectoral girdle	Humerus	Medial rotation	Subscapularis	Subscapular fossa of the scapula	Lesser tubercle of humerus
Rotates the elbow outwards, as during a tennis swing	Humerus	Abduction	Subscapularis	Subscapular fossa of the scapula	Greater tubercle of the humerus
Rotates the elbow outwards, as during a tennis swing	Humerus	Extension; abduction	Infraspinatus	Infraspinous fossa of the scapula	Greater tubercle of the humerus
Assists with medial rotation at the shoulder	Humerus	Extension; abduction	Teres major	Posterior surface of the scapula	Intertubercular sulcus of the humerus
Assists the infraspinatus in rotating the elbow outwards	Humerus	Extension; abduction	Teres minor	Lateral border of the dorsal scapular surface	Greater tubercle of the humerus

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Moves the elbow up and across the body, as when putting a hand on the chest	Humerus	Flexion; abduction	Coracobra chialis	Coracoid process of scapula	Medial surface of the humerus shaft

Forearm

Table 7.3j Movements of the Forearm Muscles[7]

7. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Anterior muscles (flexion)					
Performs a bicep curl; also allows the palm of the hand to point toward the body while flexing	Forearm	Flexion; supination	Biceps brachii	Coracoid process; tubercle above glenoid cavity	Radial tuberosity
Performs flexion at the elbow	Forearm	Flexion	Brachialis	Front of the distal humerus	Coronoid process of the ulna
Assists and stabilizes the elbow during the bicep-curl motion	Forearm	Flexion	Brachioradialis	Lateral supracondylar ridge of the humerus	Base of the styloid process of the radius
Posterior muscles (extension)					
Extends the forearm, as during a punch	Forearm	Extension	Triceps brachii	Infraglenoid tubercle of scapula; posterior shaft of humerus	Olecranon process of the ulna
Assists in extending the forearm; also allows the forearm to extend away from the body	Forearm	Extension; abduction	Anconeus	Lateral epicondyle of the humerus	Lateral aspect of the olecranon process of the ulna
Anterior muscles (pronation)					

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Turns hand palm down	Forearm	Pronation	Pronator teres	Medial epicondyle of humerus; coronoid process of ulna	Lateral radius
Assists in turning the hand palm down	Forearm	Pronation	Pronator quadratus	Distal anterior ulnar shaft	Distal anterior radius
Posterior muscles (supination)					
Turns hand palm up	Forearm	Supination	Supinator	Lateral epicondyle of humerus; proximal ulna	Proximal radius

Hand

Table 7.3k Movements of the Muscles That Move the Wrists, Hands, and Forearm[8]

8. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Superficial anterior compartment of the forearm					
Bends wrist toward body; tilts hand to the side away from the body	Wrist; hand	Flexion; abduction	Flexor carpi radialis	Medial epicondyle of the humerus	Base of second and third metacarpals
Assists in bending the hand up toward the shoulder	Wrist	Flexion	Palmaris longus	Medial epicondyle of the humerus	Palmar aponeurosis; skin and fascia of the palm
Assists in bending the hand up toward the shoulder; tilts the hand to the side away from the body; stabilizes the wrist	Wrist; hand	Flexion, adduction	Flexor carpi ulnaris	Medial epicondyle of the humerus	Pisiform, hamate bones, and base of the fifth metacarpal
Bends fingers to make a fist	Wrist; fingers 2–5	Flexion	Flexor digitorum superficialis	Medial epicondyle of the humerus	Middle phalanges; fingers 2–5
Deep anterior compartment of the forearm					
Bends tip of thumb	Thumb	Flexion	Flexor pollicis longus	Anterior surface of radius; interosseous membrane	Distal phalanx of thumb

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Bends fingers to make a fist; also bends wrist toward body	Wrist; fingers	Flexion	Flexor digitorum profundus	Coronoid process; anteromedial surface of ulna; interosseous membrane	Distal phalanges of fingers 2-5
Superficial posterior compartment of the forearm					
Straightens wrist away from body; tilts hand to the side away from body	Wrist	Extension; abduction	Extensor radialis longus	Lateral supracondylar ridge of the humerus	Base of the second metacarpal
Assists the extensor radialis longus in extending and abducting the wrist; also stabilizes the hand during finger flexion	Wrist	Extension; abduction	Extensor carpi radialis brevis	Lateral epicondyle of the humerus	Base of the third metacarpal
Opens fingers and moves them sideways away from the body	Wrist	Extension; abduction	Extensor digitorum	Lateral epicondyle of the humerus	Extensor expansions; distal phalanges of fingers
Extends the little finger	Little finger	Extension;	Extensor digiti minimi	Lateral epicondyle of the humerus	Extensor expansions; distal phalanx of finger 5

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Straightens wrist away from body; tilts hand to the side toward body	Wrist	Extension; adduction	Extensor carpi ulnaris	Lateral epicondyle of humerus; posterior border of ulna	Base of the fifth metacarpal
Deep posterior compartment of the forearm					
Moves thumb sideways toward body; extends thumb; moves hand sideways toward body	Wrist; thumb	Thumb: abduction, extension; wrist: abduction	Abductor pollicis longus	Posterior surface of radius and ulna; interosseous membrane	Base of the first metacarpal; trapezium
Extends thumb	Thumb	Extension	Extensor pollicis brevis	Dorsal shaft of radius and ulna; interosseous membrane	Base of the proximal phalanx of the thumb
Extends thumb	Thumb	Extension	Extensor pollicis longus	Dorsal shaft of radius and ulna; interosseous membrane	Base of the distal phalanx of thumb
Extends index finger; straightens wrist away from body	Wrist; index finger	Extension	Extensor indicis	Posterior surface of the distal ulna; interosseous membrane	Tendon of the extensor digitorum of the index finger

Table 7.3 Movements of the Muscles of the Hand[9]

9. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Muscle	Movement	Target	Target Motion Direction	Prime Mover	Origin	In
Thenar muscles	Moves thumb toward body	Thumb	Abduction	Abductor pollicis brevis	Flexor retinaculum and nearby carpals	La ba pr ph th
Thenar muscles	Moves thumb across palm to touch other fingers	Thumb	Opposition	Opponens pollicis	Flexor retinaculum; trapezium	Ar fir m
Thenar muscles	Flexes thumb	Thumb	Flexion	Flexor pollicis brevis	Flexor retinaculum; trapezium	La ba pr ph th
Thenar muscles	Moves thumb away from body	Thumb	Adduction	Adductor pollicis	Capitate bone; bases of metacarpals 2–4; front of metacarpal 3	M ba pr ph th
Hypothenar muscles	Moves the little finger toward the body	Little finger	Abduction	Abductor digiti minimi	Pisiform bone	M of pr ph lit
Hypothenar muscles	Flexes the little finger	Little finger	Flexion	Flexor digiti minimi brevis	Hamate bone; flexor retinaculum	M of ph lit
Hypothenar muscles	Moves the little finger across the palm to touch the thumb	Little finger	Opposition	Opponens digiti minimi	Hamate bone; flexor retinaculum	M of m

Muscle	Movement	Target	Target Motion Direction	Prime Mover	Origin	In
Intermediate muscles	Flexes each finger at the metacarpo-phalangeal joints; extends each finger at the interphalangeal joints	Fingers	Flexion	Lumbricals	Palm (lateral sides of tendons in flexor digitorum profundus)	Fi (la ec ex ex or ph
Intermediate muscles	Adducts and flexes each finger at the metacarpo-phalangeal joints; extends each finger at the interphalangeal joints	Fingers	Adduction; flexion; extension	Palmar interossei	Side of each metacarpal that faces metacarpal 3 (absent from metacarpal 3)	Ex ex or ph ea (e fir or fa fir
Intermediate muscles	Abducts and flexes the three middle fingers at metacarpo-phalangeal joints; extends the three middle fingers at interphalangeal joints	Fingers	Abduction; flexion; extension	Dorsal interossei	Sides of metacarpals	Bo of fo ot fir ex ex ov fir ph th op fir

Thigh

Table 7.3m Movements of the Gluteal Muscles That Move the Femur[10]

10. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Iliopsoas group					
Raises knee at hip, as if performing a knee attack; assists lateral rotators in twisting thigh (and lower leg) outward; assists with bending					
over, maintaining posture	Femur	Thigh: flexion and lateral rotation; torso: flexion	Psoas maior	Lumbar vertebrae (L1–L5); thoracic vertebra (T12)	Lesser trochanter of the femur Raises knee at hip, as if performing a knee attack; assists lateral rotators in twisting thigh (and lower leg) outward; assists with bending
over, maintaining posture	Femur	Thigh: flexion and lateral rotation; torso: flexion	Iliacus	Iliac Iossa; iliac crest; lateral sacrum	Lesser trochanter of the femur
Gluteal group					
Lowers the knee and moves the thigh back, as when getting ready to kick a ball	Femur	Extension	Gluteus maximus	Dorsal ilium; sacrum; coccyx	Gluteal tuberosity of the femur; iliotibial tract

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Opens thighs, as when doing a split	Femur	Abduction	Gluteus medius	Lateral surface of the ilium	Greater trochanter of the femur
Bring the thighs back together	Femur	Abduction	Gluteus minimus	External surface of the ilium	Greater trochanter of the femur
Assists with raising the knee at the hip and opening the thighs; maintains posture by stabilizing the iliotibial track, which connects to the knee	Femur	Flexion; abduction	Tensor fascia lata	Anterior aspect of iliac crest; anterior superior iliac spine	Iliotibial tract
Lateral rotators					
Twists the thigh (and lower leg) outward; maintains posture by stabilizing the hip joint	Femur	Lateral rotation	Piriformis	Anterolateral surface of sacrum	Greater trochanter of the femur

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Twists the thigh (and lower leg) outward; maintains posture by stabilizing the hip joint	Femur	Lateral rotation	Obutrator intern us	Inner surface of the obturator membrane; greater sciatic notch; margins of the obturator	
foramen	Greater trochanter in front of piriformis				
Twists the thigh (and lower leg) outward; maintains posture by stabilizing the hip joint	Femur	Lateral rotation	Obturator externus	Outer surfaces of the obturator membrane, pubic, and ischium; margins of the obturator	
foramen	Trochanteric lossa of the posterior femur				

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Twists thigh (and lower leg) outward; maintains posture by stabilizing the hip joint	Femur	Lateral rotation	Superior gemellus	tschial spine	Greater trochanter of the femur
Twists the thigh (and lower leg) outward; maintains posture by stabilizing the hip joint	Femur	Lateral rotation	Inferior gemellus	Ischial tuberosity	Greater trochanter of the femur
Twists the thigh (and lower leg) outward; maintains posture by stabilizing the hip joint	Femur	Lateral rotation	Quadratus femoris	Ischial tuberosity	Trochanteric crest of the femur
Adductors					
Brings the thighs back together; assists with raising the knee	Femur	Adduction; flexion	Adductor longus	Pubis near pubic symphysis	Linea aspera

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Brings the thighs back together; assists with raising the knee	Femur	Adduction; flexion	Adductor brevis	Body of pubis; inferior ramus of pubis	Linea aspera above the adductor longus
Brings the thighs back together; assists with raising the knee	Femur	Adduction; flexion; extension	Adductor magnus	Ischial rami; pubic rami; ischial tuberosity	Linea aspera adductor tubercle of the femur
Brings the thighs back together; assists with raising the knee	Femur	Adduction; flexion; medial rotation	Pectineus	Pectineal line of the pubis	Lesser trochanter to the linea aspera of the posterior aspect of the femur

Table 7.3n Movements of the Thigh Muscles That Move the Femur, Tibia, and Fibula[11]

11. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Medial compartment of the thigh					
Moves the back of the lower legs up toward the buttocks, as when kneeling; assists in opening thighs	Femur; tibia/ fibula	Tibia/ fibula: flexion; thigh: abduction	Gracilis	Inferior ramus; body of pubis; ischial ramus	Medial surface of tibia
Anterior compartment of thigh: Quadriceps femoris group					
Moves the lower leg out in front of the body, as when kicking; assists in raising the knee	Femur; tibia/ fibula	Tibia/ fibula: extension; thigh: flexion	Rectus femoris	Anterior inferior iliac spine; superior margin of acetabulum	Patella; tibial tuberosity
Moves the lower leg out in front of the body, as when kicking	Tibia/ fibula	Extension	Vastus lateralis	Greater trochanter; intertrochanteric line; linea aspera	Patella; tibial tuberosity

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Moves the lower leg out in front of the body, as when kicking	Tibia/ fibula	Extension	Vastus medialis	Linea aspera; intertrochanteric line	Patella; tibial tuberosity
Moves the lower leg out in front of the body, as when kicking	Tibia/ fibula	Extension	Vastus intermedius	Proximal lemur shaft	Patella; tibial tuberosity
Moves the back of the lower legs up toward the buttocks, as when kneeling; assists in moving the thigh diagonally upward and outward, as when mounting a bike	Femur; tibia/ fibula	Tibia: flexion; thigh: flexion, abduction, lateral rotation	Sartorius	Anterior superior iliac spine	Medial aspect of the proximal tibia
Posterior compartment of thigh: Hamstring group					

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Moves back of lower legs up and back toward the buttocks, as when kneeling; moves thigh down and back; twists the thigh (and lower leg) outward	Femur; tibia/ fibula	Tibia: flexion; thigh: extension, lateral rotation	Biceps femoris	Ischial tuberosity; linea aspera; distal femur	Head of fibula; lateral condyle of tibia
Moves the back of the lower legs up toward the buttocks, as when kneeling; moves the thigh down and back; twists the thigh (and lower leg) inward	Femur; tibia/ fibula	Tibia: flexion; thigh: extension, medial rotation	Semitendinosus	Ischial tuberosity	Upper tibial shaft

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Moves the back of the lower legs up and back toward the buttocks, as when kneeling; moves the thigh down and back; twists the thigh (and lower leg) inward	Femur; tibia/ fibula	Tibia: flexion; thigh: flexion, medial rotation	Semimembranosus	Ischial tuberosity	Medial condyle of tibia; lateral condyle of femur

Feet and Toes

Table 7.3o Movement of the Muscles That Move the Feet and Toes[12]

12. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Dorsal group					
Extends toes 2–5	Toes 2–5	Extension	Extensor digitorum brevis	Calcaneus; extensor retinaculum	Base of t phalanx toe; exte expansio 2–5
Plantar group (Layer 1)					
Abducts and flexes the big toe	Big toe	Adduction; flexion	Abductor hallucis	Calcaneus tuberosity; flexor retinaculum	Proximal the big t
Flexes toes 2–4	Middle toes	Flexion	Flexor digitorum brevis	Calcaneus tuberosity	Middle p toes 2–4
Abducts and flexes the small toe	Toe 5	Abduction; flexion	Abductor digiti minimi	Calcaneus tuberosity	Proximal the little
Plantar group (Layer 2)					
Assists in flexing toes 2–5	Toes 2–5	Flexion	Quadratus plantae	Medial and lateral sides of the calcaneus	Tendon digitorur Extends the inter joints; fle small toe metatars
joints	Toes 2–5	Extension; flexion	Lumbricals	Tendons of flexor digitorum longus	Medial si proximal toes 2–5
Plantar group (Layer 3)					
Flexes the big toe	Big toe	Flexion	Flexer hallucis brevis	Lateral cuneiform; cuboid bones	Base of t phalanx toe

Movement	Target	Target Motion Direction	Prime Mover	Origin	Insertion
Adducts and flexes the big toe	Big toe	Adduction; flexion	Abductor hallucis	Bases of metatarsals 2–4; fibularis longus tendon sheath; ligament across metatarsophalangeal	
joints	Base of the proximal phalanx of the big toe				
Flexes the small toe	Little toe	Flexion	Flexor digiti minimi brevis	Base of metatarsal 5; tendon sheath of fibularis longus	Base of t phalanx toe
Plantar group (Layer 4)					
Abducts and flexes middle toes at metatarsophalangeal joints; extends middle toes at interphalangeal joints	Middle toes	Abduction; flexion; extension	Dorsal interossei	Sides of metatarsals	Both sid for each extensor over the on the si toe 2
Abducts toes 3–5; flexes proximal phalanges and extends distal phalanges	Small toes	Abduction; flexion; extension	Plantar interossei	Sides of each metatarsal that face metatarsal 2 (absent from metatarsal 2)	Extensor on the fi of each t 2) on the toe 2

7.10 Glossary

Acetylcholine (ACh): A neurotransmitter that plays a key role in muscle contraction and communication between neurons in the nervous system. (**Chapter 7.3**)

Actin: A protein that forms thin filaments in muscle fibers and is essential for muscle contraction through its interaction with myosin. (**Chapter 7.3**)

Action potentials: Rapid electrical signals. (**Chapter 7.3**)

Agonist: A muscle that contracts to produce a specific movement. Also known as the "prime mover." (**Chapter 7.3**

Amyotrophic lateral sclerosis (ALS): A disease that causes the nerve cells in both the upper and lower parts of the body to stop working and die; also called Lou Gehrig's disease. (**Chapter 7.6**)

Antagonist: Muscle with the opposite action of the prime mover. (**Chapter 7.3**)

Aortic hiatus: Opening in the diaphragm that allows the aorta, the body's main artery, to pass from the thoracic cavity into the abdominal cavity. (**Chapter 7.3**)

Aponeurosis: A flat, broad connective tissue that connects muscles to each other or to bones. (**Chapter 7.3**)

Atrophy: Decrease in the size and strength (but not the number) of muscle fibers. (**Chapter 7.3**)

Belly: The central, fleshy part of a muscle, which typically contains the bulk of muscle fibers. (**Chapter 7.3**)

Biceps brachii: A muscle located in the upper arm. It has two main parts (or "heads") and is responsible for bending the elbow and rotating the forearm. (**Chapter 7.3**)

Biceps femoris: A muscle located on the lateral side of the posterior thigh. (**Chapter 7.3**)

Bipennate: Fascicles on both sides of the tendon. (**Chapter 7.3**)

Brachialis: Provides additional power in flexing the forearm at the elbow; found deep to the biceps brachii. (**Chapter 7.3**)

Brachioradialis: A muscle of the forearm that helps flex the elbow. (**Chapter 7.3**)

Brevis: Muscles that are short in length. (**Chapter 7.3**)

Buccinator: A muscle found in the cheeks that allows you to whistle, blow, and suck. (Chapter 7.3)

Calcaneal tendon: A strong tendon that inserts on the calcaneal bone; also referred to as the Achilles tendon. (Chapter 7.3)

Cardiac muscle: Involuntary, striated muscle tissue found only in the heart. (Chapter 7.2, Chapter 7.4)

Caval opening: Opening in the diaphragm that allows the inferior vena cava (a large vein) to pass from the abdomen into the chest cavity. (Chapter 7.3)

Cerebral palsy: A group of conditions that affects movement and posture caused by damage to the developing brain, most often before or right after birth. (Chapter 7.6)

Circular muscles: Muscles that are arranged in a circular pattern around an opening or a surface. (Chapter 7.3)

Concentric contraction: A type of muscle contraction where the muscle shortens while generating tension, typically occurring during the lifting phase of a movement. (Chapter 7.3)

Contractility: The ability of muscle tissue to shorten with force and pull on its attachment points. (Chapter 7.2)

Convergent muscle: Muscles that have a broad origin and converge to a single tendon or point of insertion. (Chapter 7.3)

Deltoid: A thick muscle that creates the rounded lines of the shoulder and is the major abductor of the arm, but it also facilitates flexing and medial rotation, as well as extension and lateral rotation. (Chapter 7.3)

Depolarize: The process by which the membrane potential of a cell becomes less negative. (Chapter 7.3)

Desmosome: A cell structure that anchors the ends of cardiac muscle fibers together, so the cells do not pull apart during the stress of individual fibers contracting. (Chapter 7.4)

Diaphragm: Separates the thoracic and abdominal cavities and is dome-shaped at rest. (Chapter 7.3)

Dorsal interossei: Muscles that abduct and flex the three middle fingers at the metacarpophalangeal joints and extend them at the interphalangeal joints. (Chapter 7.3)

Duchenne muscular dystrophy (DMD): Progressive weakening of the skeletal

muscles. It is one of several diseases collectively referred to as “muscular dystrophy.” (Chapter 7.6)

Eccentric contraction: A type of muscle contraction where the muscle lengthens while generating tension, typically occurring during the lowering phase of a movement. (Chapter 7.3)

Elasticity: The ability of muscle tissue to return to its original length after being stretched, due to the presence of elastic fibers. (Chapter 7.2)

Endomysium: Thin connective tissue that surrounds individual muscle fibers within a fascicle. (Chapter 7.3)

Epicranial aponeurosis: A muscle on the back of the head. (Chapter 7.3)

Epimysium: A connective tissue layer that surrounds and protects skeletal muscles. (Chapter 7.3)

Esophageal hiatus: Opening in the diaphragm through which the esophagus passes from the thoracic cavity into the abdominal cavity. (Chapter 7.3)

Excitable: Able to respond to stimulation from the nervous system by generating an electrical signal. (Chapter 7.2)

Excitation-contraction coupling: Links electrical signals to muscle contraction. (Chapter 7.3)

Extensibility: The ability of muscle tissue to stretch or extend without being damaged and still contract. (Chapter 7.2)

External oblique(s): Flat superficial skeletal muscle in the anterolateral wall of the abdomen. (Chapter 7.3)

Extrinsic eye muscles: Control the movement of the eyeball. (Chapter 7.3)

Extrinsic extensors: Located primarily on the posterior (dorsal) side of the forearm. These muscles extend the wrist and fingers to help control the release of objects and stabilize the wrist during fine motor movements. (Chapter 7.3)

Extrinsic flexors: Located primarily on the anterior (palmar) side of the forearm. These muscles flex the wrist and fingers, allowing movements such as gripping and making a fist. (Chapter 7.3)

Fascia: A fibrous tissue that encloses muscles and organs. (Chapter 7.3)

Fascicles: Bundles of muscle fibers grouped together within a muscle. (Chapter 7.3)

Fibromyalgia: A disorder characterized by widespread musculoskeletal pain accompanied by fatigue, sleep, memory, and mood issues. (**Chapter 7.6**)

Fixator: Stabilizes a joint or body part, allowing the agonist to perform its action more effectively. (**Chapter 7.3**)

Frontalis: Muscle on the forehead. (**Chapter 7.3**)

Fusiform: A type of muscle shape characterized by a tapered end and a wider belly, resembling a spindle. (**Chapter 7.3**)

Gap junction: Channels between cardiac muscle fibers to allow the depolarizing current to flow from one cardiac muscle cell to the next. (**Chapter 7.4**)

Gastrocnemius: The most superficial and visible muscle of the calf. (**Chapter 7.3**)

Gluteus maximus: The largest of the gluteus muscles that extends the femur and laterally rotates the thigh. (**Chapter 7.3**)

Gluteus medius: The muscle deep to the gluteus maximus that abducts the femur at the hip and medially rotates the thigh. (**Chapter 7.3**)

Gluteus minimus: Smallest of the gluteal muscles and deep to the gluteus medius. (**Chapter 7.3**)

Gracilis: Adducts the thigh, in addition to flexing the leg at the knee. (**Chapter 7.3**)

Hamstring group: A group of three muscles that flex the knee, extend the hip, and rotate the thigh. (**Chapter 7.3**)

Hypertonia: Excessive muscle tone. (**Chapter 7.3**)

Hypertrophy: Increased mass and bulk in a skeletal muscle. (**Chapter 7.3**)

Hypothenar Muscle Group: A group of muscles on the medial aspect of the palm. (**Chapter 7.3**)

Hypotonia: Absence of the low-level contractions that lead to muscle tone. (**Chapter 7.3**)

Iliopsoas: Muscle group consisting of the iliacus and psoas major muscles. They flex the thigh at the hip, rotate it laterally, and flex the trunk of the body onto the hip when sitting up from a supine position. (**Chapter 7.3**)

Infraspinatus: Inferior to the spine of the scapula and laterally rotates the arm. (**Chapter 7.3**)

Insertion: The movable end of a muscle that attaches to the bone being pulled. (Chapter 7.3)

Intercalated disc: Allows the cardiac muscle cells to coordinate contraction so that the heart can work as a pump. (Chapter 7.4)

Intercostal muscles: A group of muscles located between the ribs. (Chapter 7.3)

Internal oblique(s): Perpendicular to the external oblique and extending superiorly and medially, the direction the thumbs usually go when the other fingers are in the pants pocket. (Chapter 7.3)

Involuntary: Describes muscle movement that occurs without conscious control. (Chapter 7.2)

Isometric contraction: A type of muscle contraction where the muscle generates tension without changing length, maintaining a static position. (Chapter 7.3)

Isotonic contractions: Muscle contractions that involve a change in muscle length while maintaining a constant tension. (Chapter 7.3)

Lateral Peroneal Muscles: The lateral side of the leg includes two muscles (Fibularis longus and Fibularis brevis). They evert the foot, assist with plantar flexion, and help stabilize the foot and ankle while walking and standing. (Chapter 7.3)

Lateralis: Muscles located away from the midline of the body. (Chapter 7.3)

Latissimus dorsi: A broad, triangular muscle located on the inferior part of the back where it inserts into a thick connective tissue sheath called an aponeurosis. (Chapter 7.3)

Linea alba: Fibrous strip in the middle of the abdomen where the abdominal muscles meet. (Chapter 7.3)

Longus: Muscles that are elongated or long in shape. (Chapter 7.3)

Lumbricals: Muscles that flex each finger at the metacarpophalangeal joints and extend each finger at the interphalangeal joints. (Chapter 7.3)

Masseter: The main muscle used for chewing. (Chapter 7.3)

Mastication: An anatomical term for chewing. (Chapter 7.3)

Maximus: Muscles that are large or the largest in a group. (Chapter 7.3)

Medialis: Muscles located toward the midline of the body. (Chapter 7.3)

Medius: Muscles that are moderate or medium-sized. (Chapter 7.3)

Minimus: Muscles that are small in size. (Chapter 7.3)

Motor end plate: Specialized region of the sarcolemma at the neuromuscular junction where ACh receptors are concentrated. (Chapter 7.3)

Motor unit: Responsible for muscle contraction, with the number of fibers influenced by the precision of movement required. (Chapter 7.3)

Multipennate: Multiple tendons with muscle fibers branching out from each side. (Chapter 7.3)

Muscle fibers: Elongated cells that make up muscle tissue and are responsible for contraction and movement. (Chapter 7.3)

Muscle tension: Force generated by the contraction of the muscle (or shortening of the sarcomeres). (Chapter 7.3)

Muscle tone: Constant, low-level contraction of muscles that maintains posture and stability and is regulated by the nervous system. (Chapter 7.3)

Myasthenia gravis: A chronic neuromuscular disease that causes weakness in the skeletal muscles; it is an autoimmune disease. (Chapter 7.6)

Myofibrils: Long, thread-like structures within muscle fibers that contain the contractile proteins actin and myosin and are responsible for muscle contraction. They are arranged in a repeating pattern, forming sarcomeres, the functional units of muscle. (Chapter 7.3)

Myosin: A motor protein that forms thick filaments in muscle fibers and is responsible for muscle contraction by interacting with actin to generate force. (Chapter 7.3)

Neuromuscular junction (NMJ): The synapse or connection point between a motor neuron and a muscle fiber where the transmission of signals occurs to initiate muscle contraction. (Chapter 7.3)

Neurotransmitter: Chemical messengers. (Chapter 7.3)

Oblique: Muscles that are at an angle in the abdomen. (Chapter 7.3)

Occipitofrontalis: A muscle that raises the eyebrows and wrinkles the forehead. (Chapter 7.3)

Orbicularis oculi: Circular muscle around each eye that closes the eye(s). (Chapter 7.3)

Orbicularis oris: Circular muscle around the mouth that compresses and puckers the lips. (Chapter 7.3)

Origin: The end of the muscle attached to a fixed (stabilized) bone. (Chapter 7.3)

Palmar interossei: Muscles that abduct and flex each finger at the

metacarpophalangeal joints and extend each finger at the interphalangeal joints. (Chapter 7.3)

Parallel muscles: A type of muscle architecture where the muscle fibers run parallel to the long axis of the muscle. (Chapter 7.3)

Patellar ligament: Connects the patella (kneecap) to the tibia (shinbone). (Chapter 7.3)

Pectoralis major: A large, fan-shaped muscle in the chest that aids in shoulder movement. (Chapter 7.3)

Pectoralis minor: Rotates the shoulder anteriorly (throwing motion). (Chapter 7.3)

Pelvic or hip girdle: Serves as a foundation for the lower limbs. (Chapter 7.3)

Pennate muscles: Muscles characterized by a feather-like arrangement of fibers. (Chapter 7.3)

Perimysium: Connective tissue that surrounds individual muscle fascicles within a muscle. (Chapter 7.3)

Plantar aponeurosis: A thick, dense connective tissue band on the sole of the foot, stretching from the heel bone to the toes.

Polio: A highly infectious disease caused by a virus that invades the nervous system and can cause total paralysis in a matter of hours. (Chapter 7.6)

Popliteal fossa: Diamond-shaped space at the back of the knee. (Chapter 7.3)

Prime mover: A muscle that plays the primary role in producing a specific movement. Also known as an “agonist.” (Chapter 7.3)

Quadriceps femoris group: Consists of four muscles that extend and stabilize the knee; often referred to as the “quads.” (Chapter 7.3)

Quadriceps tendon: Connects the quadriceps muscle group (located in the front of the thigh) to the patella (kneecap). (Chapter 7.3)

Raphe: Very slender tendon. (Chapter 7.3)

Recruitment: The process by which an increase in the number of active motor units enhances muscle contraction strength. (Chapter 7.3)

Rectus: Muscles characterized by their straight alignment. (Chapter 7.3)

Rectus abdominis: The straight muscle in the anterior wall of the abdomen; commonly called the “sit-up” muscle. (Chapter 7.3)

Rectus femoris: On the anterior aspect of the thigh. (Chapter 7.3)

Rectus sheaths: Fibrous coverings that enclose the rectus abdominis muscles. (Chapter 7.3)

Repolarizes: The process by which a cell's membrane potential returns to its resting state after depolarization, typically involving the efflux of potassium ions from the cell. (Chapter 7.3)

Rhomboid major: Attaches the vertebral border of the scapula to the spinous process of the thoracic vertebrae. (Chapter 7.3)

Rhomboid minor: Attaches the vertebral border of the scapula to the spinous process of the thoracic vertebrae. (Chapter 7.3)

Rotator cuff: A circle of tendons around the shoulder joint. (Chapter 7.3)

Sarcolemma: Cell membrane that surrounds a muscle fiber, playing a crucial role in conducting electrical impulses and maintaining the fiber's structural integrity. (Chapter 7.3)

Sarcomere: The basic functional unit of a muscle fiber; the segment between two Z discs. They contain overlapping thin (actin) and thick (myosin) filaments, which interact to produce muscle contraction. (Chapter 7.3)

Sarcoplasm: The cytoplasm of a muscle fiber, containing various organelles, myofibrils, and energy stores, such as glycogen and myoglobin, essential for muscle function. (Chapter 7.3)

Sarcoplasmic reticulum: A specialized form of the endoplasmic reticulum in muscle cells that stores and regulates calcium ions that are crucial for muscle contraction and relaxation. (Chapter 7.3)

Sartorius: A band-like muscle that extends from the anterior superior iliac spine of the pelvis to the medial side of the proximal tibia. (Chapter 7.3)

Semimembranosus: The most medial muscle of the three from mid-thigh to medial knee. Part of it is deep to the semitendinosus. (Chapter 7.3)

Semitendinosus: Muscle located medially next to the biceps femoris. (Chapter 7.3)

Serratus anterior: Moves the arm from the side of the body to the front of the body. (Chapter 7.3)

Skeletal muscle: Voluntary, striated muscle tissue attached to bones and around the entrance points of the body. (Chapter 7.2, Chapter 7.3)

Sliding filament model of muscle contraction: Actin and myosin filaments slide past each other to shorten the sarcomere, resulting in muscle fiber shortening and contraction. (**Chapter 7.3**)

Smooth muscle: Involuntary, nonstriated muscle tissue found in the walls of organs. (**Chapter 7.2**, **Chapter 7.5**)

Soleus: A wide and flat muscle found deep to the gastrocnemius. (**Chapter 7.3**)

Spasticity: An increase in muscle tone and stiffness. (**Chapter 7.3**)

Sphincters: Circular muscles that encircle and control the opening of various passages in the body. (**Chapter 7.3**)

Sternocleidomastoid: A major muscle that laterally flexes and rotates the head. (**Chapter 7.3**)

Striations: Stripes in muscle tissue created by the regular arrangement of proteins within the cells. (**Chapter 7.2**)

Subscapularis: A large muscle located on the anterior surface of the scapula and responsible for internal rotation and adduction of the shoulder. (**Chapter 7.3**)

Supraspinatus: A shoulder muscle located above the scapula that initiates arm abduction and stabilizes the shoulder joint. (**Chapter 7.3**)

Synaptic cleft: A small gap between a motor neuron and the muscle fiber's sarcolemma. (**Chapter 7.3**)

Synergist: A muscle that assists the agonist (prime mover) in performing a specific movement. (**Chapter 7.3**)

Temporalis: A muscle that lifts and pulls back the mandible. (**Chapter 7.3**)

Tendinitis: Inflammation of a tendon, the thick band of fibrous connective tissue that attaches a muscle to a bone. (**Chapter 7.6**)

Tendinous intersections: Fibrous bands that divide the rectus abdominis muscle into segments, creating the "six-pack" appearance. (**Chapter 7.3**)

Tendons: A fibrous connective tissue that attaches muscle to bone. (**Chapter 7.3**)

Teres major: Thick and flat; inferior to the teres minor and extends the arm and assists in adduction and medial rotation. (**Chapter 7.3**)

Teres minor: Laterally rotates, adducts, and extends the arm. (**Chapter 7.3**)

Tetanus: A serious disease of the nervous system caused by a toxin-producing

bacterium that affects the neuromuscular junction and causes muscle contractions, particularly of the jaw and neck muscles. (Chapter 7.6)

Thenar Muscle Group: A group of muscles on the lateral aspect of the palm. (Chapter 7.3)

Thick filaments: Composed primarily of myosin, these filaments are thicker than actin and are responsible for generating force during muscle contraction by interacting with thin filaments in the sarcomere. (Chapter 7.3)

Thin filaments: Composed primarily of actin, these filaments are thinner than myosin and are referred to as thin filaments in the sarcomere. They play a key role in muscle contraction by interacting with thick filaments (myosin). (Chapter 7.3)

Tibialis anterior: A long and thick muscle on the anterolateral surface of the tibia. (Chapter 7.3)

Transverse abdominis: The deep muscle is the transversus abdominis. (Chapter 7.3)

Trapezius: A muscle that elevates shoulders (shrugging), pulls shoulder blades together, and tilts the head backward. (Chapter 7.3)

Triceps brachii: A muscle located at the back of the upper arm. It has three heads (points of origin) and is responsible for straightening the elbow. (Chapter 7.3)

Unipennate: Fascicles located on one side of the tendon. (Chapter 7.3)

Vastus intermedius: Between vastus lateralis and vastus medialis and deep to the rectus femoris. (Chapter 7.3)

Vastus lateralis: On the lateral aspect of the thigh. (Chapter 7.3)

Vastus medialis: On the medial aspect of the thigh. (Chapter 7.3)

Voltage-gated sodium channels: Membrane proteins that open in response to changes in electrical potential. (Chapter 7.3)

Voluntary: Muscle movement that is under conscious control. (Chapter 7.2)

Zygomaticus: Muscle from the zygomatic bone to the mouth; the “smiling” muscle. (Chapter 7.3)

PART VIII

CHAPTER 8 NERVOUS SYSTEM

8.1 Introduction to the Nervous System

Chapter Competency

Analyze how components of the nervous system function in the body.

Learning Objectives

- Identify the gross and microscopic structural components of the nervous system.
- Correlate the structural components of the nervous system with their functions.
- Correlate cranial nerves to their respective physiological functions.
- Illustrate the relationships among the components of the nervous system.
- Summarize the functions of the nervous system.
- Identify the gross and microscopic structural components of the somatic and special senses.
- Correlate the structural components of the somatic and special senses with their functions.

Imagine you are working as an occupational therapy assistant helping a patient recover after a stroke, traumatic brain injury, or nervous system disorder. During therapy, you observe how the patient senses touch, maintains balance, coordinates movement, responds to instructions, and completes daily activities. To support recovery and independence, you must understand how the nervous system receives information, processes it, and generates responses throughout the body.

Neurology is the study of the nervous system, a complex communication network made up of the brain, spinal cord, nerves, neurons, and supporting cells called neuroglia. This system allows the body to detect changes in the internal and external environment,

interpret sensory information, coordinate voluntary and involuntary responses, and maintain homeostasis. The nervous system also supports thought, memory, emotion, movement, reflexes, and the special senses of vision, hearing, equilibrium, taste, and smell.

In this chapter, you will explore the structure and function of the nervous system. You will learn about the major functions of sensation, integration, and response; the organization of the central and peripheral nervous systems; and the roles of neurons, neuroglia, the brain, spinal cord, spinal nerves, and cranial nerves. You will also examine the autonomic nervous system, including the sympathetic and parasympathetic divisions, and study the structures involved in the somatic and special senses. Finally, you will learn about common disorders of the nervous system and sense organs.

By mastering these concepts, you will gain a deeper understanding of how the nervous system coordinates communication, movement, sensation, reflexes, and homeostasis. This foundation will help you connect nervous system structure to patient assessment, rehabilitation, sensory changes, neurological disorders, and the body's ability to respond to its environment.

Video

Watch the video "Nervous System" below to learn about the structure and function of the nervous system and how it coordinates communication throughout the body.[1]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

1. Amoeba Sisters. (2022, November 8). *Nervous system* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=RNLceVI8jcc

8.2 Major Functions of the Nervous System

The major functions of the nervous system are sensation, integration, and response.[1]

Sensation

The first major function of the nervous system is **sensation**—receiving information about the environment to take in what is happening outside the body and also within the body. The sensory functions of the nervous system can detect a change in homeostasis or the environment, known as a **stimulus**. The senses we think of most are the "big five" or the major senses: taste, smell, touch, sight, and hearing, but there are actually more senses than just those. Those five are all senses that detect and allow us to consciously perceive stimuli from the outside world. Additional sensory receptors can receive information from the inside of the body (internal environment), such as temperature, blood pressure, the stretch of an organ wall, or the concentration of certain ions in the blood. Additional information about the senses is discussed in the "**Senses**" section.

Integration

Stimuli received by sensory structures are communicated to the nervous system, where the information is analyzed in a process called **integration**. Stimuli are interpreted and compared with other stimuli, memories of previous stimuli, and the state of the individual at the particular time. Decisions are made whether to ignore a stimulus or to generate a specific response to the stimulus. For example, during a baseball game, the stimulus of a baseball pitched to a batter does not automatically cause a response from the batter swinging. The batter considers the trajectory of the ball and its speed,

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

the current count of three balls and one strike, and the score of the game when deciding whether to swing at the ball or let it pass by in the hope of getting a walk to first base.

Response

The nervous system produces a **response** to a stimulus perceived by our senses. An example of a response is the movement of voluntary muscles, such as moving your fingers to answer a text that you just received and read with your eyes, but there are numerous ways our body responds to sensory stimuli.

Responses can be divided into those that are under voluntary control or involuntary control. For example, the nervous system can respond by stimulating all three types of muscle tissue to contract, such as voluntary skeletal muscle being stimulated to move the skeleton, involuntary cardiac muscle being stimulated to increase heart rate during exercise, and smooth muscle being stimulated to move food through the digestive tract. Responses also include the neural control of glands in the body, such as the production and secretion of sweat by the sweat glands to decrease body temperature.

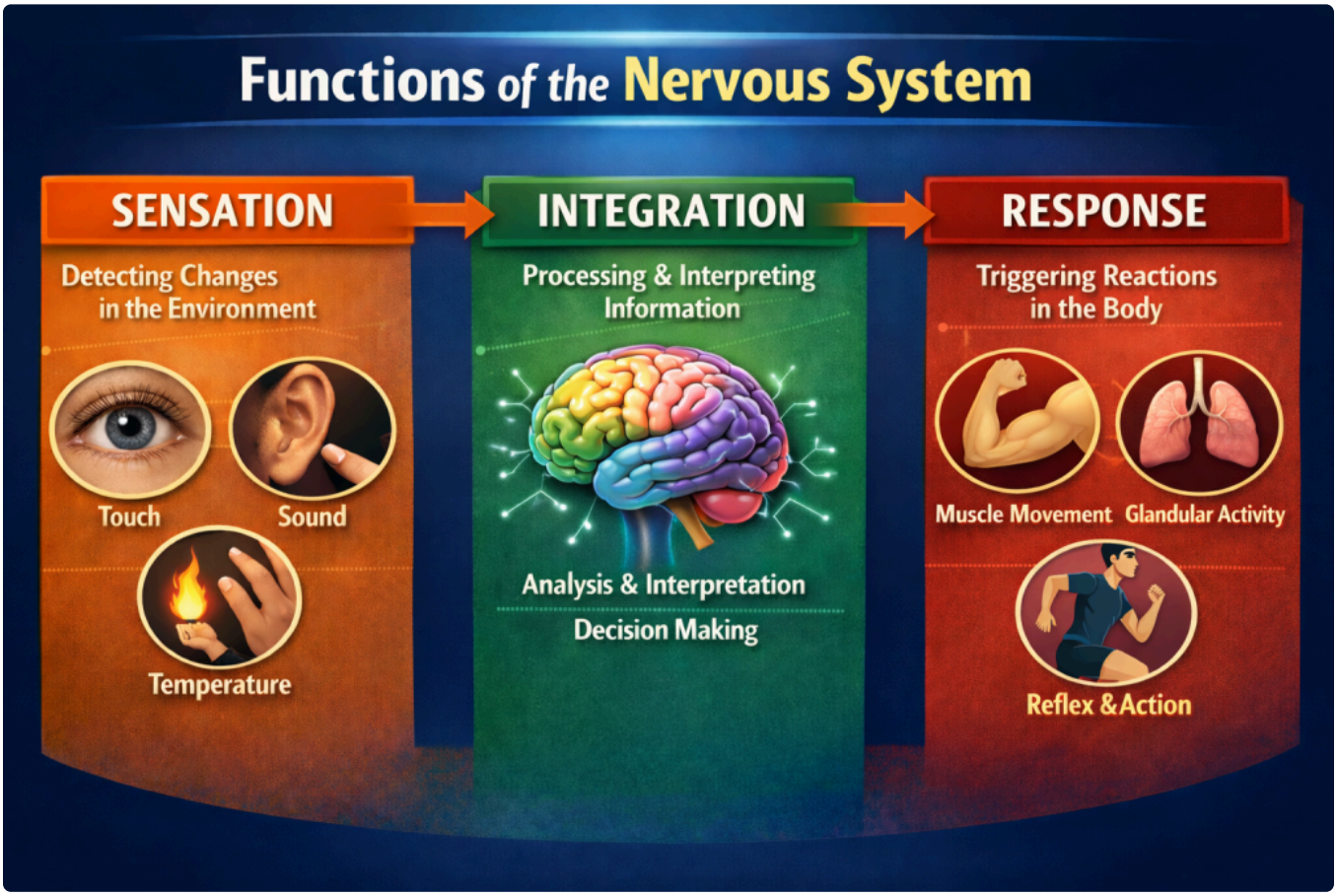


Figure 8.1 Functions of the Nervous System

2

2. OpenAI. (2026, January 10). *Functions of the nervous system* [Large language model prompt]. ChatGPT. chatgpt.com

8.3 Anatomy of the Nervous System

The nervous system serves as the body's communication and control center, allowing us to sense, process, and respond to the world around us.[1]

Nervous System Divisions

The nervous system can be divided into two major regions: the central nervous system and the peripheral nervous system. The **central nervous system (CNS)** includes the brain and spinal cord, and the **peripheral nervous system (PNS)** includes all of the parts of the nervous system found outside of the brain and spinal cord. The peripheral nervous system is so named because it is on the periphery—meaning beyond the brain and spinal cord. See Figure 8.2[2] for an illustration of these two systems. The peripheral system is further divided into the somatic, autonomic, and enteric nervous systems.

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. OpenAI. (2026, January 10). *Major divisions of the nervous system* [Large language model prompt]. ChatGPT. chatgpt.com

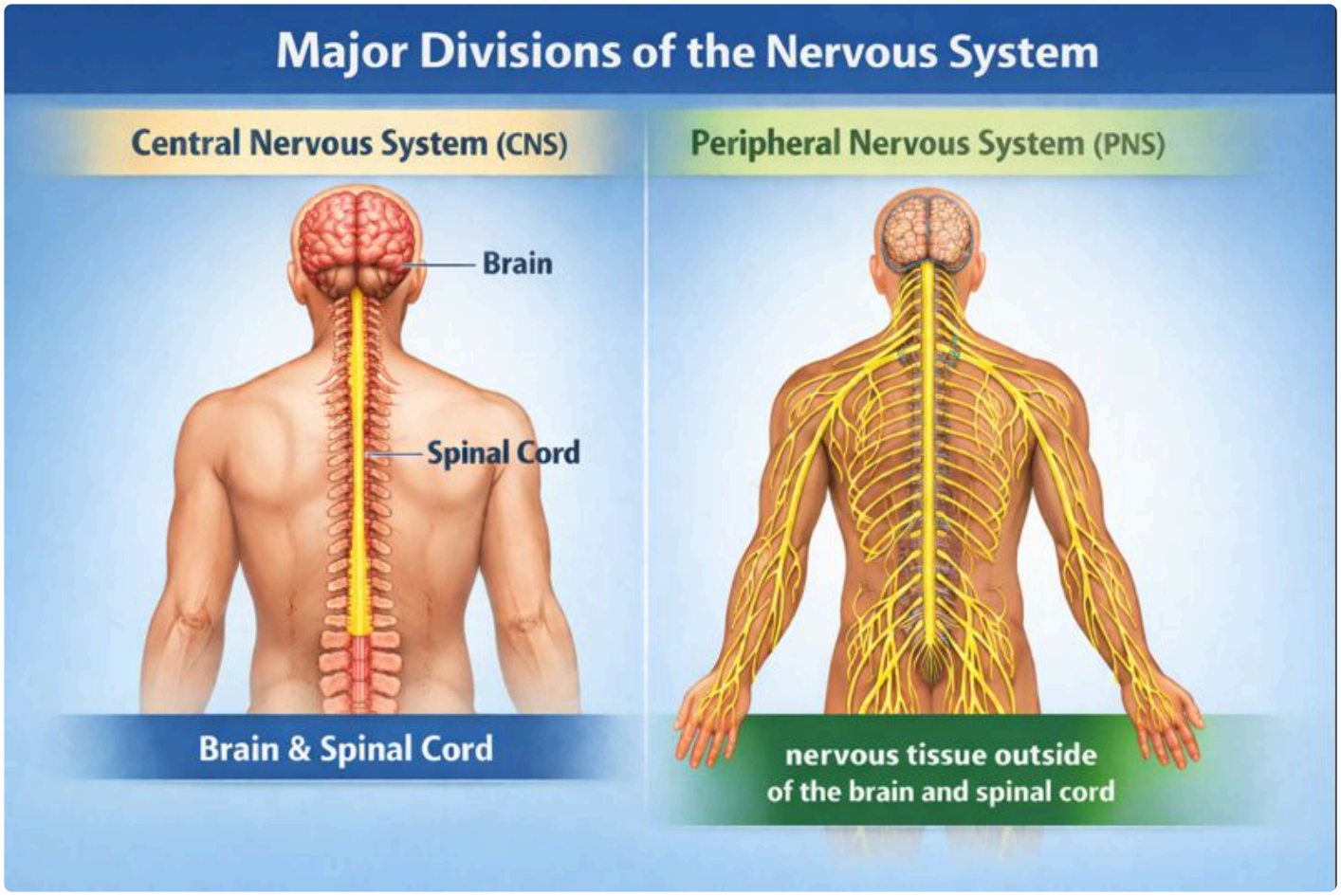


Figure 8.2 Central and Peripheral Nervous Systems

Nervous Tissue

Nervous tissue in the CNS and PNS contains two basic types of cells: neurons and neuroglia (also known as glial cells). **Neurons** are the communicating cells of the nervous system. They are excitable and can generate and conduct electrical signals. **Neuroglia** include a variety of cells that support the neurons in their communication activities.

Neurons

Neurons are the functional cells of the nervous system. They carry electrical signals that communicate sensory information, facilitate thought processes within the brain, and produce movements in response to sensory stimuli. The same neurons last throughout a lifetime, as they don't readily undergo mitosis. If they are lost due to

damage or disease, they are not replaced, which may lead to permanent deficits or disability.

Anatomy of a Neuron

The main part of a neuron is the cell body, also known as the soma (*soma* = "body"). The **cell body** contains the nucleus and most of the major organelles. Neurons are specialized cells because they have many extensions of their cell membranes that are generally referred to as processes. Neurons usually have one **axon** – a fiber that emerges from the cell body and sends an electrical nerve impulse to target cells. That single axon can have many branches, allowing it to communicate with many target cells. The other processes on the neuron are **dendrites**, which receive information from other neurons at synapses. A **synapse** is where two neurons (or a neuron and muscle) meet. Although they are close together, there is a small gap of space between them. Information flows through a neuron from the dendrites, across the cell body, and down the axon. This gives the neuron a polarity—meaning that information flows in one direction. See Figure 8.3[3] for an illustration of the parts of a neuron, and Figure 8.4[4] for a microscopic image of a neuron.

3. OpenStax College. (2016). *1206_The_Neuron* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1206_The_Neuron.jpg
4. Panzer VI-II. (2016). *Neuron-section* [Photograph]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Neuron-section.jpg

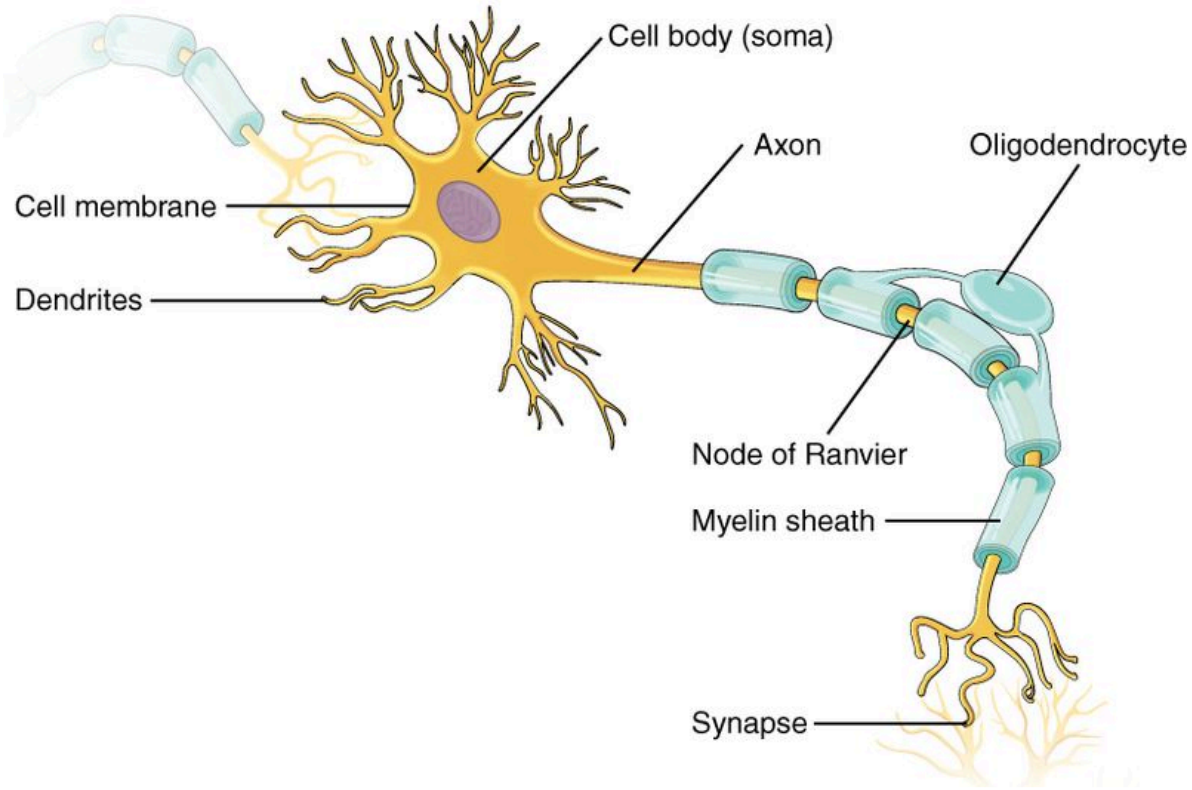


Figure 8.3 Neuron

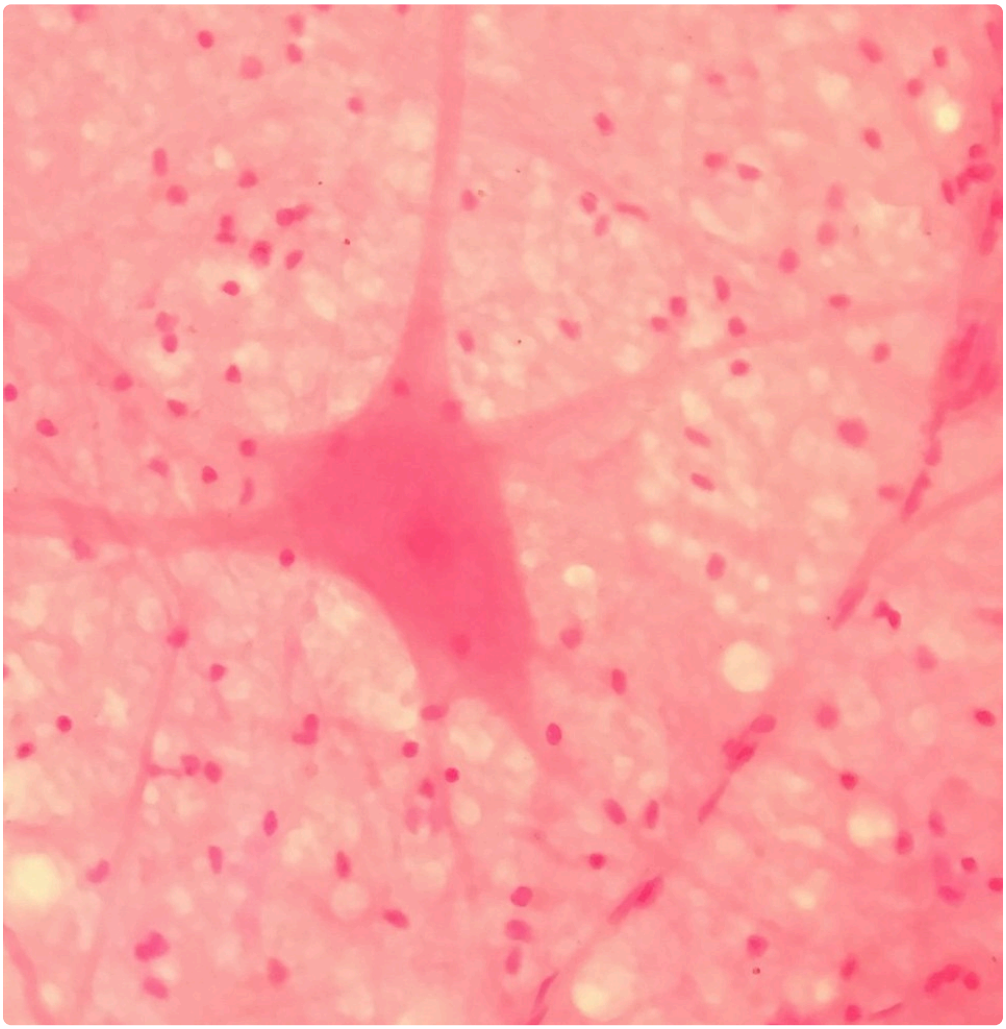


Figure 8.4 Microscopic Image of a Neuron

Some axons have a lipid-rich, insulating substance called **myelin** made from neuroglia. Myelin acts as insulation, much like the plastic or rubber that is used to insulate electrical wires. A key difference between myelin and the insulation on a wire is that there are gaps in the myelin covering an axon. Each gap is called a **node of Ranvier** and is important to the way that electrical signals travel down the axon. At the end of the axon are the **axon terminals** that are several branches extending toward the target cell. Each axon terminal has an enlarged tip called a **synaptic end bulb**. These bulbs are what make the connection with the target cell at the synapse. See Figure 8.5[5] for an illustration of a myelinated axon and an unmyelinated axon.

5. OpenAI. (2026, January 10). *Myelinated vs unmyelinated axon* [Large language model prompt]. ChatGPT. chatgpt.com

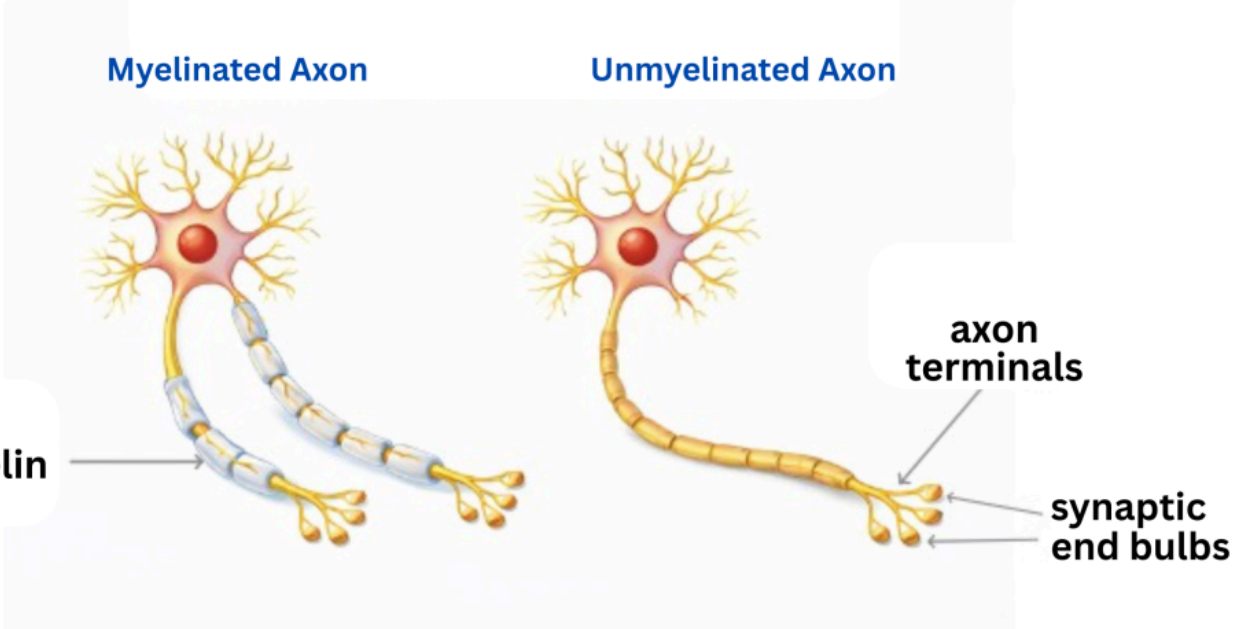


Figure 8.5 Myelinated versus Unmyelinated Axon

Gray Matter and White Matter

There are regions of nervous tissue that contain mostly cell bodies and regions that are largely composed of just axons. These two regions within nervous system structures are often referred to as **gray matter** (the regions with many cell bodies and dendrites) or **white matter** (the regions with many myelinated axons).

The colors used to describe these regions are the colors of unstained nervous tissue. Gray matter is not necessarily gray. It can be pinkish because of blood content, or slightly tan, depending on how long the tissue has been preserved. White matter is white because axons are insulated by myelin and lipids appear as white ("fatty") material, similar to fat on a raw piece of beef. See Figure 8.6[6] for an image of the appearance of white and gray matter in a brain removed during autopsy.

6. OpenStax College. (2016). *1202_White_and_Gray_Matter* [Photograph]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1202_White_and_Gray_Matter.jpg

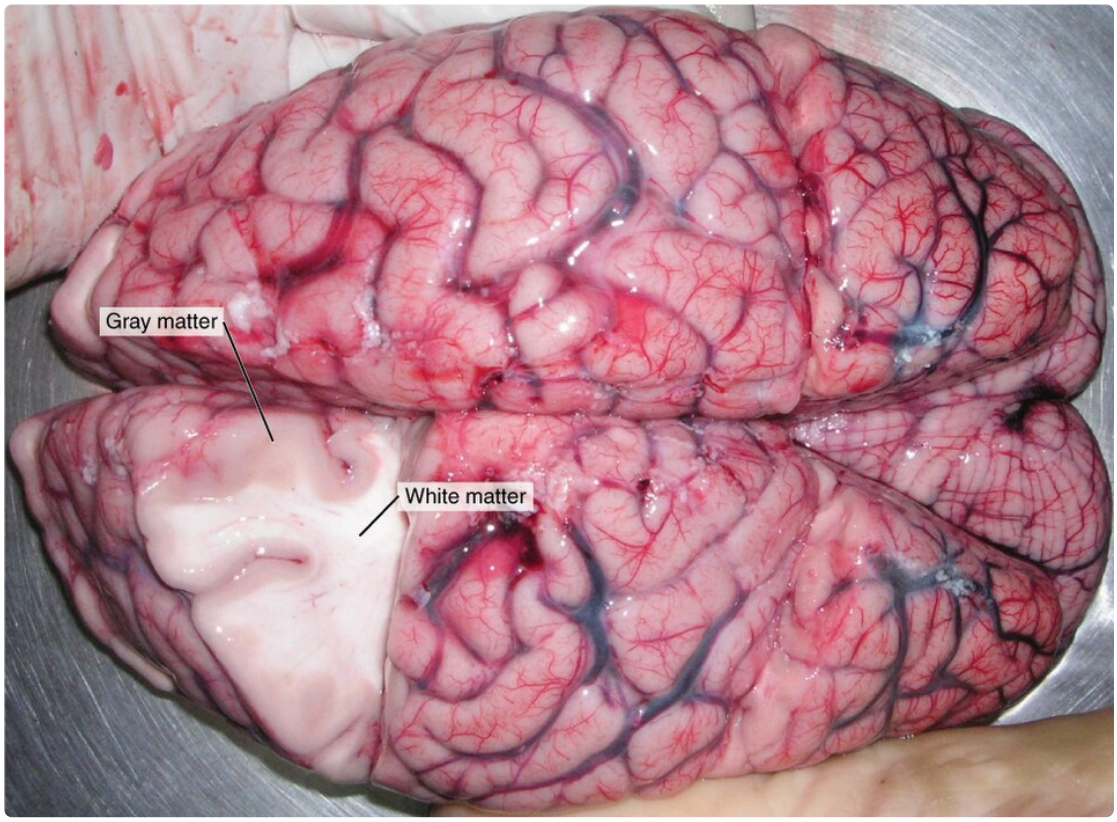


Figure 8.6 Gray and White Matter of the Brain

Neuron Terminology in the Central Nervous System and Peripheral Nervous System

The cell bodies and axons of neurons can be located in the central nervous system (CNS) or the peripheral nervous system (PNS); therefore, separate names are given to identify their location. A collection of neuron cell bodies in the CNS is referred to as a **nucleus**. In the PNS, a collection of neuron cell bodies is referred to as a **ganglion** (plural = ganglia).

Note that the word *nucleus* has several different meanings in anatomy and physiology. It is the center of an atom, where protons and neutrons are found; it is the control center of a cell, where the DNA is found; and it is a collection of nerve cell bodies in the CNS. Figure 8.7[7] illustrates these three different meanings of the word nucleus within anatomy and physiology.

7. OpenStax College. (2016). *1203_Concept_of_NucleusN* [Diagram]. Wikimedia Commons. CC BY 4.0. https://en.wikipedia.org/wiki/File:1203_Concept_of_NucleusN.jpg

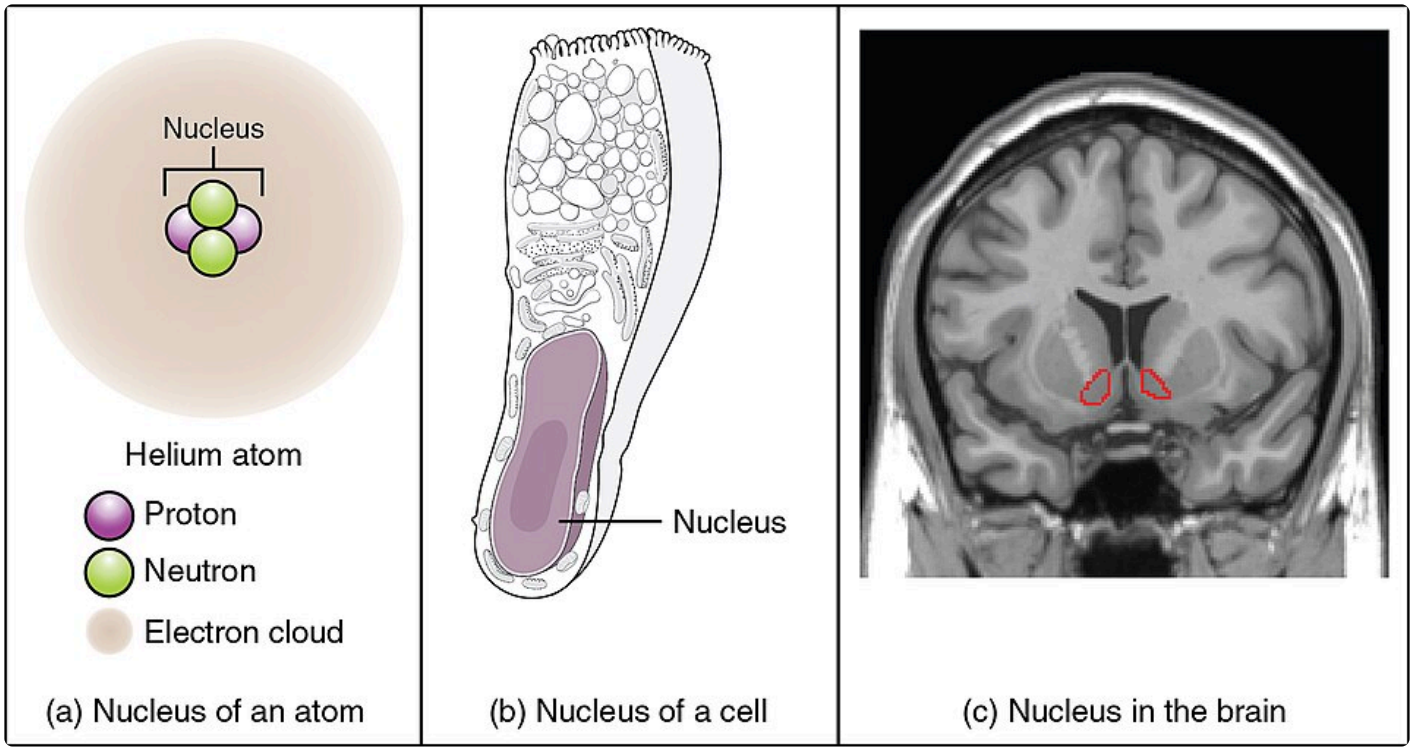


Figure 8.7 Nucleus: (a) in an Atom, (b) in a Cell, and (c) in the Brain

Terminology applied to bundles of axons also differs depending on location. A bundle of axons, or fibers, found in the CNS is called a **tract**. Ascending tracts carry sensory information up the spinal cord, and descending tracts carry motor information down the spinal cord. A bundle of axons in the PNS is called a **nerve**. An important point to make about these two terms is that they can both be used to refer to the same bundle of axons. When those axons are in the PNS, the term is nerve, but if they are in the CNS, the term is tract. For example, axons that project from the retina to the brain are called the optic nerve as they leave the eye, but when they enter the brain, they are referred to as the optic tract. See Figure 8.8[8] for an illustration of the optic nerve and optic tract.

8. OpenStax College. (2016). *1204_Optic_Nerve_vs_Optic_Tract* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1204_Optic_Nerve_vs_Optic_Tract.jpg

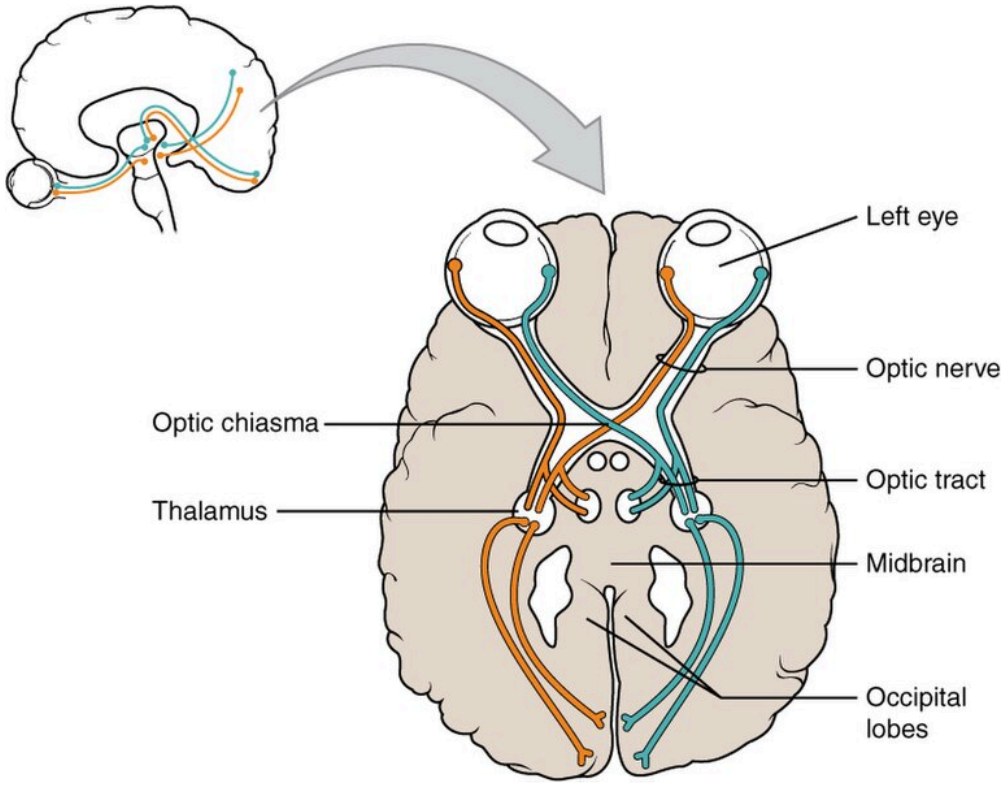


Figure 8.8 Optic Nerve Versus Optic Tract

Table 8.3a helps to clarify which of these terms apply to the central or peripheral nervous systems.

Table 8.3a. Structures of the CNS and PNS[9]

Structure	CNS	PNS
Group of Neuron Cell Bodies (i.e., Gray Matter)	Nucleus	Ganglion
Bundle of Axons (i.e., White Matter)	Tract	Nerve

9. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Types of Neurons

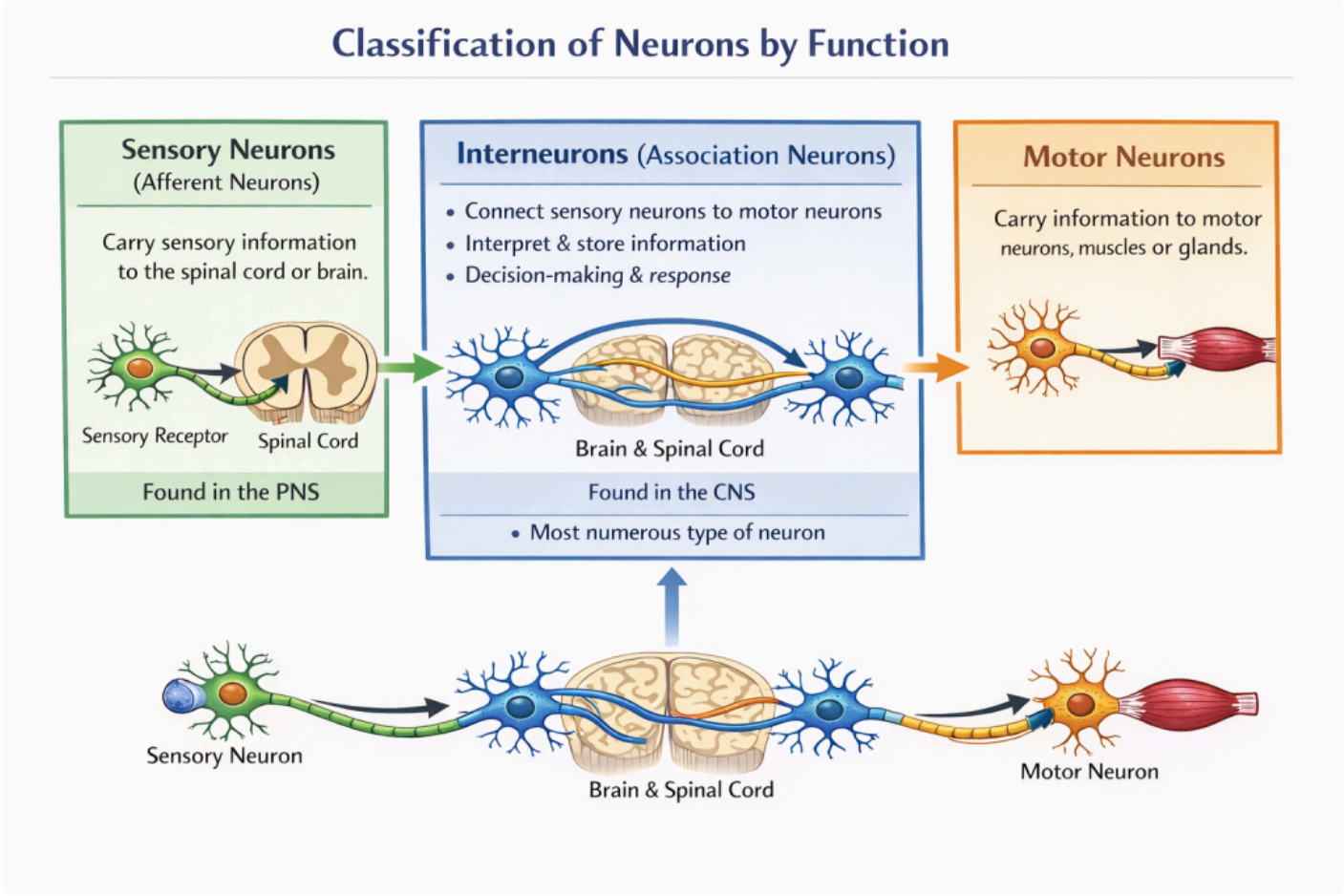
There are trillions of neurons in the nervous system that can be classified by many different criteria. The first way is to classify them by function.

Classification by Function

Sensory neurons

are also known as afferent neurons (the prefix *af-* means "toward"). These neurons carry sensory information to the spinal cord or brain. **Motor neurons** are known as efferent neurons (the prefix *ef-* means "away from"). These neurons carry information to other motor neurons, muscles, or glands. Both sensory and motor neurons are found in the PNS. **Interneurons** are also referred to as association neurons. They connect the sensory neurons to the motor neurons and are responsible for interpreting sensory information, storing information, and making decisions or determining what response, if any, is needed. Interneurons are found within the CNS. Most neurons in the nervous system are interneurons. See Figure 8.9[10] for an illustration showing the classification of neurons by function.

10. OpenAI. (2026, January 10). *Classification of neurons by structure* [Large language model prompt]. ChatGPT. chatgpt.com



8.9 Classification of Neurons by Function

Classification by Structure

Another way to classify neurons is by the number of processes attached to the cell body. Using the standard model of neurons, one of these processes is the axon, and the rest are dendrites. Because information flows through the neuron from dendrites and cell bodies toward the axon, these names are based on the neuron's polarity.

Unipolar cells have only one process emerging from the cell (*uni-* = "one"). True unipolar cells are only found in invertebrate animals, so the unipolar cells in humans are more appropriately called "pseudo-unipolar" cells. **Bipolar** cells have two processes (*bi-* = "two"), which extend from each end of the cell body, opposite to each other. One is the axon, and one is the dendrite. Bipolar cells are not very common. They are found mainly in the olfactory epithelium (where smell stimuli are sensed) and as part of the retina (where light is detected). **Multipolar** neurons are any neurons that are not unipolar or bipolar. They have one axon and two or more dendrites (usually many more) (*multi-* =

"many"). Most of the neurons in the human body are multipolar. See Figure 8.10[11] for an illustration of unipolar, bipolar, and multipolar neurons.

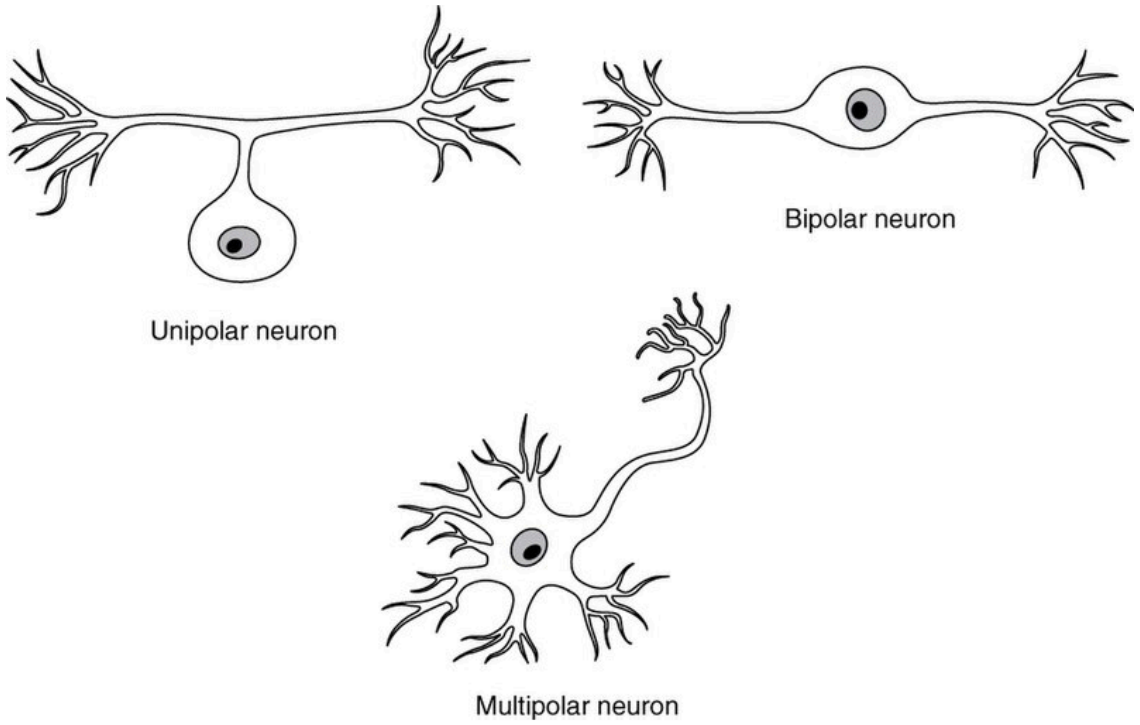


Figure 8.10 Unipolar, Bipolar, and Multipolar Neurons

Other Ways to Classify Neurons

Neurons can also be classified by where they are found, who found them, what they do, or even what chemicals they use to communicate with each other. For example, a multipolar neuron that has a very important role in the cerebellum is known as a Purkinje cell, named after the anatomist who discovered it. See Figure 8.11[12] for an illustration of other ways to classify neurons.

11. OpenStax College. (2016). *1207_Neuron_Shape_Classification* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1207_Neuron_Shape_Classification.jpg

12. OpenStax College. (2016). *1208_Other_Types_of_Neurons* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1208_Other_Types_of_Neurons.jpg

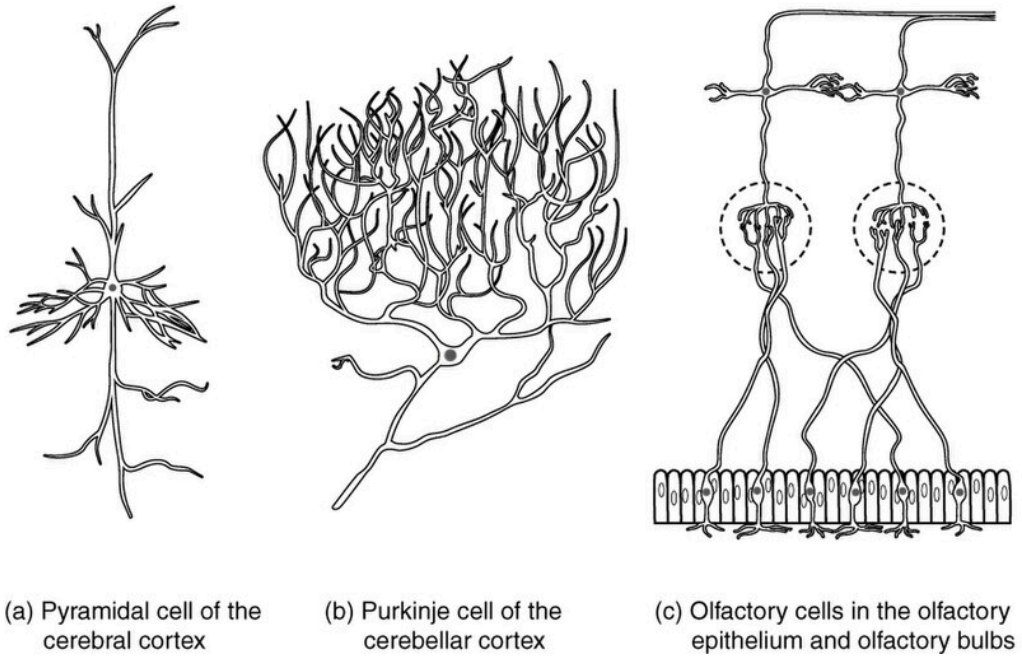


Figure 8.11 Other Neuron Classifications: (a) the Pyramidal Cell, (b) the Purkinje Cell, and (c) the Olfactory Cells

Neuroglia

In addition to neurons, neuroglia, also referred to as glial cells or simply glia, are the other type of nervous tissue. They are support cells that help neurons communicate. There are six types of neuroglial cells, each with specific jobs relative to their location. Unlike neurons, neuroglia are able to go through mitosis. Because of this, most brain tumors (uncontrolled cell growth) are glial cells, not neuronal cells.

Neuroglia of the CNS

The CNS has four different neuroglia called astrocytes, oligodendrocytes, microglia, and ependymal cells. The **astrocyte** is named because it appears to be star-shaped under the microscope (*astro-* = "star"). It provides support to neurons of the CNS. Astrocytes have many processes extending from their main cell body. These processes extend to interact with neurons, blood vessels, or the connective tissue covering the CNS, which is called the pia mater. Astrocytes support neurons in the central nervous system by maintaining the concentration of chemicals in the extracellular space, removing excess signaling molecules, reacting to tissue damage, promoting the formation of synapses, and contributing to the **blood-brain barrier (BBB)**. The blood-

brain barrier is a physical barrier that restricts what can cross from the blood into the brain. Nutrients, such as glucose or amino acids, can pass through the BBB, but other molecules cannot. While this barrier protects the CNS from exposure to toxins and pathogens, it also keeps out cells that could protect the brain and spinal cord from disease and damage. The BBB also makes it challenging for medications to be developed that can treat brain diseases.

Also found in the CNS is the **oligodendrocyte**, which is the neuroglia that insulates axons with myelin. The name means "cell of a few branches" (*oligo-* = "few"; *dendro-* = "branches"; *-cyte* = "cell"). There are only a few processes that extend from the cell body. Each one reaches out and surrounds an axon to insulate it with a myelin sheath. The function of myelin will be discussed below.

Microglia, as the name implies (*micro-* = "small"), are smaller than most of the other neuroglia. Microglia are a type of macrophage. When macrophages encounter diseased or damaged cells, they ingest and digest those cells or the pathogens that cause disease. Microglia are also referred to as CNS-resident macrophages.

The **ependymal cell** is a neuroglial cell that filters blood to make **cerebrospinal fluid (CSF)**, the fluid that circulates through and around the brain and spinal cord. Because of the blood-brain barrier (BBB), the extracellular space in nervous tissue does not easily exchange components with the blood. Ependymal cells line the four spaces in the brain called **ventricles**. The **choroid plexus** is a specialized structure in the ventricles where ependymal cells come in contact with blood vessels and filter and absorb components of the blood to produce cerebrospinal fluid. The neuroglia appears similar to epithelial cells with only a single layer. They also have cilia on their apical surface to help move the CSF through the ventricular space. See Figure 8.12[13] for an illustration of astrocyte, oligodendrocytes, microglia, and ependymal cells.

13. OpenStax College. (2013). *1209_Glial_Cells_of_the_CNS-02* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1209_Glial_Cells_of_the_CNS-02.jpg

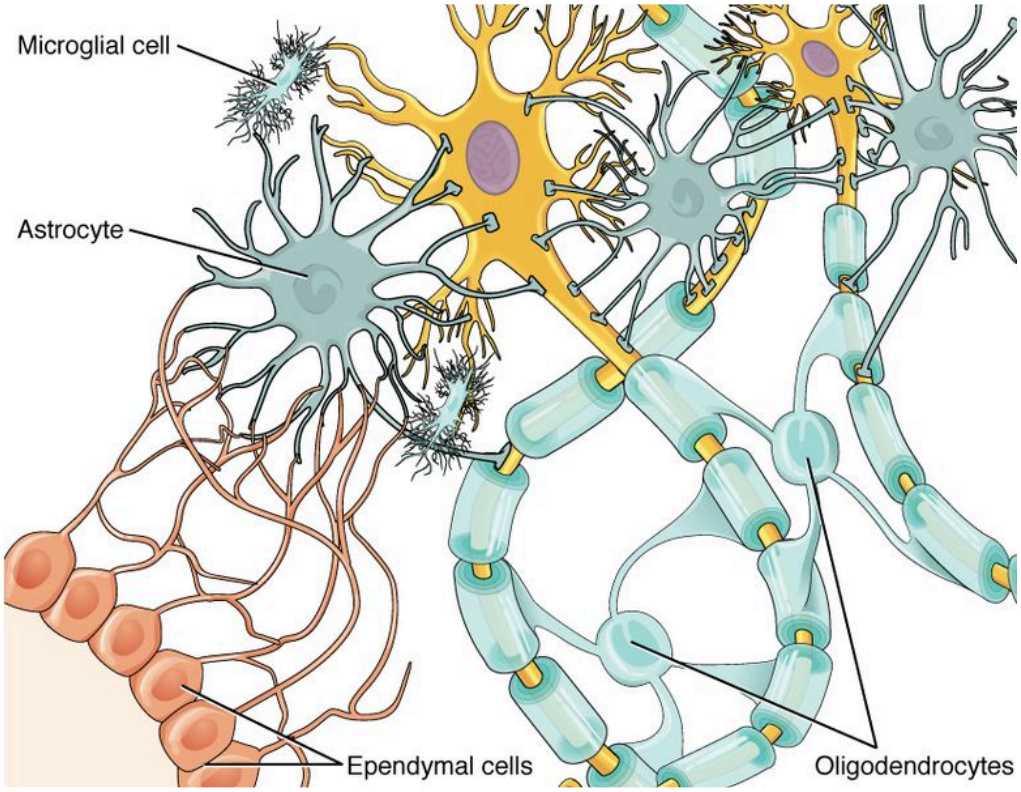


Figure 8.12 Astrocyte, Oligodendrocytes, Microglia, and Ependymal Cells

Neuroglia of the PNS

The peripheral nervous system has two types of neuroglia: satellite cells and Schwann cells. **Satellite cells** provide support to neurons, performing similar functions in the PNS as astrocytes do in the CNS—except for establishing the BBB. The second type of neuroglia in the PNS is the **Schwann cell**, which insulates axons with myelin. See Figure 8.13[14] for an illustration of satellite cells and Schwann cells.

14. OpenStax College. (2016). *1210_Glial_Cells_of_the_PNS* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1210_Glial_Cells_of_the_PNS.jpg

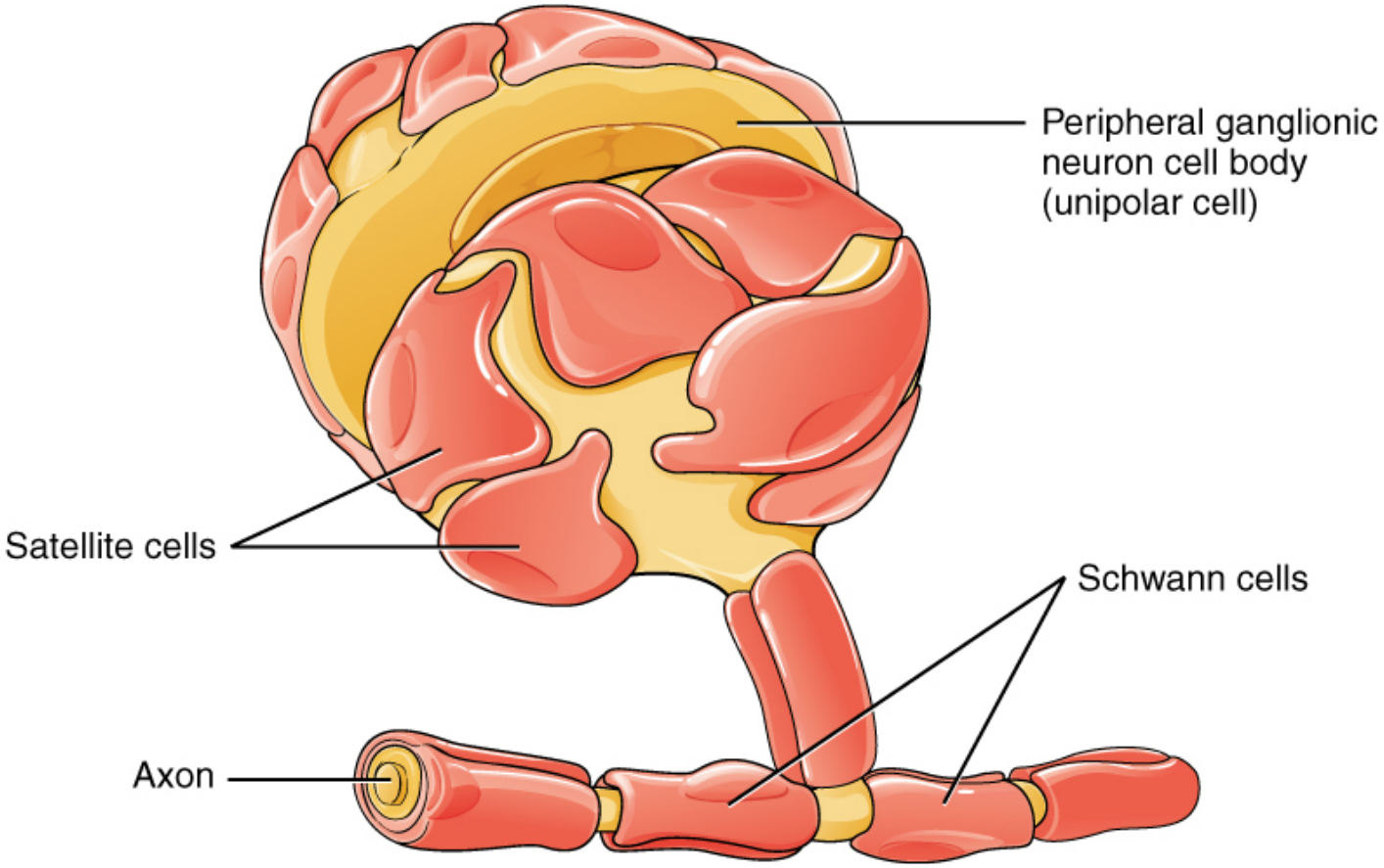


Figure 8.13 Neuroglia Cells of the PNS: Satellite Cells and Schwann Cells

Myelin Sheath

The insulation for axons in the nervous system is provided by two different neuroglia or glial cells, oligodendrocytes in the CNS and Schwann cells in the PNS. Myelin is a lipid-rich covering that surrounds the axon, creating a **myelin sheath** that helps increase the speed of electrical signals along the axon. The appearance of the myelin sheath can be thought of like pastry wrapped around a hot dog for creating "pigs in a blanket." See Figure 8.14[15] for an illustration of the myelin sheath.

15. OpenStax College. (2016). *1211_Myelinated_Neuron* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1211_Myelinated_Neuron.jpg

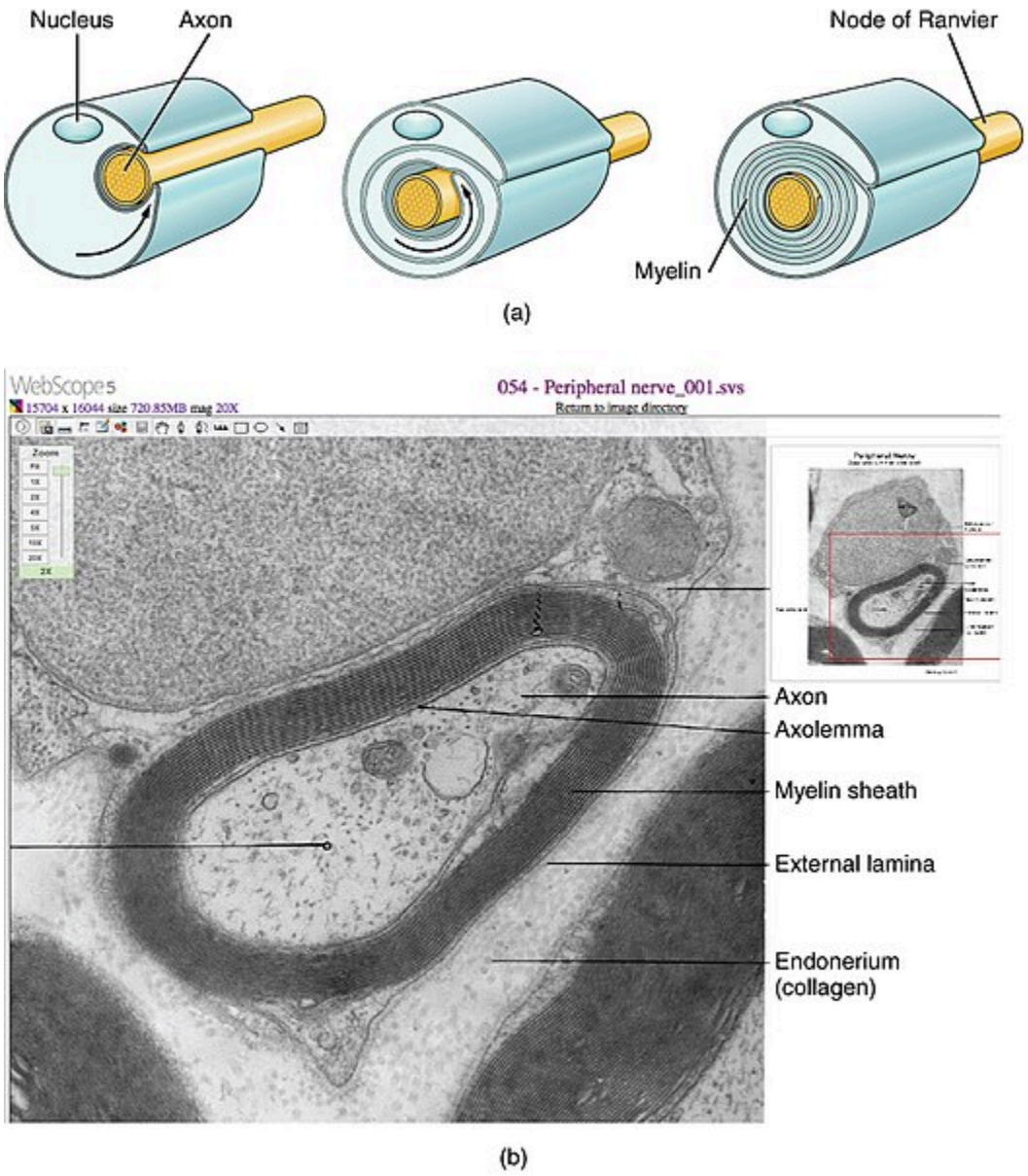


Figure 8.14 Myelin Sheath

Central Nervous System

The brain and the spinal cord are the two main components of the central nervous system. The spinal cord is a single structure, whereas the brain has four major regions: cerebrum, diencephalon, brain stem, and cerebellum.

Functions of the Central Nervous System

The central nervous system is responsible for **integration**. This integration process requires the analysis of sensory information and the development of thoughts, emotions, and conscious experiences in the brain. It is the location where memories are stored. The regulation of homeostasis throughout the body is also governed by the CNS. Decisions are made on whether and how to respond. Finally, the coordination of reflexes depends on the integration of sensory and motor pathways in the spinal cord.

Anatomy of the Central Nervous System

The adult brain is separated into four major regions: the cerebrum, the diencephalon, the brain stem, and the cerebellum.

Cerebrum

The iconic gray structure of the human brain, which appears to make up most of the mass of the brain, is the **cerebrum**. It is responsible for higher neurological functions such as memory, emotion, and consciousness. The wrinkled outer portion is the **cerebral cortex**, and the rest of the cerebrum is deep to the cortex. The large groove between the two sides of the cerebrum is called the **longitudinal fissure**. It separates the cerebrum into two distinct halves, a right and left **cerebral hemisphere**. Deep within the cerebrum, the white matter of the **corpus callosum** provides the major pathway for communication between the two hemispheres of the cerebrum. See Figure 8.15[16] for an illustration of the cerebrum and its associated structures, and Figure 8.16[17] for an image of the corpus callosum.

16. OpenStax College. (2016). *1305_CerebrumN* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1305_CerebrumN.jpg

17. Anatomist90. (2012). *Slide1oo* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Slide1oo.JPG

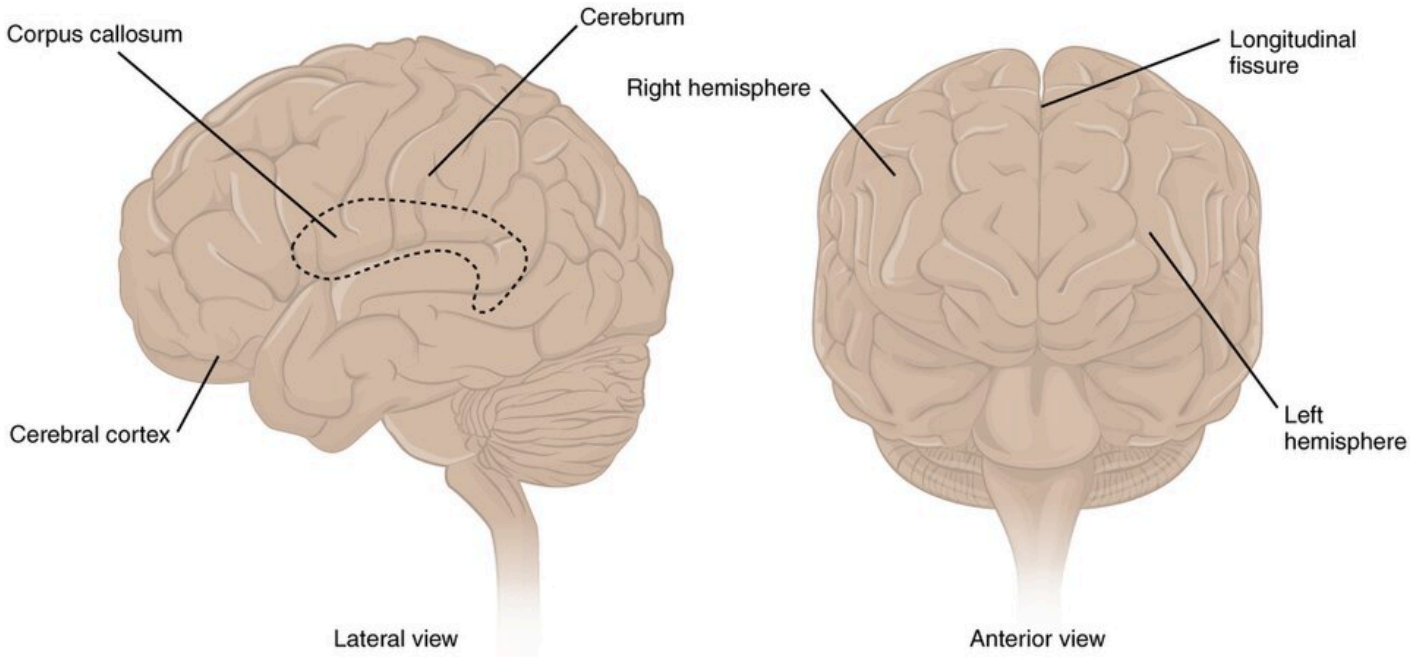


Figure 8.15 The Cerebrum

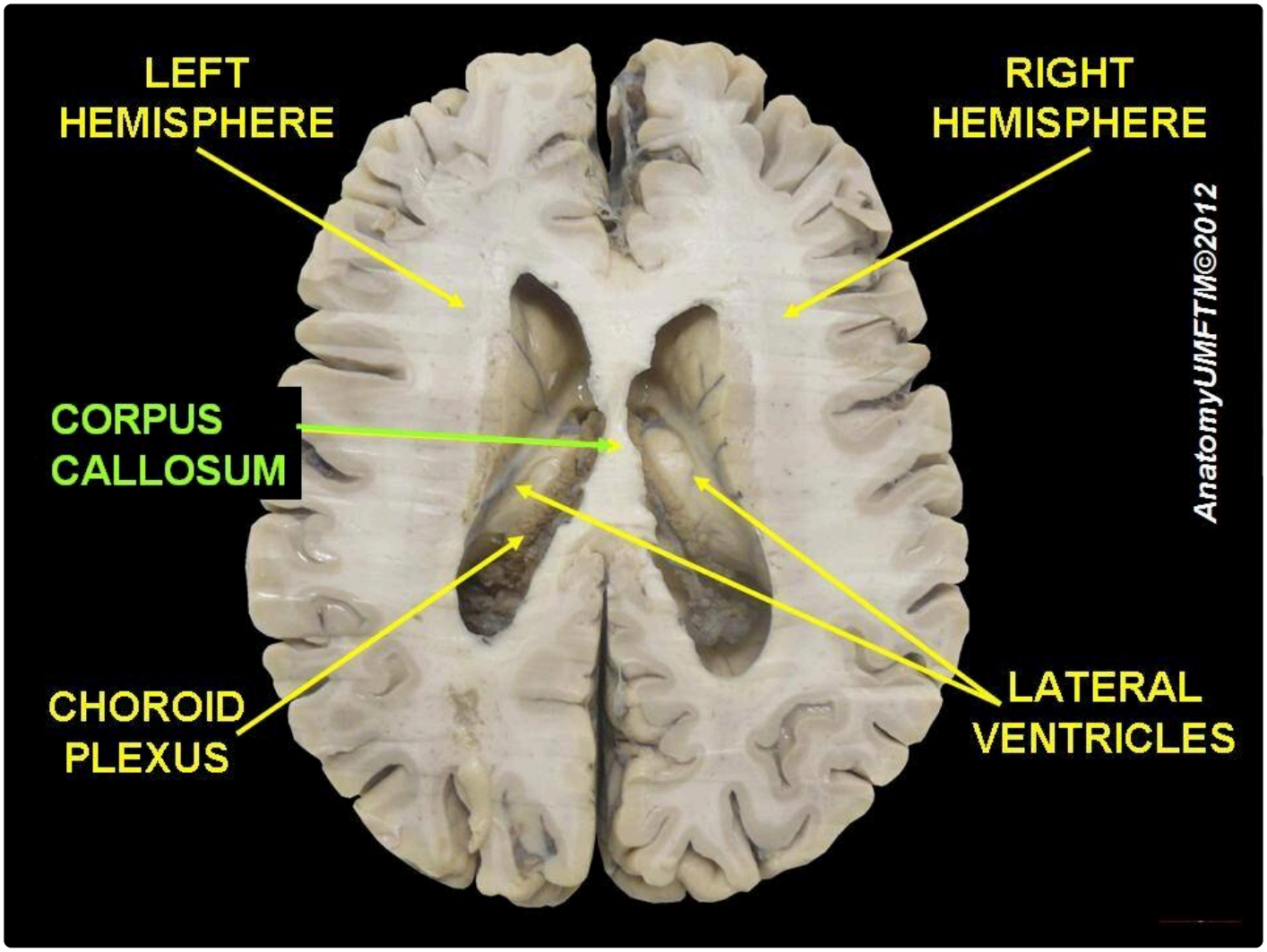


Figure 8.16 Corpus Callosum

The Myth of Left Brain/Right Brain

There is a persistent myth that people are “right-brained” or “left-brained,” which is an oversimplification of an important concept about the cerebral hemispheres. There is some lateralization of function, in which the left side of the brain is devoted to language and math function, and the right side is devoted to spatial and nonverbal reasoning. While these functions are predominantly associated with those sides of the brain, there is no monopoly by either side on these functions. For example, many functions, such as language, are distributed throughout the cerebrum. Damage to the left side of the brain may result in aphasia, a loss of speech function. However, there are also well-documented cases of language functions lost from damage to the right side of the brain. Right-side damage can result in a loss of ability to understand figurative aspects of speech, such as jokes, irony, or metaphors. Nonverbal aspects of speech can be affected

by damage to the right side, such as facial expression or body language, and right-side damage can lead to a “flat affect” in speech, or a loss of emotional expression in speech, sounding like a robot when talking.

Cerebral Cortex

As mentioned earlier, the cerebrum is covered by a continuous wrinkled layer of gray matter called the cerebral cortex. Extensive folding in the cerebral cortex enables more gray matter to fit into the limited space of the cranium. If the gray matter of the cortex were peeled off the cerebrum and laid out flat, its surface area would be roughly equal to one square meter. This thin, extensive region is responsible for the higher functions of the nervous system.

Gyri and Sulci

A **gyrus** (plural = gyri) is the ridge of one of those wrinkles, and a **sulcus** (plural = sulci) is the groove between two gyri. The pattern of these folds of tissue indicates specific regions of the cerebral cortex.

Lobes of the Cerebral Cortex

The surface of the brain can be mapped on the basis of the locations of large gyri and sulci. Using these landmarks, the cortex can be separated into four major regions or lobes. Notice that these lobes have the same names as the bones that cover them:

- **Temporal lobes**: The temporal lobes, one on each side of the brain, are the regions of the cerebral cortex deep to the temporal bones. The **lateral sulcus** is the landmark that separates the temporal lobe from the other regions.
- **Parietal lobes**: The parietal lobes are regions of the cerebral cortex deep to the parietal bones. They are superior to the lateral sulcus and are directly behind the frontal lobe.
- **Frontal lobes**: The frontal lobes are regions of the cerebral cortex deep to the frontal bone. The frontal lobe is also superior to the lateral sulcus. It is separated from the parietal lobe by the **central sulcus**.
- **Occipital lobes**: The occipital lobes are regions of the cerebral cortex deep to the occipital bone. It is in the posterior region of the cortex and has no obvious

anatomical border between it and the parietal or temporal lobes on the lateral surface of the brain. From the medial surface, an obvious landmark separating the parietal and occipital lobes is called the **parieto-occipital sulcus**. The fact that there is no obvious anatomical border between these lobes is consistent with the functions of these regions being interrelated.

See Figure 8.17[18] for an illustration of the lobes of the cerebral cortex.

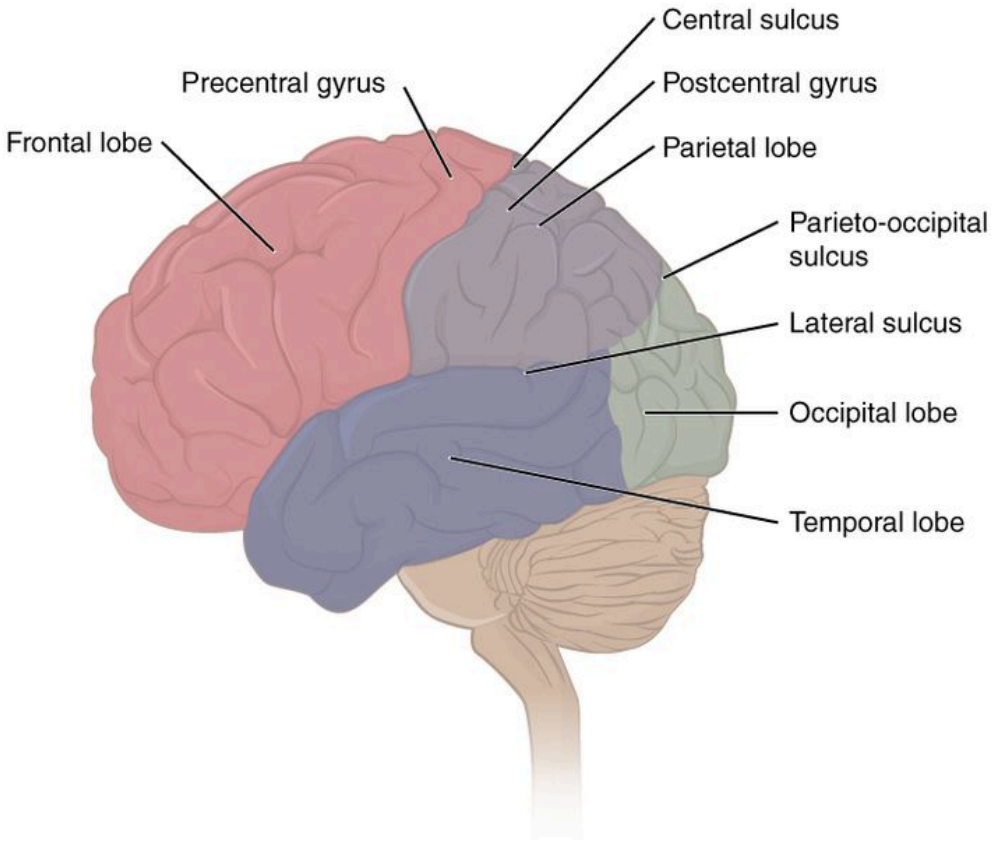


Figure 8.17 Lobes of the Cerebral Cortex

Higher Mental Functions of the Cerebral Cortex

The cerebral cortex performs higher mental functions referred to as **cognitive abilities**. The responsibilities for these cognitive abilities are distributed across the regions of the cortex, and specific locations are responsible for particular functions. For this reason, if a particular area of the brain becomes injured or diseased, specific cognitive abilities are affected. Cognitive abilities can be classified by four areas:

18. OpenStax College. (2016). *1306_Lobes_of_Cerebral_CortexN* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1306_Lobes_of_Cerebral_CortexN.jpg

orientation and memory, language and speech, sensorium, and judgment and abstract reasoning.

- Orientation and Memory: **Orientation** is the patient's awareness of their immediate circumstances. An adult with normal cognitive functioning is aware of their name, where they are and why, and the date. This function occurs in the prefrontal cortex (the anterior portion of the frontal lobe), and it can be temporarily or permanently affected by many medical conditions. **Memory** refers to how the brain stores and remembers information. It is a function of the temporal lobe.
- Language and Speech: Wernicke's area and Broca's area are two separate areas involved in speech and language. Both areas are found in a person's dominant hemisphere, which for most people is the left side of the brain. See Figure 8.18[19] for an illustration of the location of Wernicke's area and Broca's area in the brain. **Broca's area** is responsible for controlling movements of the structures of speech production. It is named after a French surgeon and anatomist who studied patients who could not produce speech. Patients could understand speech, but had difficulty producing speech sounds, suggesting a damaged or underdeveloped Broca's area. This is known as an **expressive aphasia**, which means that speech production is compromised. This type of aphasia is often described as nonfluency because the ability to say some words leads to broken or halting speech. Grammar can also appear to be lost. **Wernicke's area** is responsible for speech comprehension. The aphasia associated with Wernicke's area is known as **receptive aphasia**, which is not a loss of speech production, but a loss of understanding. Patients, after recovering from acute forms of this aphasia, report not being able to understand what is said to them or what they are saying themselves, but they often cannot keep from talking.
- **Sensorium**: Sensorium refers to interpretation of sensory stimuli. The cerebral cortex has several regions responsible for sensory perception. From the primary cortical areas of the somatosensory (touch), visual, auditory, and gustatory senses to the association areas that process information, the cerebral cortex is the source of conscious sensory perception. In contrast, sensory information can also be processed by deeper brain regions, which we may vaguely describe as subconscious. For instance, we are not constantly aware of the proprioceptive stimuli (information concerning the position and movement of the body) that the cerebellum uses to maintain balance.
- **Judgment and abstract reasoning**: Judgment and abstract reasoning refer to making sense of concepts and making appropriate decisions. For example, when

19. OpenStax College. (2013). *1605_Brocas_and_Wernickes_Areas-02* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1605_Brocas_and_Wernickes_Areas-02.jpg

your alarm goes off in the morning, you must decide whether to hit the snooze button or jump out of bed. You use judgment and abstract reasoning to decide if the ten extra minutes of sleep are worth rushing through your morning routine or risk being late. The prefrontal cortex is responsible for these functions of planning and making decisions.

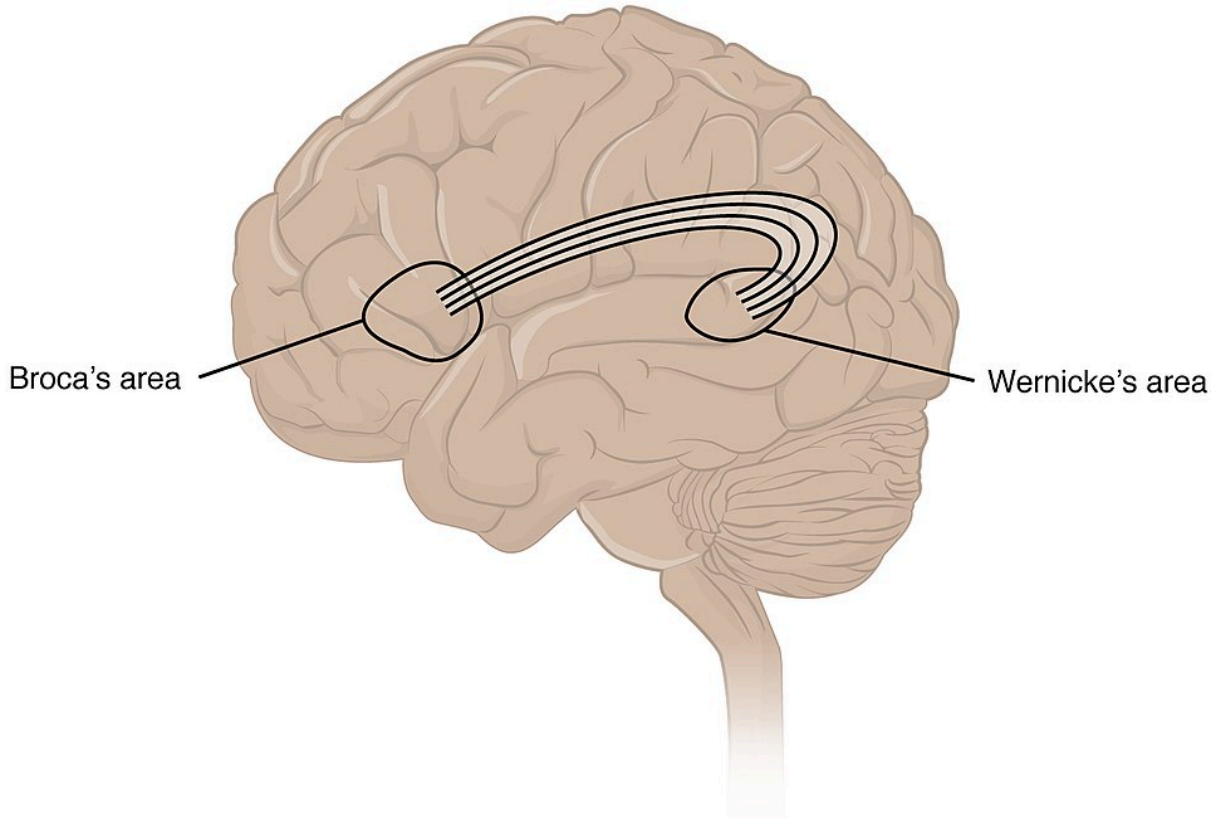


Figure 8.18 Broca's Area and Wernicke's Area

Brodmann's Areas

Different regions of the cerebral cortex can be associated with particular functions, a concept known as localization of function. In the early 1900s, a German neuroscientist named Korbinian Brodmann performed an extensive study of the cerebral cortex. His work resulted in a system of classification known as **Brodmann's areas**, which is still used today to describe the anatomical distinctions within the cortex. See Figure 8.19[20] for an illustration of Brodmann's areas of the cerebral cortex.

20. OpenStax College. (2016). *1307_Brodmann_Areas* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1307_Brodmann_Areas.jpg

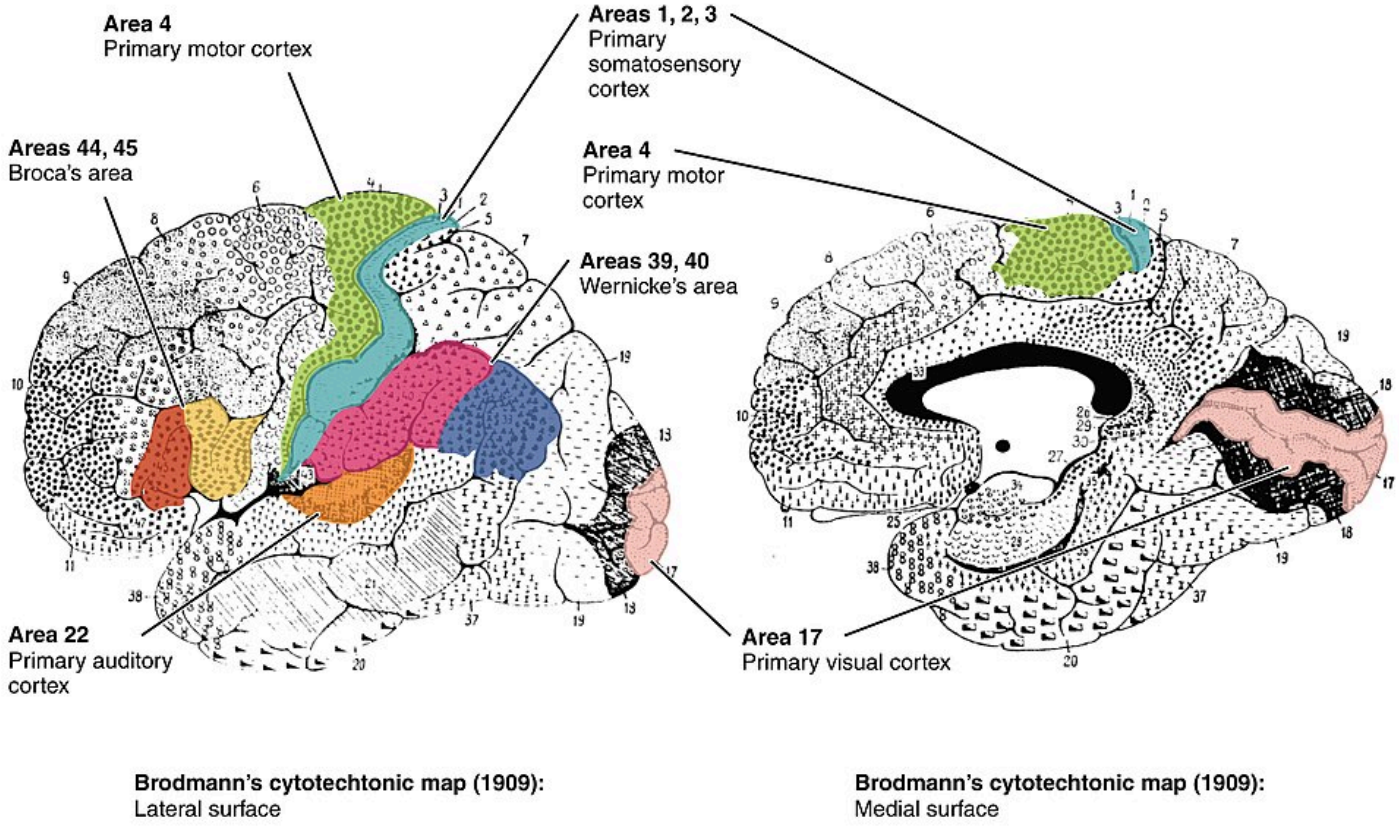


Figure 8.19 Brodmann's Areas of the Cerebral Cortex

Sensory Areas in the Cortex

The main sensation associated with the parietal lobe is somatosensation or touch, meaning the general sensations associated with the body. Posterior to the central sulcus is the **postcentral gyrus**, the primary somatosensory area, which is identified as Brodmann's areas 1, 2, and 3. All the tactile senses are processed in this area, including touch, pressure, tickle, pain, itch, and vibration, as well as more general senses of the body such as proprioception (body position) and kinesthesia (movement).

The primary visual area is found in the occipital lobe, specifically areas 17 and 18. Because visual information is complex, it is processed in the temporal and parietal lobes as well.

The temporal lobe contains the primary auditory (hearing) area and the primary olfactory (smell) area. Because regions of the temporal lobe are also part of the limbic system (the system related to emotional processing), memory is another important function associated with that lobe. Memory is essentially a sensory function; memories are recalled sensations, such as the smell of Grandma's apple pie or the sound of a

barking dog. Even memories of movement are really the memory of sensory feedback from those movements, such as stretching muscles or the movement of the skin around a joint. Structures in the temporal lobe are responsible for establishing long-term memory, but the ultimate location of those memories is usually in the region in which the sensory perception was processed.

The primary gustatory area (sense of taste) is located in the insula. The insula is a fifth lobe of the cerebrum that is located deep to the temporal lobes.

Motor Areas of the Cerebral Cortex

Anterior to the central sulcus is the **precentral gyrus** of the frontal lobe, which contains the primary motor cortex. The primary motor cortex has voluntary control over skeletal muscles. Cells from this region of the cerebral cortex are the upper motor neurons that tell cells in the spinal cord to move skeletal muscles.

Broca's area is responsible for the production of language or controlling movements of muscles responsible for speech. In most people, it is located in the left frontal lobe.

Association Areas of the Cerebral Cortex

A number of other regions that extend beyond the primary sensory and motor areas are **association areas** of the cortex that are also referred to as integrative areas. These areas are found in the spaces between the primary areas for sensory and motor functions, and they integrate multisensory information or process sensory or motor information in more complex ways. For example, these association areas can integrate visual and motor functions to be able to reach and pick up a glass. The somatosensory function is the proprioceptive feedback from moving the arm and hand. The weight of the glass, based on what it contains, will influence how those movements are made.

Subcortical Structures

The **basal nuclei** (also called the basal ganglia) are responsible for planning and coordinating movements. They also can prevent or suppress unwanted movements and regulate muscle tone. For example, while a student is sitting in a classroom listening to a lecture, the basal nuclei will keep the urge to jump up and scream from actually happening. Damage to the basal nuclei is seen in the movement disorder called

Parkinson's disease. The **basal forebrain** contains nuclei that are important in learning and memory. Alzheimer's disease is associated with a loss of neurons in the basal forebrain. The **limbic cortex** is the region of the cerebral cortex that is part of the **limbic system**, a collection of structures involved in emotion, memory, and behavior. Read more about Parkinson's disease and Alzheimer's disease in the "Disorders of the Nervous System and Sense Organs" section.

The **hippocampus** and **amygdala** are involved in long-term memory formation and emotional responses.

The amygdala is located in the temporal lobe, which is part of the **limbic lobe**. See Figure 8.20[21] for an illustration of the limbic lobe. The limbic lobe includes structures that are involved in emotional responses, as well as structures that contribute to memory. The limbic lobe has strong connections with the hypothalamus and influences the state of its activity on the basis of the emotional state. For example, when you are anxious or scared, the amygdala will send signals to the hypothalamus to stimulate the sympathetic **fight-or-flight response**. The hypothalamus will also stimulate the release of stress hormones through its control of the endocrine system in response to amygdala input.

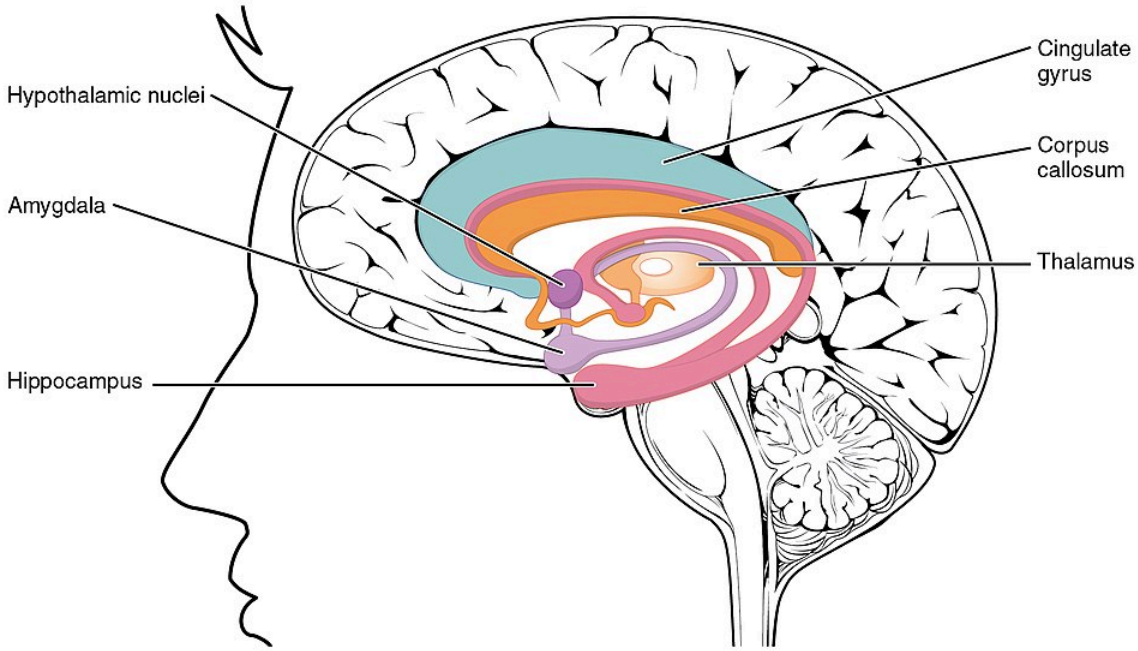


Figure 8.20 Limbic Lobe

21. OpenStax College. (2013). *1511_The_Limbic_Lobe* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1511_The_Limbic_Lobe.jpg

The Diencephalon

The diencephalon is located inferior to the cerebrum. The diencephalon can be described as any region of the brain with "thalamus" in its name. The two major regions of the diencephalon are the thalamus and the hypothalamus.

Thalamus

The **thalamus** relays information between the cerebral cortex and the brain stem, spinal cord, and nerves. All sensory information, except for the sense of smell, passes through the thalamus to the cortex. However, the thalamus does not just pass the information on; it also processes that information. For example, the portion of the thalamus that receives visual information will influence what visual stimuli are important or what receives attention. The cerebrum also sends information down to the thalamus, which usually communicates motor commands.

Hypothalamus

Inferior and slightly anterior to the thalamus is the **hypothalamus**, the other major region of the diencephalon. The hypothalamus is the major regulator of homeostasis with its control of the autonomic nervous system and the endocrine system. The hypothalamus also controls body temperature, appetite, thirst, and sleep. Other parts of the hypothalamus are involved in memory and emotion as part of the limbic system. See Figure 8.21[22] for an illustration of the diencephalon, thalamus, and hypothalamus.

22. OpenStax College. (2016). *1310_Diencephalon* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1310_Diencephalon.jpg

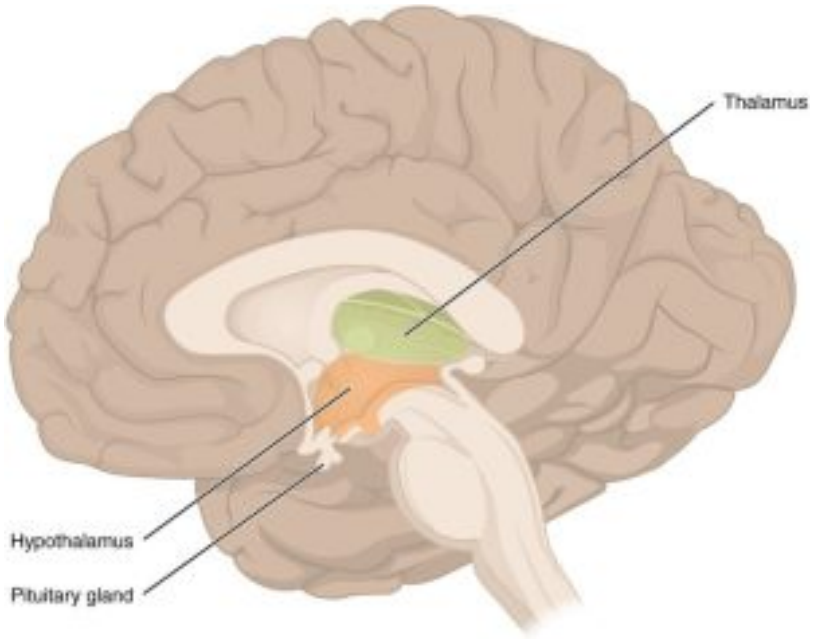


Figure 8.21 Diencephalon, Thalamus, and Hypothalamus

Brain Stem

The midbrain and hindbrain (composed of the pons and the medulla oblongata) are collectively referred to as the brain stem. The brain stem connects the brain to the spinal cord.

The cranial nerves connect through the brain stem and provide the brain with the sensory input and motor output associated with the head and neck, including most of the special senses. The major ascending and descending tracts between the spinal cord and brain, specifically the cerebrum, pass through the brain stem.

An area of gray matter spread throughout the brain stem, known as the **reticular formation** (also called the reticular activating system), is related to sleep and wakefulness, general brain activity, and attention. It also has a role in maintaining muscle tone. Damage to this structure in a person may result in a coma.

Midbrain

The midbrain is a small region between the thalamus and pons. The midbrain coordinates sensory representations of the visual, auditory, and somatosensory perceptual spaces.

The **tectum** is a region of the midbrain composed of four nuclei or "bumps" known as the colliculi (singular = colliculus), which means "little hill" in Latin. These colliculi are subdivided into inferior and superior colliculi.

The **inferior colliculus** is the inferior pair of these enlargements and is part of the auditory brain stem pathway. Neurons of the inferior colliculus project to the thalamus, which then sends auditory information to the cerebrum for the conscious perception of sound.

The **superior colliculus** is the superior pair and combines sensory information about visual space, auditory space, and somatosensory space. Activity in the superior colliculus is related to orienting the eyes to a sound or touch stimulus. For example, if you are walking along the sidewalk on campus and you hear chirping, the superior colliculus coordinates that information with your awareness of the visual location of the tree right above you.

Another structure found in the midbrain is the **substantia nigra**. This structure is responsible for regulating automatic skeletal muscle movements, such as swinging your arms when you walk. Cells in the substantia nigra degenerate in Parkinson's disease.

Pons

The **pons** is the main connection between the cerebellum and the brain stem. The word *pons* comes from the Latin word for "bridge." It is visible on the anterior surface of the brain stem as a thick bundle of white matter attached to the cerebellum. The pons, along with the medulla oblongata, regulate respiration.

Medulla Oblongata

The **medulla oblongata**, sometimes just referred to as medulla, is the most inferior of the brain stem before it transitions into the spinal cord. It contains both the ascending sensory tracts and descending motor tracts. Upon entering the medulla, the descending motor tracts make up the two large white matter lateral bulges referred to as the **pyramids**. See Figure 8.22[23] for an illustration of the midbrain, pons, and medulla.

23. OpenStax College. (2016). *1311_Brain_Stem* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1311_Brain_Stem.jpg

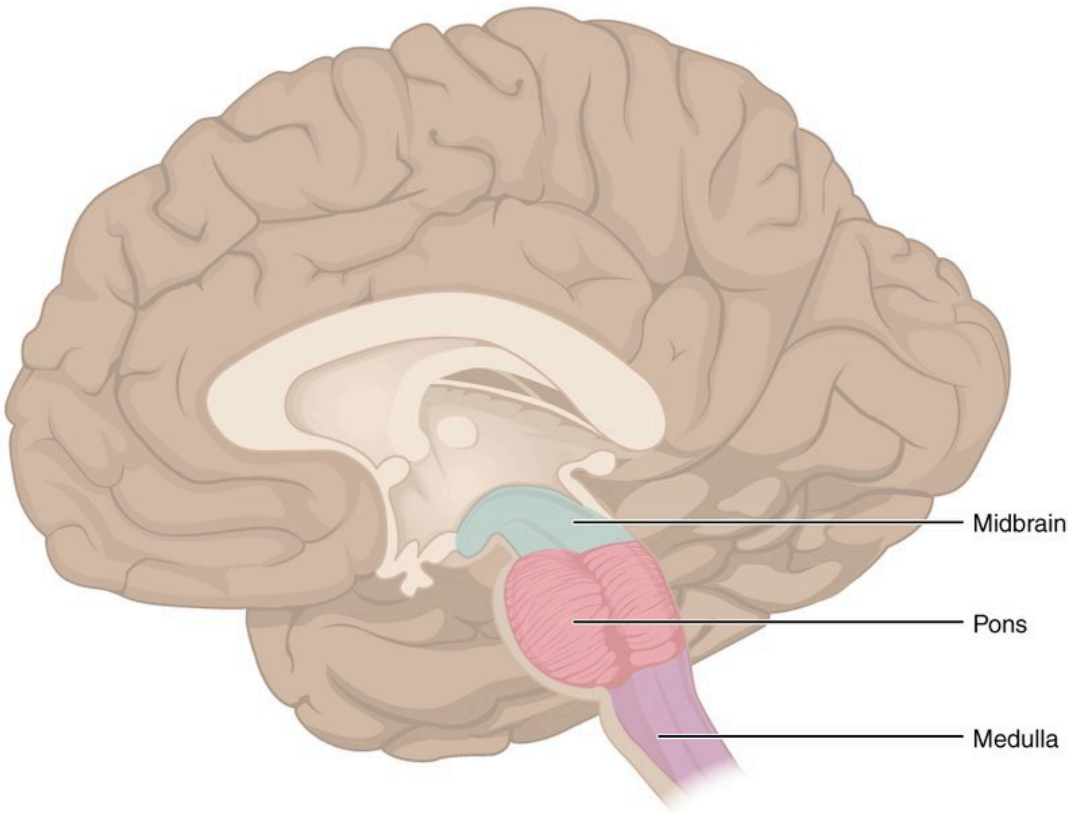


Figure 8.22 Midbrain, Pons, and Medulla

The defining landmark of the medullary-spinal border is the **pyramidal decussation**, which is where the motor tracts cross over to the opposite side of the brain. This is why the right side of the brain controls the left side of the body, and the left side of the brain controls the right side of the body. See Figure 8.23[24] for an illustration of the pyramids in the medulla oblongata.

24. OpenStax College. (2013). *1426_Corticospinal_Pathway* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1426_Corticospinal_Pathway.jpg

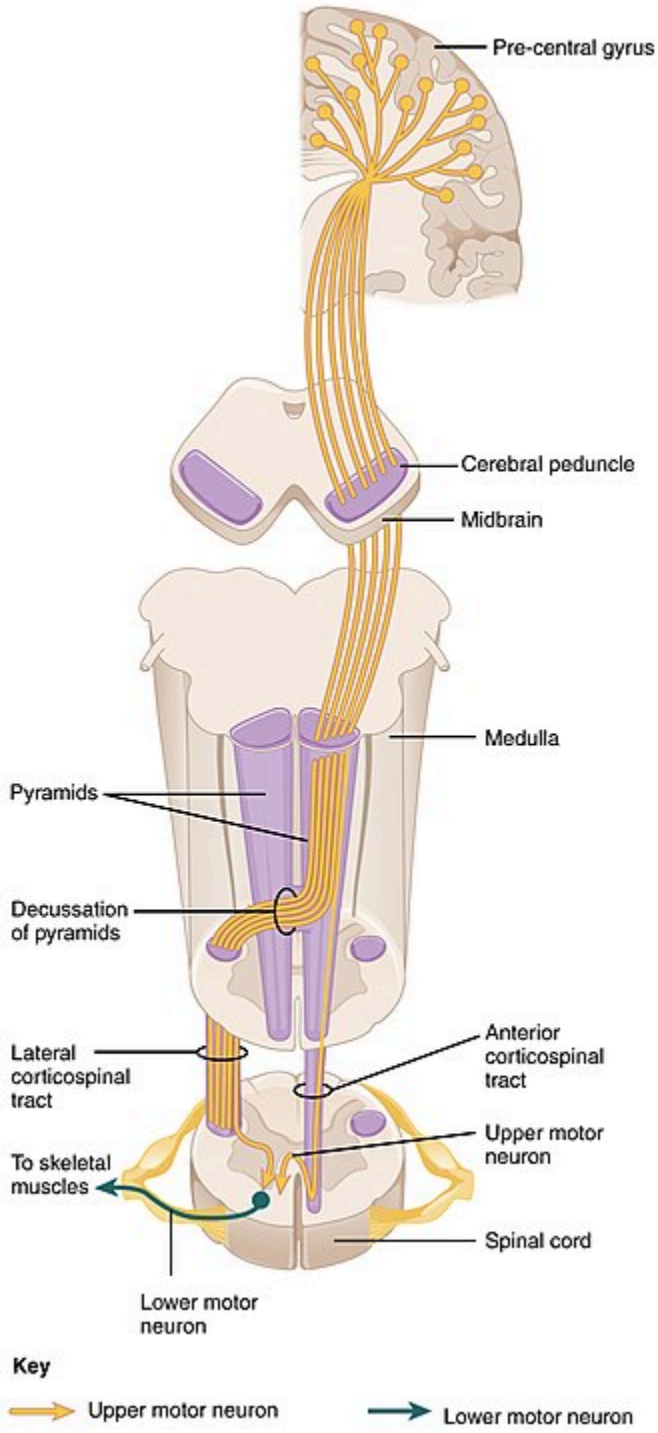


Figure 8.23 Pyramids in the Medulla Oblongata

The medulla oblongata is the **cardiovascular control center**, controlling heart rate, force of the heart's contraction, and blood pressure.

Respiration rate is also controlled by the respiratory center in the medulla oblongata,

which responds primarily to changes in hydrogen, carbon dioxide, and pH levels in the body.

Cerebellum

Attached to the brain stem, but considered a separate region of the brain, is the cerebellum. The **cerebellum**, as the name suggests, is the "little brain" as it accounts for approximately 10 percent of the brain's mass. It is covered in folds and grooves like the cerebrum and looks like a miniature version of that part of the brain. See Figure 8.24[25] for an illustration of the cerebellum.

25. OpenStax College. (2016). *1312_CerebellumN* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1312_CerebellumN.jpg

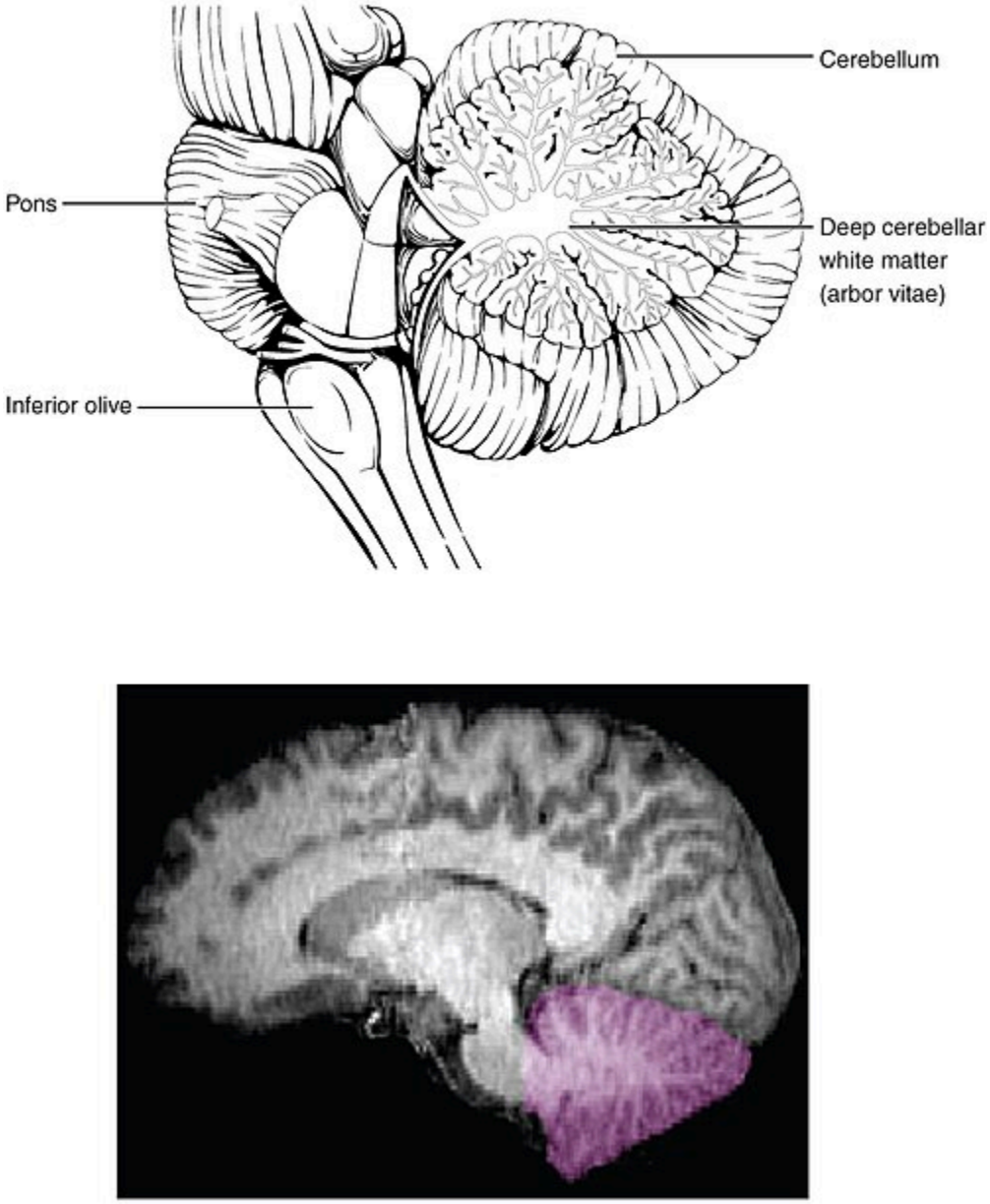


Figure 8.24 Cerebellum

The cerebellum is largely responsible for balance, coordination, and complex movements. When the cerebellum does not work properly, coordination and balance are severely affected. The most dramatic example of this is during the overconsumption of alcohol. Alcohol inhibits the ability of the cerebellum to interpret proprioceptive feedback, making it more difficult to coordinate body movements, such as walking a straight line or guiding the movement of the hand to touch the tip of the nose.

The Spinal Cord

The spinal cord is another major organ of the central nervous system. The anterior midline of the spinal cord is marked by the **anterior median fissure**, and the posterior midline is marked by the **posterior median sulcus**.

The posterior or dorsal regions of the spinal cord are responsible for sensory functions, and the anterior or ventral regions are associated with motor functions. Axons enter the posterior side through the **dorsal (posterior) nerve root**, and the axons emerging from the anterior side do so through the **ventral (anterior) nerve root**. Note that it is common to see the terms dorsal (*dorsal* = "back") and ventral (*ventral* = "belly") used interchangeably with posterior and anterior in humans, particularly in reference to nerves and the structures of the spinal cord.

The length of the spinal cord is divided into regions that correspond to the regions of the vertebral column. Immediately below the brain stem is the cervical region, followed by the thoracic, then the lumbar, and finally the sacral region and coccyx. The spinal cord is not the full length of the vertebral column, ending around L1, because the spinal cord stops growing after the first or second year, but the skeleton continues to grow.

The long bundle of nerves that emerges from the end of the spinal cord resembles a horse's tail and is named the **cauda equina**.

In a cross-section, the gray matter of the spinal cord has the appearance of a butterfly and is divided into regions referred to as horns. The **posterior horn** is responsible for sensory processing, while the **anterior horn** sends out motor signals to the skeletal muscles. The **lateral horn**, which is only found in the thoracic, upper lumbar, and sacral regions, contains cell bodies of motor neurons of the autonomic nervous system.

See Figure 8.25[26] for an illustration of the cross-section of a spinal cord.

26. OpenStax College. (2016). *1313_Spinal_Cord_Cross_Section* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1313_Spinal_Cord_Cross_Section.jpg

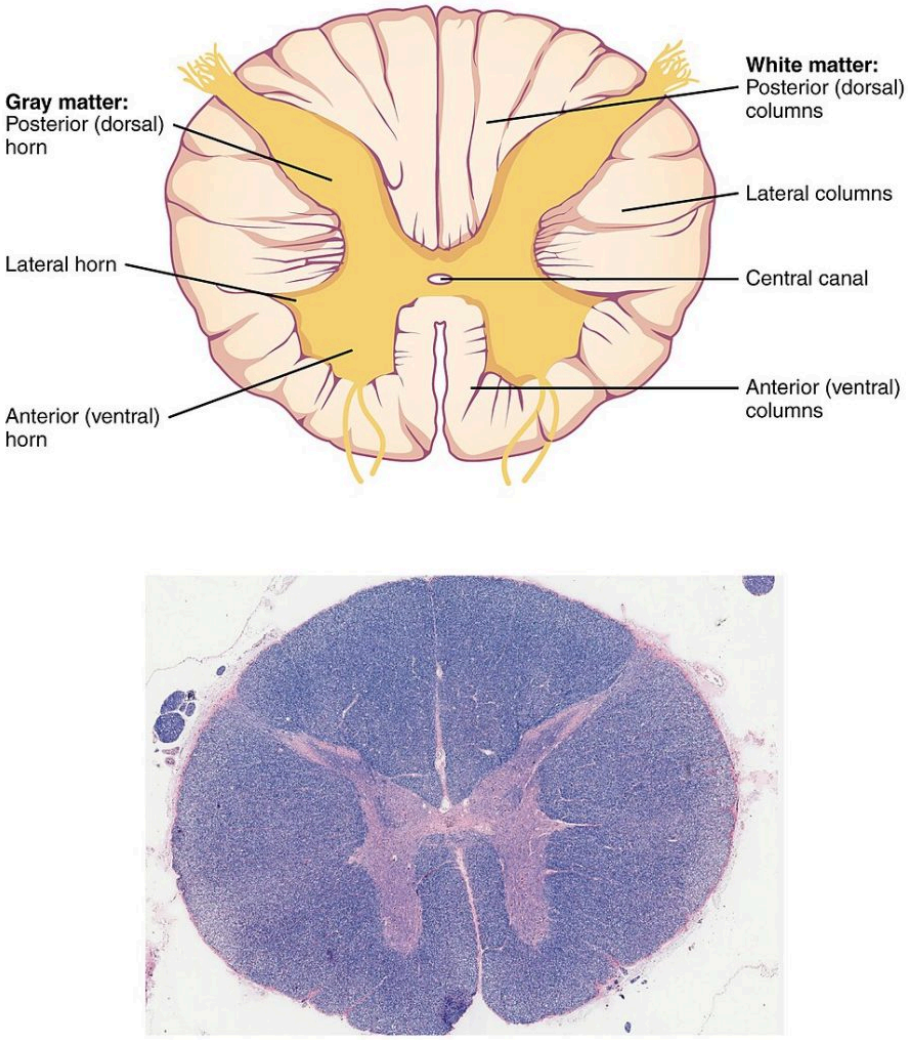


Figure 8.25 Cross-Section of a Spinal Cord

Gray Horns

White Columns (Tracts)

Just as the gray matter is separated into horns, the white matter of the spinal cord is separated into columns or tracts. Looking at the spinal cord longitudinally, the columns extend along its length as continuous bands of white matter. Between the two posterior horns of gray matter are the **posterior columns**. Between the two anterior horns are the **anterior columns**. The white matter on either side of the spinal cord, between the posterior horn and the anterior horn, is the **lateral columns**. **Ascending tracts** of nervous system fibers in these columns carry sensory information up to the brain, and **descending tracts** carry motor commands down from the brain.

CNS Blood Supply

The central nervous system is crucial to survival, and any compromise in the brain and/or spinal cord can lead to severe difficulties. To protect this region from the toxins and pathogens that may be traveling through the bloodstream, there is strict control over what can pass into the brain and spinal cord. This begins with a unique arrangement of blood vessels carrying fresh blood into the CNS. The CNS filters that blood into cerebrospinal fluid (CSF), which then circulates both through and around the brain and spinal cord.

A lack of oxygen to the CNS can be devastating, and the cardiovascular system has specific regulatory mechanisms to ensure that the blood supply is not interrupted. There are multiple routes for blood to get into the CNS, with specializations to protect that blood supply and to maximize the ability of the brain to get an uninterrupted blood supply.

Neurons are very sensitive to oxygen deprivation and will start to deteriorate within one or two minutes, and permanent damage (cell death) could result within a few hours. The loss of blood flow to part of the brain is known as a stroke, or a **cerebrovascular accident (CVA)**. Read more about CVAs in the "Disorders of the Nervous System and Sense Organs" section.

Meninges

The outer surface of the CNS is covered and protected by three membranes composed of connective tissue called the **meninges**. The layers of the meninges are the dura mater, arachnoid mater, and pia mater.

The outermost layer, the **dura mater**, is a thick fibrous layer creating a strong protective sheath over the entire brain and spinal cord. The name comes from Latin for "tough mother" to represent its physically protective role. It encloses the entire CNS and the major blood vessels that enter the cranium and vertebral cavity. It is directly attached to the inner surface of the bones of the cranium and to the very end of the vertebral cavity. The **epidural space** (*epi-* = "on or upon" the dura) is the space between the dura and the vertebrae. The **subdural space** (*sub-* = "below" the dura) is the space between the dura and the middle layer or arachnoid mater.

The middle layer of the meninges is the **arachnoid mater**, a membrane of thin fibrous tissue that forms a loose sac around the CNS. Deep to the arachnoid is a thin, filamentous mesh called the **arachnoid trabeculae**, which looks like a spider web, giving

this layer its name. The trabeculae are found in the **subarachnoid space**, which is filled with circulating CSF. CSF provides a liquid cushion for the brain and spinal cord.

Directly on the surface of the CNS is the **pia mater**, a thin fibrous membrane that follows the bumps and grooves of the gyri and sulci. The name *pia mater* comes from the Latin for "tender mother," suggesting the thin membrane is a gentle covering for the brain. See Figure 8.26[27] for an illustration of the meningeal layers.

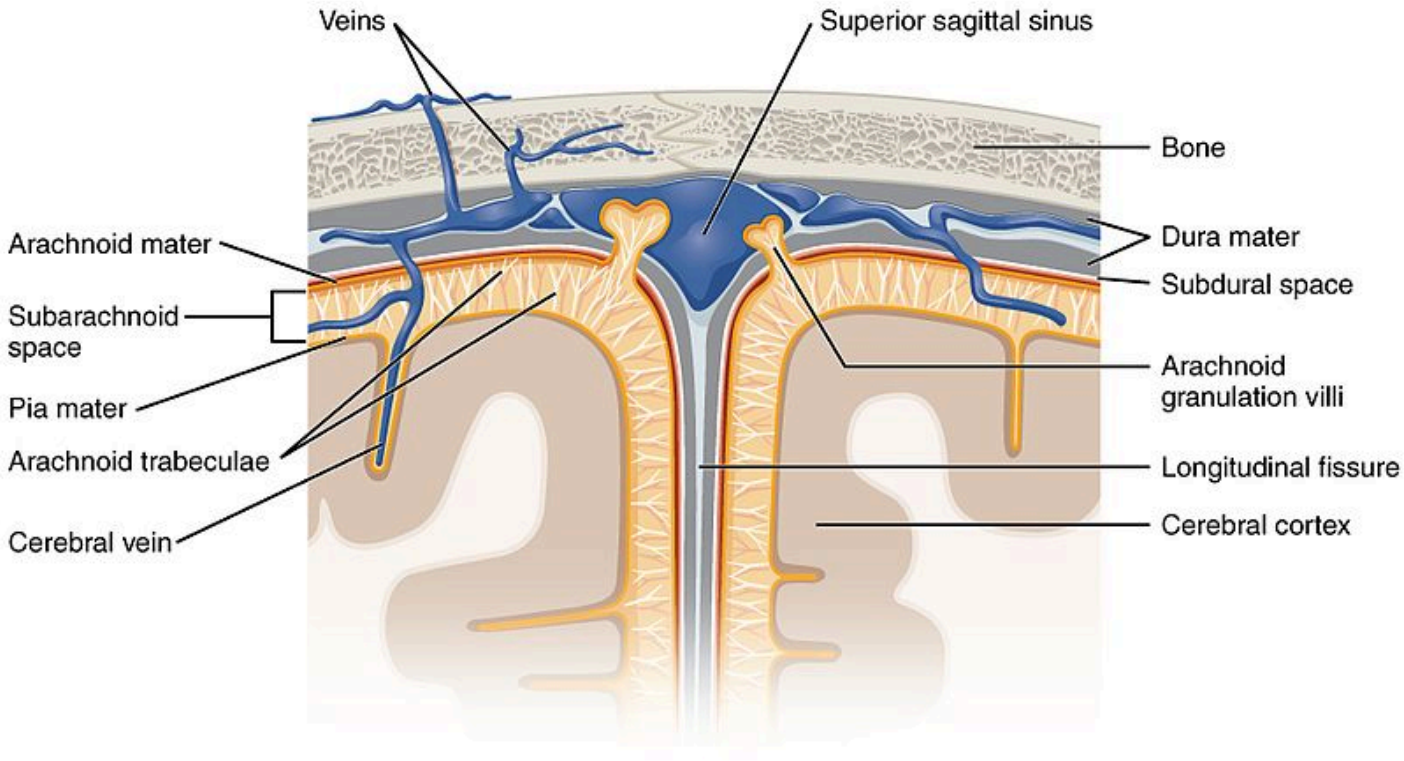


Figure 8.26 Meningeal Layers

Lumbar Puncture

Because the spinal cord does not extend through the lower lumbar region of the vertebral column, a needle can be inserted through the dura and arachnoid layers to withdraw cerebrospinal fluid (CSF). This procedure is called a **lumbar puncture** and avoids the risk of damaging the spinal cord.

27. OpenStax College. (2016). *1316_Meningeal_LayersN* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1316_Meningeal_LayersN.jpg

Ventricles and Cerebrospinal Fluid (CSF)

Cerebrospinal fluid (CSF) is a colorless fluid that circulates throughout the brain and spinal cord. It is constantly being produced and reabsorbed into the blood. The fluid is essentially water, small molecules, and electrolytes. Oxygen and carbon dioxide are dissolved into the CSF, as they are in blood, and can diffuse between the fluid and the nervous tissue. In addition to supplying essential nutrients, CSF is also a cushion for the brain, protecting it from injury.

The **ventricles** are the open spaces within the brain where CSF circulates. In the ventricles, CSF is produced by filtering the blood with a **choroid plexus**, a specialized structure in the ventricles where ependymal cells come in contact with blood vessels and filter and absorb components of the blood to produce cerebrospinal fluid. The CSF circulates through all the ventricles and into the subarachnoid space, where excess CSF is reabsorbed into the blood.

There are four ventricles within the brain. The first two are named the **lateral ventricles** and are located within each cerebral hemisphere. These ventricles are connected to the **third ventricle**, which is the space between the left and right sides of the diencephalon. The third ventricle opens into the **cerebral aqueduct** that passes through the midbrain and opens into the **fourth ventricle**, which is the space between the cerebellum and the pons and upper medulla oblongata. This fourth ventricle narrows into the central canal of the spinal cord. See 8.27[28] for an illustration of the ventricles.

28. OpenStax College. (2016). *1317_CFS_Circulation* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1317_CFS_Circulation.jpg

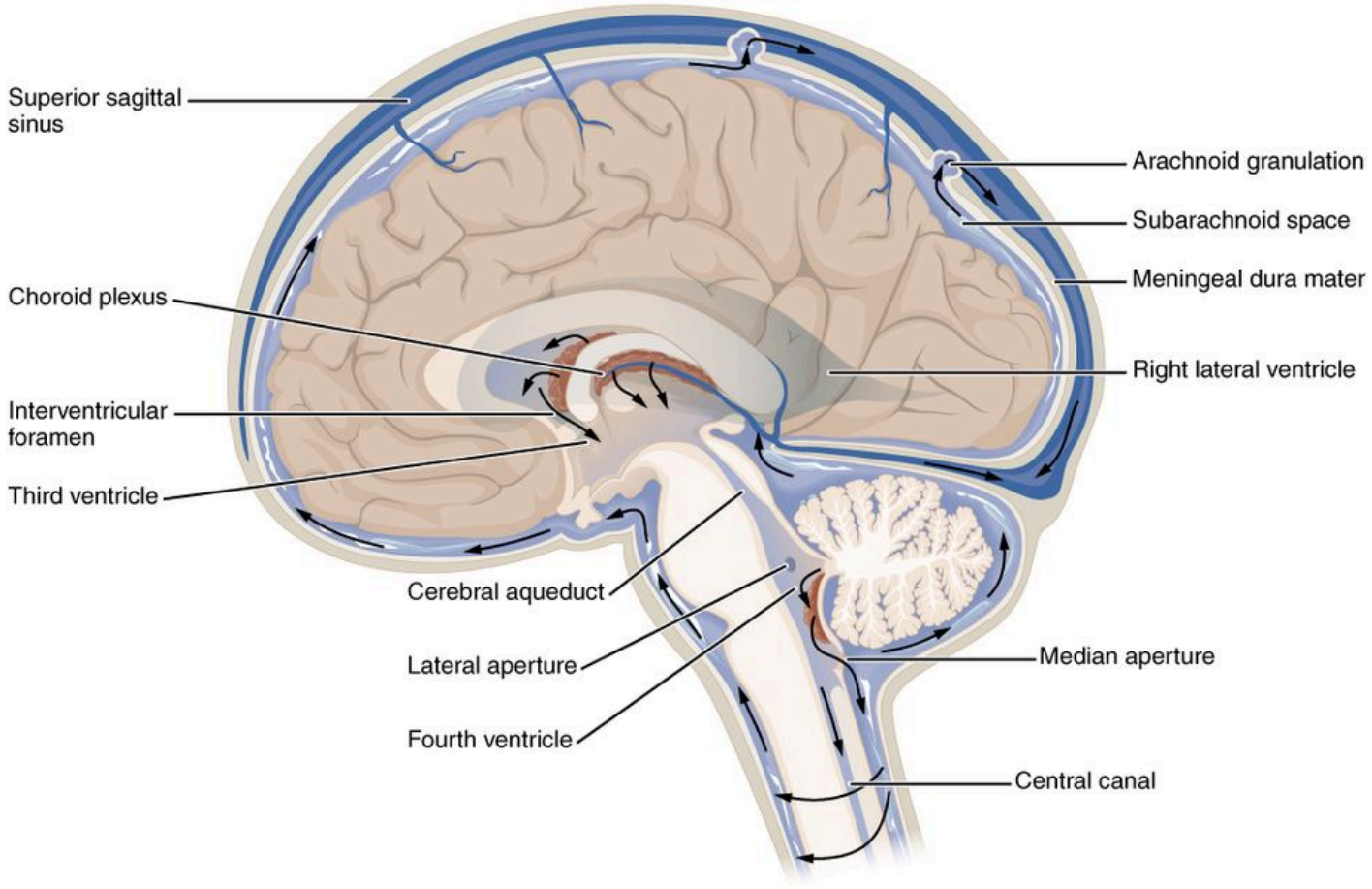


Figure 8.27 Cerebrospinal Fluid Circulation

Peripheral Nervous System

The peripheral nervous system is the division of the nervous system containing everything outside of the brain and spinal cord. The PNS is composed of groups of neuron cell bodies (ganglia) and bundles of axons (nerves), each discussed below.

Ganglia

A ganglion (pleural = ganglia) is a group of neuron cell bodies located outside of the CNS or in the periphery. Ganglia can be categorized as either sensory ganglia or autonomic ganglia, referring to their primary functions. The most common type of sensory ganglion is a **dorsal (posterior) root ganglion**. These ganglia contain the cell bodies of neurons with axons that have sensory endings in the periphery, such as in

the skin, and extend into the CNS through the dorsal nerve root. The ganglion is an enlargement of the nerve root. See Figure 8.28[29] for an image of a dorsal root ganglion.

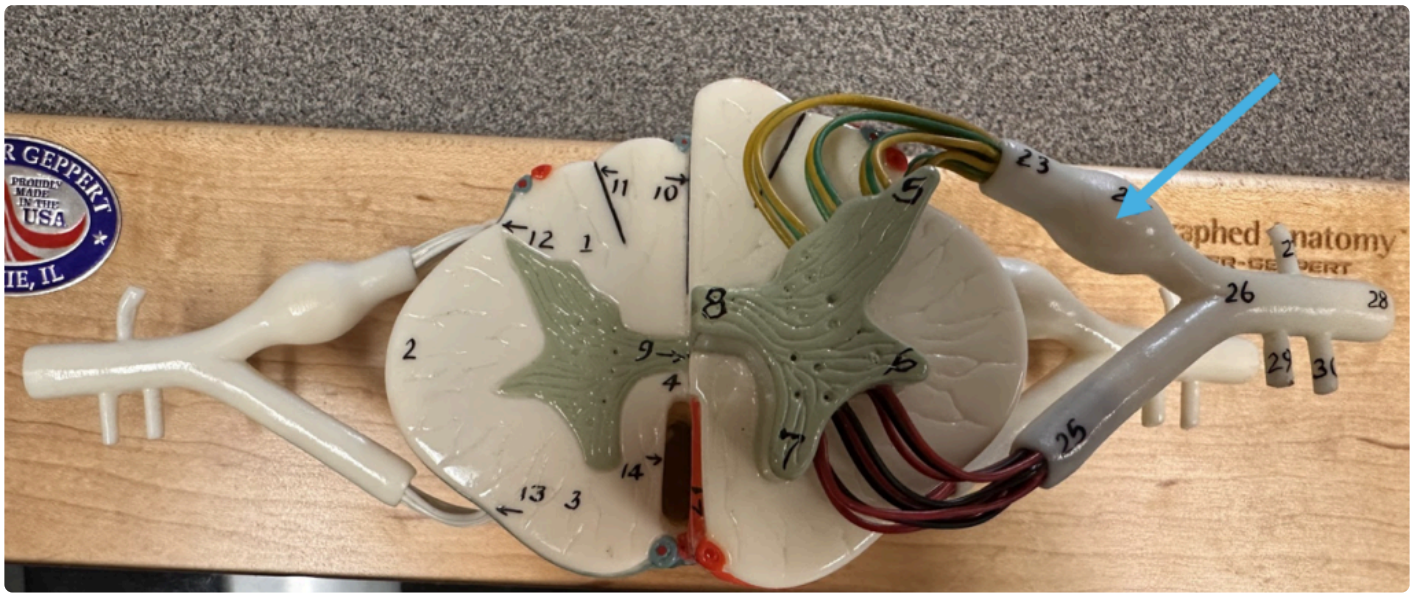


Figure 8.28 Dorsal Root Ganglion

Nerves

Bundles of axons in the PNS are referred to as nerves. Nerves are composed of more than just nervous tissue. They have connective tissue in their structure, as well as blood vessels that supply the tissues with nourishment.

The outer surface of a nerve is surrounded by a layer of fibrous connective tissue called the **epineurium**. Within the nerve, groups of axons are bundled into **fascicles**, which are surrounded by their own layer of fibrous connective tissue called the **perineurium**. Finally, individual axons are surrounded by loose connective tissue called the **endoneurium**. See Figure 8.29[30] for an illustration of these connective tissue layers. These three layers are similar to the connective tissue coverings for skeletal muscles.

29. WisTech Open. (2026). *Dorsal root ganglion by Julia Brown* [Photograph]. Chippewa Valley Technical College. CC BY-SA 4.0.

30. OpenStax College. (2013). *1319_Nerve_StructureN* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1319_Nerve_StructureN.jpg

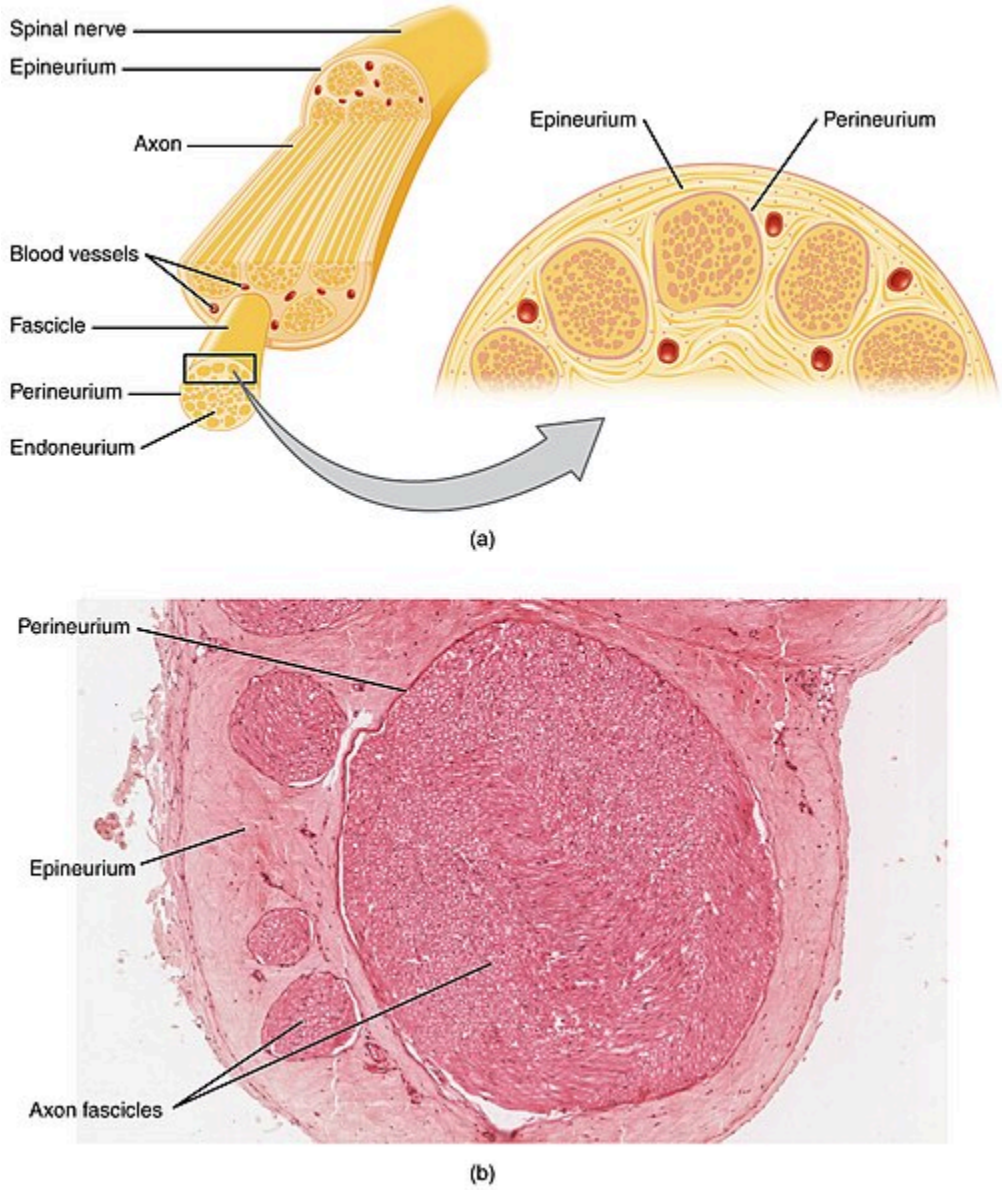


Figure 8.29 Nerve Structure

Nerves are associated with the region of the CNS to which they are connected, either as cranial nerves connected to the brain or spinal nerves connected to the spinal cord.

Cranial Nerves

The twelve pairs of nerves attached to the brain are the **cranial nerves**, which are primarily responsible for the sensory and motor functions of the head and neck, although one of these nerves targets organs in the thoracic and abdominal cavities as part of the parasympathetic nervous system. There are twelve cranial nerves, which are

designated CN I through CN XII with CN abbreviated for “Cranial Nerve” and Roman numerals for nerves 1 through 12. Cranial nerves can be classified as sensory nerves, motor nerves, or a combination of both. Three of the nerves are solely composed of sensory fibers; five are strictly motor; and the remaining four are mixed nerves.[31] An overview of the cranial nerves, their functions, and whether they are sensory, motor, or mixed nerves is provided in Table 8.3b.

Table 8.3b. Cranial Nerves

31. Ernstmeyer, K., & Christman, E. (Eds.). (2023). *Nursing Skills 2e.* Open RN. https://wtcs.pressbooks.pub/nursingskills/

Cranial Nerve	Function	Type of Nerve
CN I: Olfactory Nerve	Smell (olfaction)	Sensory nerve
CN II: Optic Nerve	Vision	Sensory nerve
CN III: Oculomotor Nerve	Eye movements, including lifting the upper eyelid when the eyes point up, and pupillary constriction	Motor nerve
CN IV: Trochlear Nerve	Up and down eye movements	Motor nerve
CN V: Trigeminal Nerve	Sensations of the face and control of chewing muscles	Both sensory and motor nerves
CN VI: Abducens Nerve	Abduction (movement to the outside) of the eyes	Motor nerve
CN VII: Facial Nerve	Facial expressions, as well as part of the sense of taste and the production of saliva	Both sensory and motor nerves
CN VIII: Vestibulocochlear Nerve	Hearing and balance	Sensory nerve

CN IX: Glossopharyngeal Nerve	Contraction of muscles in the tongue and upper throat, as well as part of the sense of taste, and the production of saliva	Both sensory and motor nerves
CN X: Vagus Nerve	Parasympathetic control of the organs of the thoracic and upper abdominal cavities	Both sensory and motor nerves
CN XI: Spinal Accessory (or Accessory) Nerve	Contraction of neck muscles	Motor nerve
CN XII: Hypoglossal Nerve	Responsible for controlling the muscles of the lower throat and tongue	Motor nerve

See Figure 8.30[32] for an illustration of the cranial nerves.

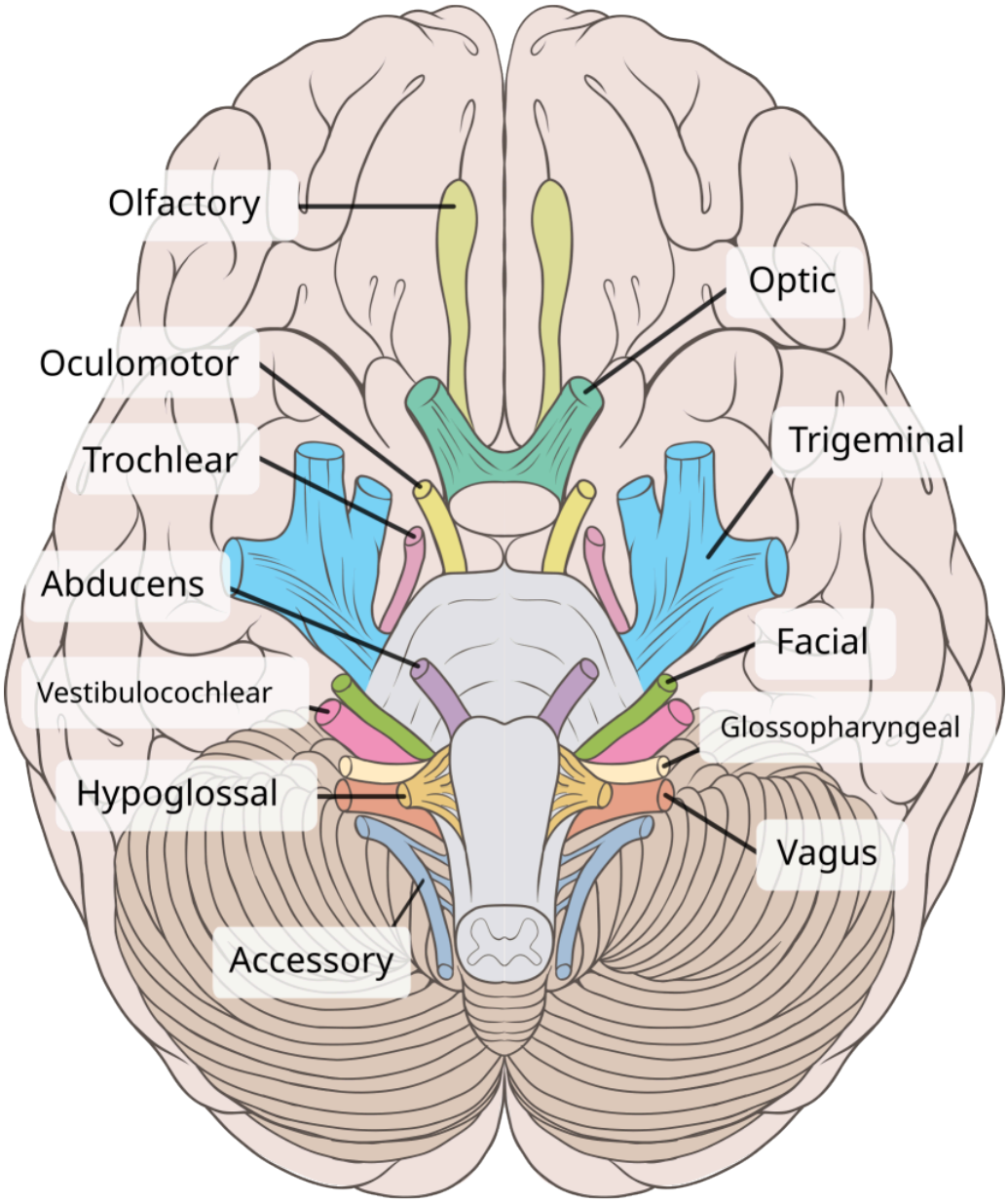


Figure 8.30 Cranial Nerves

The first, second, and eighth nerves are purely sensory: the olfactory (CN I), optic (CN II), and vestibulocochlear (CN VIII) nerves. The three eye-movement nerves are only motor: the oculomotor (CN III), trochlear (CN IV), and abducens (CN VI). The spinal accessory (CN XI) and hypoglossal (CN XII) nerves are also strictly motor. The remainder

32. Lynch, P.J. (2011). *Brain_human_normal_inferior_view_with_labels_en-2* [Diagram]. Wikimedia Commons. CC BY 2.5. https://commons.wikimedia.org/wiki/File:Brain_human_normal_inferior_view_with_labels_en-2.svg

of the nerves contain both sensory and motor fibers and are mixed nerves. They are the trigeminal (CN V), facial (CN VII), glossopharyngeal (CN IX), and vagus (CN X) nerves. The nerves that are mixed are often related to each other. For example, the trigeminal and facial nerves both concern the face; one concerns the sensations and the other concerns the muscle movements. The facial and glossopharyngeal nerves are both responsible for conveying gustatory or taste sensations, as well as controlling salivary glands. The vagus nerve is involved in visceral responses to taste, namely the gag reflex.

Spinal Nerves

The nerves connected to the spinal cord are the **spinal nerves**. The arrangement of these nerves is much more regular than that of the cranial nerves. All the spinal nerves are mixed nerves with combined sensory and motor axons that separate into two nerve roots. The sensory axons enter the spinal cord as the dorsal nerve root. The motor axons emerge as the ventral nerve root.

There are 31 pairs of spinal nerves, named for the level of the spinal cord at which each one emerges. There are eight pairs of cervical nerves designated C1 to C8, twelve thoracic nerves designated T1 to T12, five pairs of lumbar nerves designated L1 to L5, five pairs of sacral nerves designated S1 to S5, and one pair of coccygeal nerves. See Figure 8.31[33] for an illustration of the spinal nerves.

33. VectorMine. (2018). *Spinal cord schematic diagram with all sections* [Diagram]. Shutterstock. Used under paid license from Shutterstock.com. https://www.shutterstock.com/image-vector/spinal-cord-schematic-diagram-all-sections-1008694237

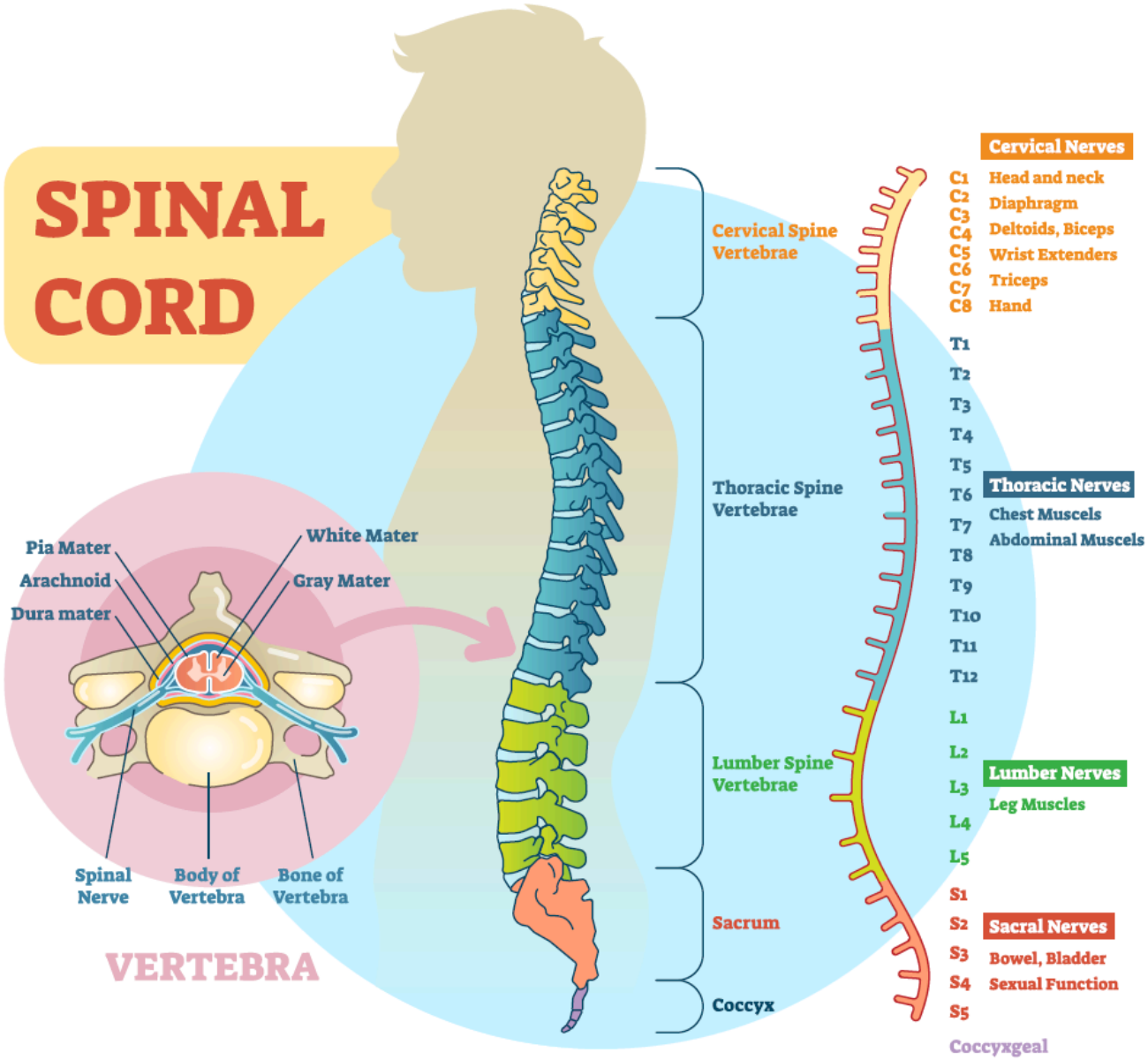


Figure 8.31 Spinal Nerves. Used With a Paid Shutterstock License.

Nerve Plexuses

Spinal nerves extend outward from the vertebral column into the periphery. Axons from different spinal nerves come together and form networks of nerve fibers. This occurs at four places along the length of the vertebral column, each identified as a **nerve plexus**. Of the four nerve plexuses, two are found at the cervical level, one at the lumbar

level, and one at the sacral level. See Figure 8.32[34] for an illustration of the nerve plexus locations.

34. OpenStax College. (2016). *1321_Spinal_Nerve_Plexuses* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1321_Spinal_Nerve_Plexuses.jpg

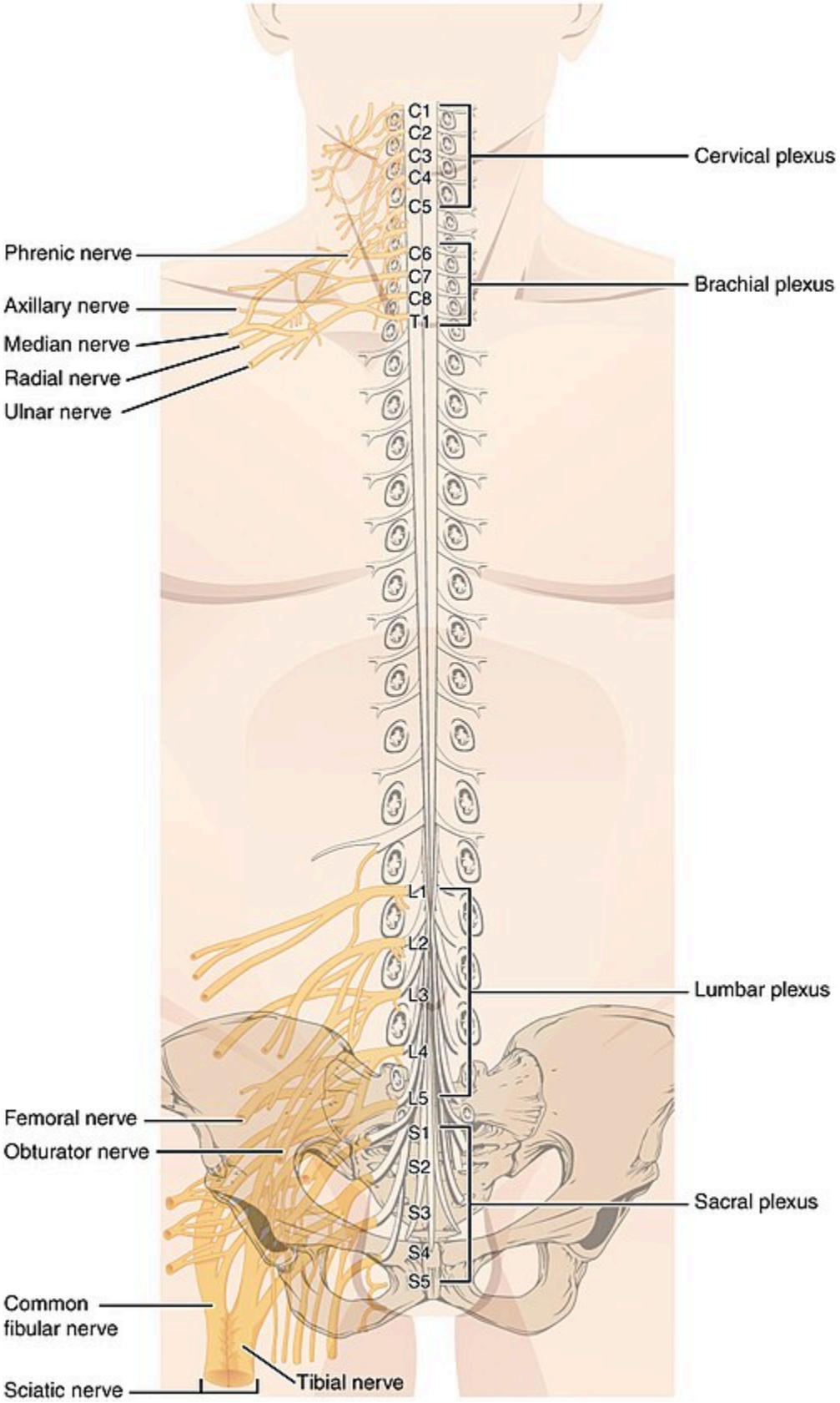


Figure 8.32 Nerve Plexuses of the Body

The **cervical plexus** is composed of axons from spinal nerves C1 through C5 and branches into nerves in the posterior neck and head, as well as the **phrenic nerve**, which connects to the diaphragm at the base of the thoracic cavity.

The other plexus from the cervical level is the **brachial plexus**. Spinal nerves C4 through T1 reorganize through this plexus to give rise to the nerves of the upper extremities, as the name brachial suggests. A large nerve from this plexus is the radial nerve, from which the axillary nerve branches to go to the armpit region. The radial nerve continues through the arm and is paralleled by the ulnar nerve and the median nerve.

The **lumbar plexus** arises from all the lumbar spinal nerves and gives rise to nerves innervating the pelvic region and the anterior lower extremity. The **femoral nerve** is one of the major nerves from this plexus, which gives rise to the saphenous nerve as a branch that extends through the anterior lower extremity. Another major nerve coming from the lumbar plexus is the **obturator nerve**, which descends to the medial thigh to provide motor innervation to the adductor muscles and sensory innervation to the skin of the medial thigh.

The **sacral plexus** comes from the lower lumbar nerves L4 and L5 and the sacral nerves S1 to S4 to supply nerves to the posterior lower extremity. The most significant nerve to come from this plexus is the **sciatic nerve**, which is a combination of the tibial nerve and the fibular nerve. The sciatic nerve extends across the hip joint and is most commonly associated with the condition **sciatica**, which is the result of compression or irritation of the nerve or any of the spinal nerves giving rise to it.

Divisions of the PNS

The PNS (peripheral nervous system) can be divided into three main divisions: the somatic nervous system (SNS), responsible for voluntary skeletal movements and senses, the autonomic nervous system (ANS), responsible for sympathetic (flight, fight, or fright) and parasympathetic (rest and digest) functions, and the enteric nervous system (ENS), responsible for digestive functions. See Figure 8.33[35] for examples of where these divisions of the nervous system are found.

35. OpenStax College. (2016). *1205_Somatic_Autonomic_Enteric_StructuresN* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1205_Somatic_Autonomic_Enteric_StructuresN.jpg

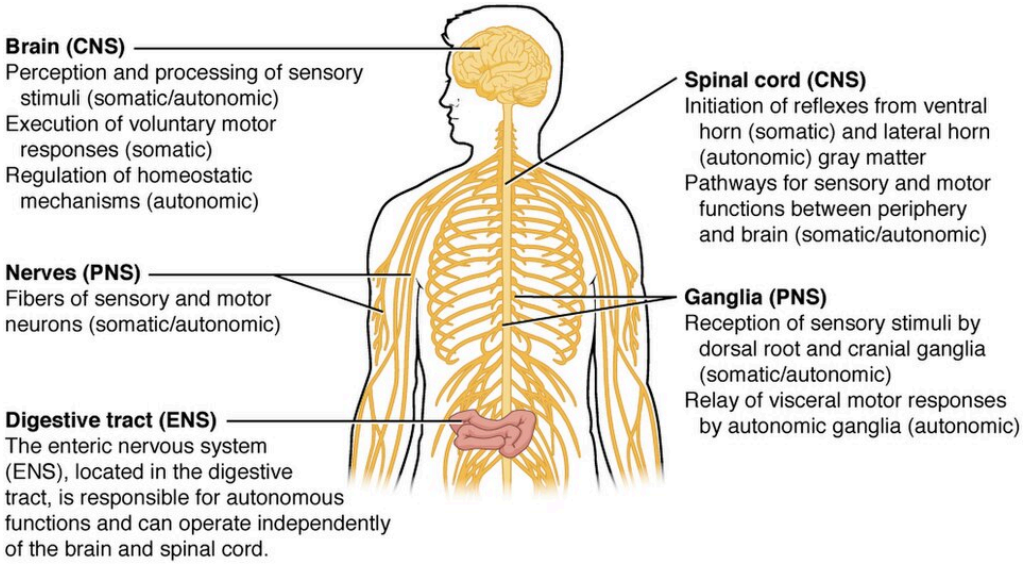


Figure 8.33 Somatic, Autonomic, and Enteric Structures of the Nervous System

Somatic Nervous System

The **somatic nervous system (SNS)** is responsible for our conscious perception of the environment (senses) and voluntary motor responses to that perception by the contraction of skeletal muscles, such as moving your leg or raising your hand. It also includes reflexes and automatic muscle control.

Senses

Sensory receptors help us to take in and understand both the external environment and the internal environment inside the body. Different types and functions of the senses are discussed in more detail in the "**Senses**" section.

Skeletal Muscle Movement

Somatic function includes conscious or voluntary (skeletal) muscle movement. For example, reading of this text starts with visual sensory input to the retina, which then projects to the thalamus and on to the cerebral cortex. A sequence of regions of the cerebral cortex processes the visual information, starting in the primary visual cortex of the occipital lobe, and resulting in the conscious perception of these letters. Subsequent

cognitive processing results in an understanding of the content. As you continue reading, regions of the cerebral cortex in the frontal lobe plan how to move the eyes to follow the lines of text. The output from the cortex causes activity in motor neurons in the brain stem that cause movement of the extraocular muscles through the third, fourth, and sixth cranial nerves. This example also includes sensory input (the retinal projection to the thalamus), central processing (the thalamus and subsequent cortical activity), and motor output (activation of neurons in the brain stem that lead to coordinated contraction of extraocular muscles).

Reflexes

Somatic motor responses also include reflexes. A **reflex** is a quick, predictable automatic response to a stimulus and occurs without a conscious decision by the brain to perform it. For example, if something startles you, you might scream or jump backwards. Even though you may not consciously decide to perform those actions, they are the result of reflexes that involve skeletal muscle contractions.

Another example of a reflex is the withdrawal reflex. When you touch a hot stove, you pull your hand away. Sensory receptors in the skin sense extreme temperature. This triggers a nerve impulse, which travels along the sensory nerve from the skin through the dorsal spinal root to the processing center of the spinal cord, which then activates a motor neuron in the ventral horn of the spinal cord. That motor neuron sends a signal along its axon to stimulate the biceps brachii, causing contraction of the muscle and flexion of the forearm at the elbow to withdraw the hand from the hot stove.

The basic withdrawal reflex explained above includes sensory input (the painful stimulus of the hot stove), central processing (the interneuron in the spinal cord deciding what to do), and motor output (activation of a ventral motor neuron that causes the contraction of the biceps brachii to remove the hand from the stove).

Automatic (Unconscious) Movement

Other motor responses can become automatic or unconscious as a person learns motor skills (referred to as “habit learning” or “procedural memory”), for example, driving a car or riding a bike. Some other aspects of the somatic system also use voluntary muscles without conscious control. One example is the ability of our breathing to switch to involuntary control while we are focused on another task. The muscles that are responsible for the basic process of breathing are also utilized for speech, which is entirely voluntary.

Autonomic Nervous System

The **autonomic nervous system (ANS)** is responsible for involuntary control of the body to maintain homeostasis. Sensory input for autonomic functions can be from sensory structures tuned to external or internal environmental stimuli. The motor output extends to smooth and cardiac muscle, as well as glandular tissue. The role of the autonomic nervous system is to regulate the organ systems of the body. Sweat glands, for example, are controlled by the ANS. When you are hot, sweating helps cool your body down as a homeostatic mechanism. However, you may also start sweating when you are nervous, which is not a homeostatic mechanism but a physiological response to an emotional state.

The autonomic nervous system is further divided into the sympathetic nervous system and the parasympathetic nervous system. The autonomic nervous system is discussed in more detail in the "**Autonomic Nervous System**" section.

Enteric Nervous System

Another division of the nervous system, called the **enteric nervous system (ENS)**, controls the smooth muscle and glandular tissue in the digestive system. It is not dependent on the CNS. The enteric system is also considered part of the autonomic system because the neural structures that make up the enteric system are a component of the autonomic output that regulates digestion.

8.4 Autonomic Nervous System

In addition to the endocrine system, the autonomic nervous system is instrumental in maintaining homeostasis in the body. The autonomic nervous system regulates many of the body's internal organs through a balance of two divisions called the **sympathetic division** and the **parasympathetic division**. The sympathetic system is associated with the "**fight-or-flight response**," and the parasympathetic system is associated with the "**rest and digest**" response. These two branches have opposite effects and are considered antagonistic to each other. Most organs have both a sympathetic and parasympathetic nerve innervating them (dual innervation). The sympathetic division will increase body activities that are crucial for survival in a potentially dangerous situation and will decrease body activities that aren't essential. The parasympathetic division does the opposite of the sympathetic branch. It increases activities like digestion and decreases others like heart rate and blood pressure.[1]

For example, the heart receives stimuli from both the sympathetic and parasympathetic divisions. The sympathetic nervous system increases heart rate, whereas the parasympathetic nervous system decreases it.

Sympathetic Nervous System

The "fight-or-flight response" of the sympathetic nervous system prepares the body to either run away from a threat or to stand and fight. The autonomic system controls the physiological response to make that possible. Epinephrine (adrenaline) is released in the circulatory system, causing the heart rate to increase. Sweat glands become active. The bronchi of the lungs dilate to allow more air exchange. Pupils dilate to increase visual information. Blood pressure increases, and blood vessels dilate to allow more oxygen-rich blood to reach the skeletal muscle for anticipated movement. The autonomic nervous system creates emotional reactions associated with anxiety, and the corresponding physiological reactions can feel like a panic attack.

When responding to a real or perceived threat, the sympathetic system activates many organs for a common purpose of fighting or fleeing. The respiratory,

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

cardiovascular, and musculoskeletal systems are activated together to allow more oxygen to be inhaled and delivered to skeletal muscle for ATP production. Sweating prevents the body from overheating from the excess heat resulting from muscle contraction. The digestive system shuts down to divert more blood to deliver oxygen to skeletal muscles instead of absorbing nutrients. To coordinate all these responses, the connections in the sympathetic system diverge from a limited region of the central nervous system (CNS) to a wide array of organs simultaneously.

The sympathetic division of the autonomic nervous system controls the various organ systems of the body through connections emerging from the thoracic and upper lumbar spinal cord. Because of this, the sympathetic nervous system is also referred to as the **thoracolumbar system**. A diagram that shows the connections of the sympathetic system is somewhat like a circuit diagram that shows the electrical connections between different receptacles and devices. Neurons from the spinal cord travel to ganglia and then project to target effectors throughout the body. See Figure 8.35[2] for an illustration of the connections of the sympathetic division of the autonomic nervous system.

2. OpenStax College. (2013). *1501_Connections_of_the_Sympathetic_Nervous_System* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1501_Connections_of_the_Sympathetic_Nervous_System.jpg

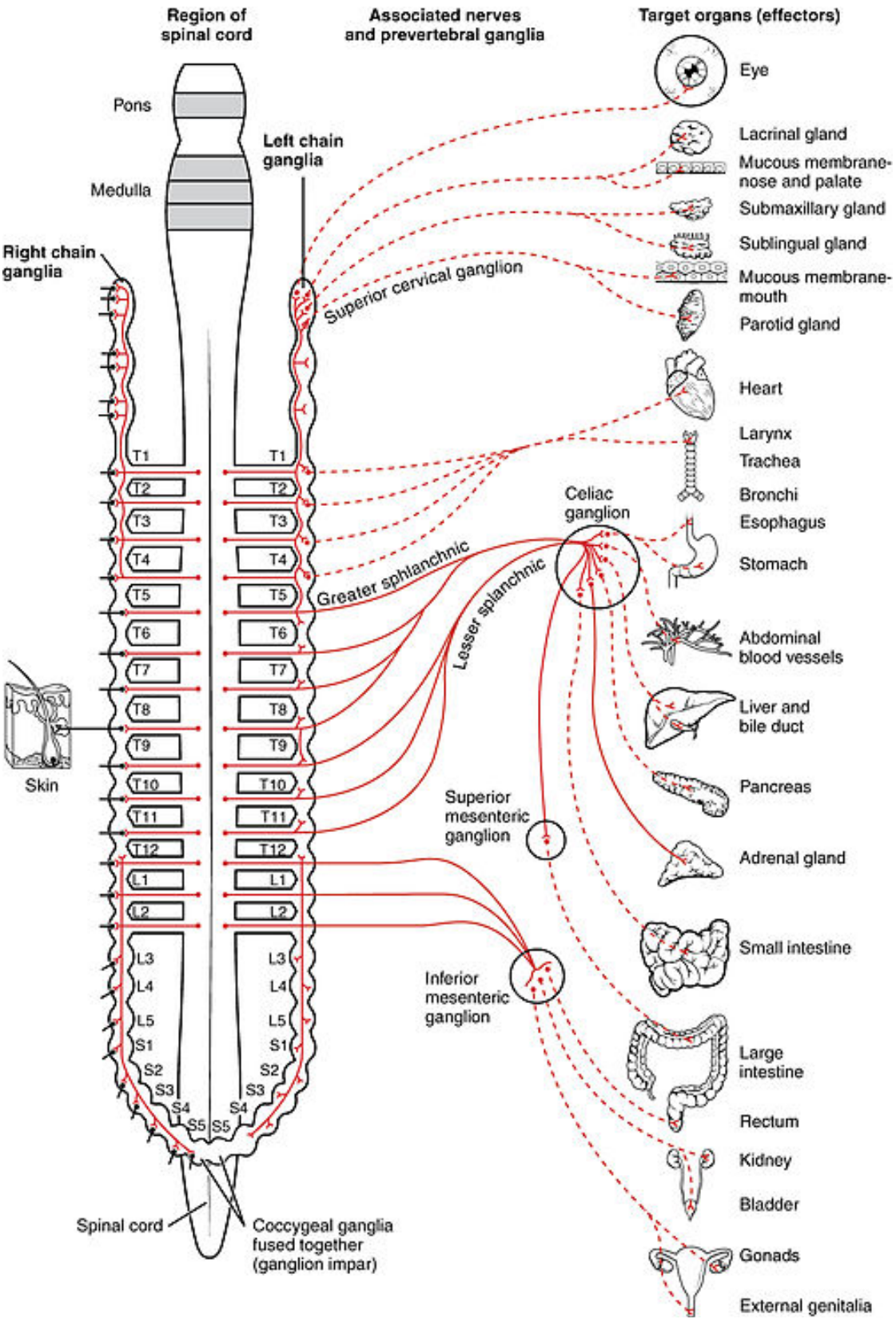


Figure 8.35 Connections of the Sympathetic Division of the Autonomic Nervous System

Video

Watch the video "Fight or Flight Response" below to learn how the body responds to stress through the activation of the sympathetic nervous system and the release of hormones.[3]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Parasympathetic Nervous System

In contrast to the "fight-or-flight" responses by the sympathetic nervous system, the parasympathetic nervous system responses are commonly known as "rest and digest." This system is normally in charge of the body and helps maintain normal homeostasis. An acronym associated with some functions of the parasympathetic nervous system is **SLUDD**, which stands for salivation, lacrimation (secretion and shedding of tears), urination, digestion, and defecation. The parasympathetic nervous system reverses the effects of fight or flight, helping return the body to its normal resting state.

The parasympathetic system is also referred to as the **craniosacral system** because the preganglionic neurons are located in the brain stem and the sacral spinal cord. Neurons from the brain stem and sacral spinal cord project to terminal ganglia near or within the various organs of the body. Axons from these ganglionic neurons then

3. Bozeman Science. (2012, January 9). *Fight or flight response* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=m2GywoS77qc

project a short distance to those target effectors. See Figure 8.36[4] for an illustration of the connections of the parasympathetic division of the autonomic nervous system.

4. OpenStax College. (2013). *1503_Connections_of_the_Parasympathetic_Nervous_System* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1503_Connections_of_the_Parasympathetic_Nervous_System.jpg

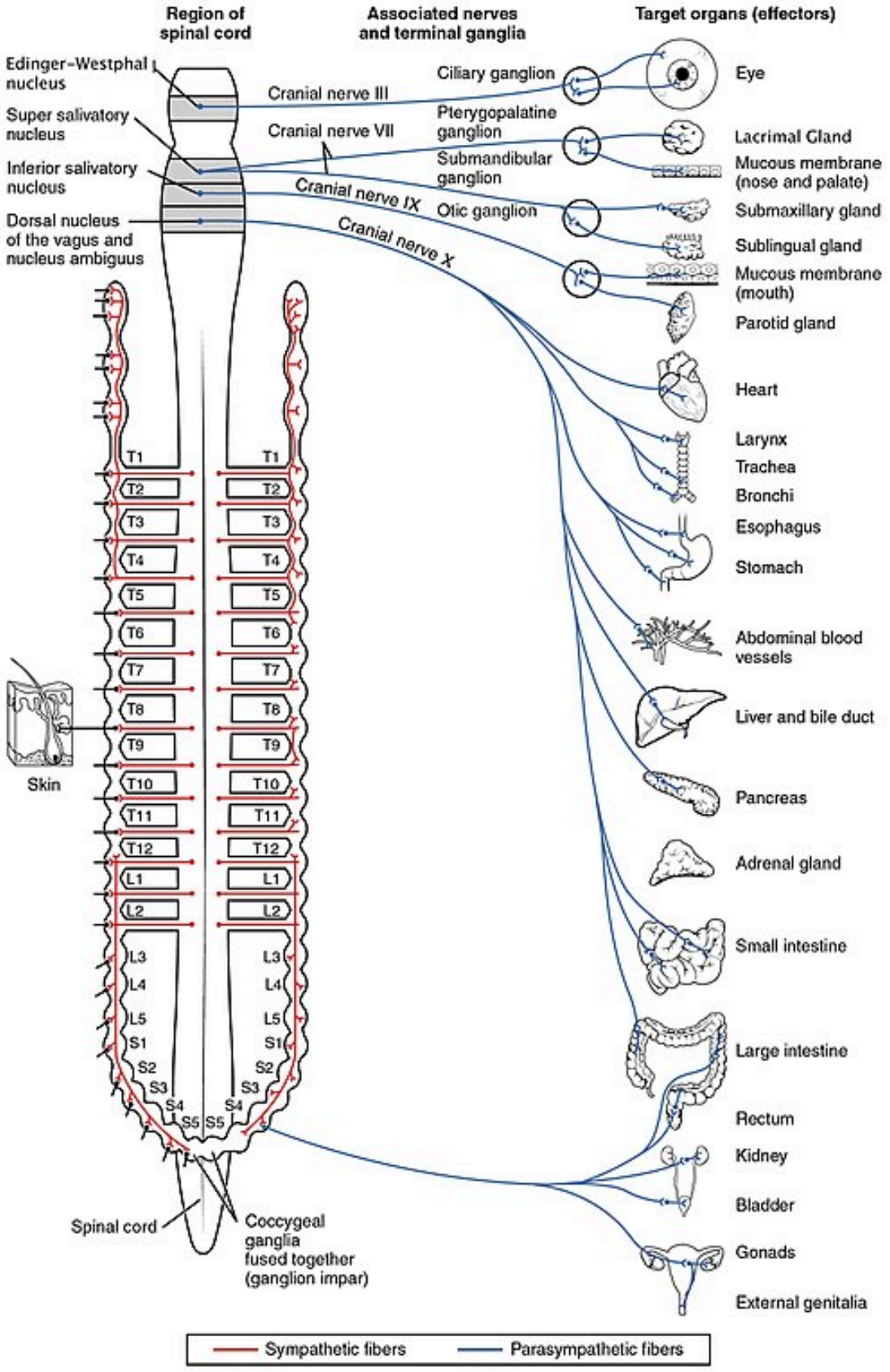


Figure 8.36 Connections of the Parasympathetic Division of the Autonomic Nervous System

Body Function	Sympathetic Nervous System ("Fight or Flight")	Parasympath
Overall Role	Prepares the body for stress, emergency, activity	Conserves en
Heart Rate	Increases heart rate	Decreases he
Blood Pressure	Increases blood pressure	Decreases blo
Pupil Size	Dilates pupils (mydriasis)	Constricts pu
Bronchi (Lungs)	Dilates airways	Constricts air
Salivation	Decreases saliva production	Increases sali
Digestive Activity	Inhibits digestion	Stimulates di
Liver	Releases glucose into blood	Promotes glu
Bladder	Relaxes bladder wall (urine retention)	Contracts bla
Sweat Glands	Stimulates sweating	No significan
Adrenal Medulla	Stimulates release of epinephrine & norepinephrine	No effect
Sexual Response	Ejaculation (male)	Erection (mal

Autonomic tone refers to the continuous, baseline activity of both the sympathetic and parasympathetic divisions of the autonomic nervous system. Even at rest, neither division is completely inactive; instead, both provide a steady level of stimulation to organs. The balance between these two systems—rather than the complete activation of one or the other—maintains homeostasis, or the stability of the body's internal environment. For example, parasympathetic tone typically predominates at rest, helping keep heart rate low, while sympathetic tone maintains blood vessel constriction to support blood pressure. When the body's needs change, such as during exercise or stress, sympathetic activity increases, and parasympathetic activity decreases. Once the demand passes, parasympathetic influence rises again to restore resting conditions. This constant, dynamic adjustment allows the body to respond efficiently to internal and external changes while keeping physiological variables within normal limits.

Video

Watch the video “Autonomic Nervous System Explained (Structure and Function Overview)” below to learn more about the autonomic nervous system and automatic body functions.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.



8.5 Senses

As mentioned previously, a major role of sensory receptors is to receive information about the external environment around us or the state of our internal environment. Stimuli from multiple sources are received and relayed to the central nervous system, where they are integrated with other sensory information and sometimes higher cognitive functions to become a conscious perception of that stimulus. This central integration may then lead to a motor response.

Describing sensory function uses two different terms: sensation and perception. **Sensation** refers to receiving information from the environment that activates sensory receptor cells. **Perception** refers to the central processing of sensory stimuli into a meaningful pattern. Perception is dependent on sensation, but not all sensations are perceived.[1]

Sensory Receptors

Sensory Receptor Classification by Cell Type

There are many different cells that interpret information about the environment. A neuron that has a **free nerve ending** has dendrites embedded in tissue that receive a sensation. Pain receptors called **nociceptors** and temperature receptors called **thermoreceptors** in the dermis of the skin are examples of neurons that have free nerve endings.

A neuron that has an **encapsulated ending** has sensory nerve endings that are encapsulated in connective tissue to enhance their sensitivity. An example of a neuron with an encapsulated ending is the Pacinian corpuscle (also known as the lamellated corpuscle) that responds to pressure and touch in the dermis of the skin.

Specialized receptor cells have distinct structural components that interpret a specific type of stimulus. **Photoreceptors**, the cells in the retina that respond to light

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

stimuli, are an example of a specialized receptor. See Figure 8.37[2] for an illustration of cells with free nerve endings, an encapsulated ending, and a specialized receptor cell.

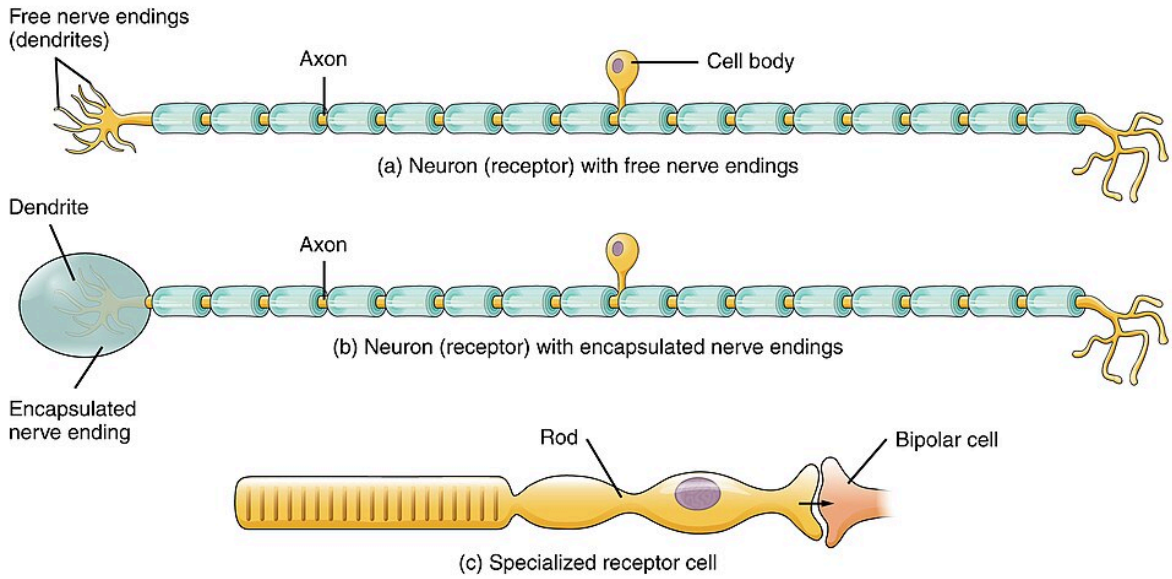


Figure 8.37 Sensory Receptor Classification by Cell Type: (a) Free Nerve Ending, (b) Encapsulated Nerve Ending, and (C) Specialized Receptor Cell

Sensory Receptor Classification by Location

Another way that receptors can be classified is based on their location relative to the stimuli. An **exteroceptor** is a receptor that is located near a stimulus in the external environment, such as the somatosensory receptors that are located in the skin. An **interoceptor** is one that interprets stimuli from internal organs and tissues, such as the **baroreceptors** that sense the increase in blood pressure in the aorta or carotid sinus. Finally, a **proprioceptor** is a receptor located near a moving part of the body, such as a muscle, that interprets position and movement.

Sensory Receptor Classification by Function

Sensory receptors called osmoreceptors, nociceptors, mechanoreceptors, and thermoreceptors are classified by their function. Table 8.5a provides an overview of the actions of sensory receptors.

2. OpenStax College. (2016). *1401_Receptor_Types* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1401_Receptor_Types.jpg

Table 8.5a. Actions of Sensory Receptors

Type of Receptor	Action
Osmoreceptor	Sense solute concentrations of body fluids. For example, osmoreceptors help maintain the osmolality of blood.
Nociceptor	Sense presence of chemicals from tissue damage, or similar intense stimuli. For example, pain is sensed by nociceptors.
Mechanoreceptor	Sense physical stimuli, such as pressure and vibration, as well as sound and body position (balance). For example, mechanoreceptors sense a buzzing insect on your skin.
Thermoreceptor	Senses temperatures above (hot) or below (cold) normal body temperature. For example, a thermoreceptor senses a cold environment and stimulates shivering.
Baroreceptor	Senses the stretch of blood vessels to indicate changes in blood pressure.
Chemoreceptor	Senses chemical composition in body fluids.
Photoreceptor	Senses light stimuli.

General and Special Senses

Senses can be classified as either general or specific. A **general sense** is one that is distributed throughout the body, such as touch or pain. A **special sense** is any sensory system that is localized to a specific organ structure, namely the senses of smell, taste, sight, hearing, and balance.

General Senses

General senses are touch, **proprioception** (body movement), **kinesthesia** (body movement), or **visceral sense** (organ information), which is important to autonomic functions. The general sense of touch, which is known as **somatosensation**, can be separated into light pressure, deep pressure, vibration, itch, pain, temperature, or hair movement.

Somatosensation (Touch)

Somatosensation (touch) is considered a general sense, as opposed to the special senses discussed below. This means that its receptors are not associated with a specialized organ but are instead spread throughout the body in a variety of organs. Many of the somatosensory receptors are located in the skin, but receptors are also found in muscles, tendons, joint capsules, ligaments, and in the walls of visceral organs.

Two types of somatosensory signals that are transmitted by free nerve endings are pain and temperature. Temperature receptors (thermoreceptors) are stimulated when local temperatures differ from body temperature. Some thermoreceptors are sensitive to just cold and others to just heat. Nociceptors detect potentially damaging stimuli. Mechanical, chemical, or thermal stimuli beyond a set threshold will elicit painful sensations. Stressed or damaged tissues release chemicals that activate the nociceptors.

If you drag your finger across a textured surface, the skin of your finger will vibrate. Such low-frequency vibrations are sensed by mechanoreceptors called Merkel cells, also known as Type I cutaneous mechanoreceptors. Merkel cells are located in the stratum basale of the epidermis. Deep pressure and vibration are sensed by Pacinian (lamellated) corpuscles, which are receptors with encapsulated endings found deep in the dermis and subcutaneous tissue. Light touch is sensed by the encapsulated endings known as Meissner (tactile) corpuscles. Follicles are also wrapped in a plexus of nerve endings known as the hair follicle plexus. These nerve endings detect the movement of hair at the surface of the skin, such as when an insect may be walking along the skin. Stretching of the skin is sensed by stretch receptors known as bulbous corpuscles. Bulbous corpuscles are also known as Ruffini corpuscles, or Type II cutaneous mechanoreceptors. Other somatosensory receptors are found in the joints and muscles. Stretch receptors monitor the stretching of tendons, muscles, and the components of joints. See Table 8.5b for a list of all the somatosensory receptors, where they are located, and the stimuli they detect.

Table 8.5b. Mechanoreceptors of Somatosensation[3]

3. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Name	Historical (eponymous) Name	Location(s)	Stimuli
Free nerve endings	None	Dermis, cornea, tongue, joint capsules, and visceral organs	Pain, temperature, mechanical deformation
Tactile discs	Merkel's discs	Epidermal–dermal junction and mucosal membranes	Low frequency vibration (5–15 Hz)
Bulbous corpuscle	Ruffini's corpuscle	Dermis and joint capsules	Stretch
Tactile corpuscle	Meissner's corpuscle	Papillary dermis, especially in the fingertips and lips	Light touch and vibrations below 50 Hz
Lamellated corpuscle	Pacinian corpuscle	Deep dermis and subcutaneous tissue	Deep pressure and high-frequency vibration (around 250 Hz)
Hair follicle plexus	None	Wrapped around hair follicles in the dermis	Movement of hair
Muscle spindle	None	In line with skeletal muscle fibers	Muscle contraction and stretch
Tendon stretch organ	Golgi tendon organ	In line with tendons	Stretch of tendons

Special Senses

A **special sense** is one that has a specific organ devoted to it, namely the eye, ear, tongue, or nose. The special senses include smell, taste, audition (hearing), balance, and vision.

Olfaction (Smell)

The sense of smell, or **olfaction**, is responsive to chemical stimuli. Humans can detect more than one trillion different scents![4] The olfactory receptors are located in the superior nasal cavity. As airborne molecules are inhaled through the nose, they dissolve into the mucus and are transported to the olfactory dendrites, where they stimulate the olfactory neurons. The impulse is carried to the **olfactory bulb** on the frontal lobe. From there, the axons split to travel to several brain regions. Some travel to the cerebrum, specifically to the primary olfactory cortex that is located in the temporal lobe. Others project to structures within the limbic system and hypothalamus, where smells become associated with long-term memories and emotional responses. Smell is the one sense that does not synapse in the thalamus before traveling to the cerebral cortex. This intimate connection between the olfactory system and the cerebral cortex is another reason why smell can be a potent trigger of memories and emotion. See Figure 8.38[5] for an illustration of the olfactory system.

4. Bushdid, C., Magnasco, M. O., Vosshall, L. B., & Keller, A. (2014). Humans can discriminate more than 1 trillion olfactory stimuli. *Science, 343*(6177). https://pmc.ncbi.nlm.nih.gov/articles/PMC4483192/

5. OpenStax College. (2016). *1403_Olfaction* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1403_Olfaction.jpg

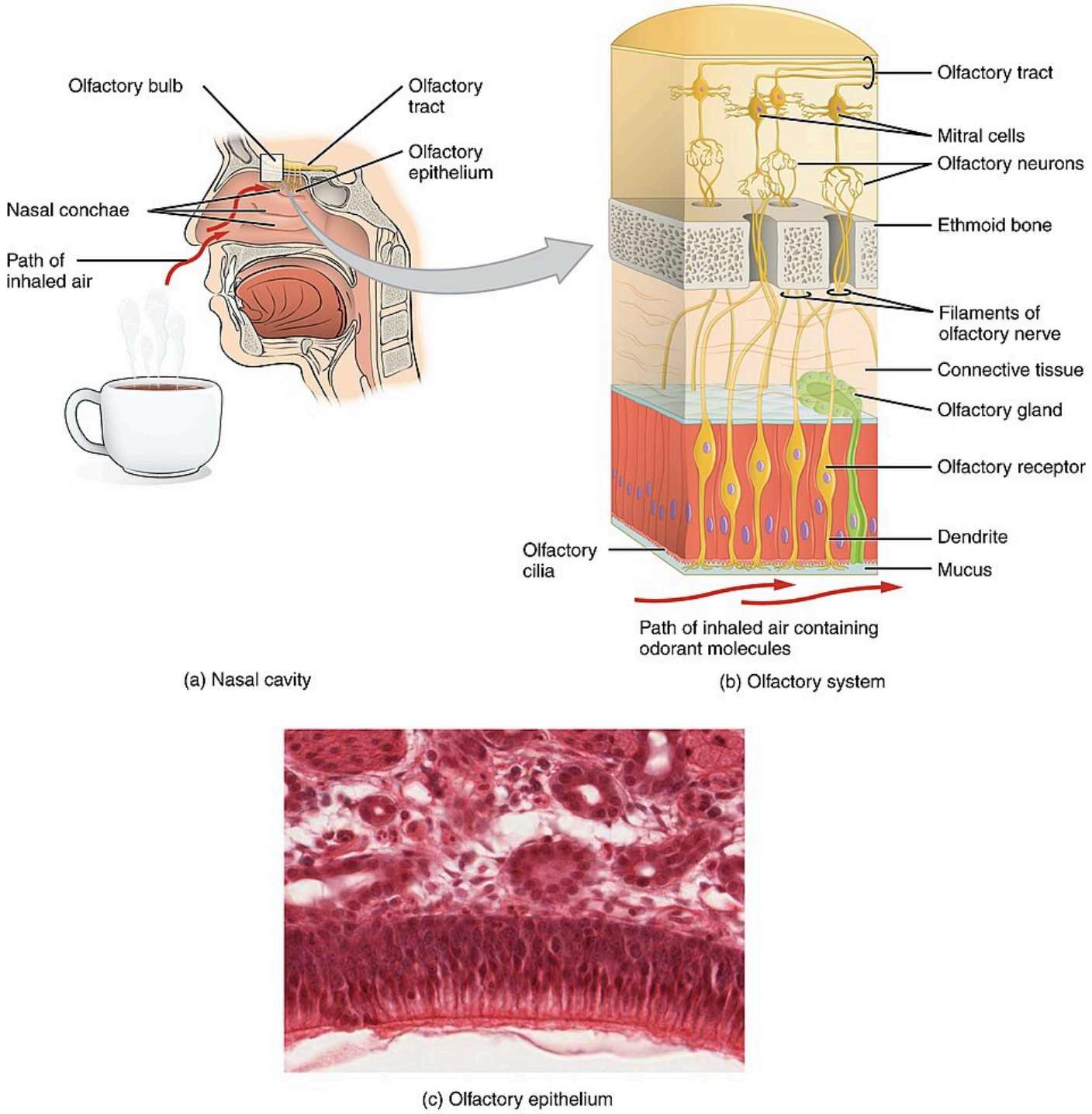


Figure 8.38 Olfactory System: (a) Nasal Cavity, (b) Olfactory System, and (c) Olfactory Epithelium

Gustation (Taste)

The sense of taste is also known as **gustation**. Until recently, only four tastes were recognized: sweet, salty, sour, and bitter. Recent research led to recognition of the fifth

taste called umami. **Umami** is a Japanese word that means “delicious taste” and is often translated to mean savory. Additional research suggests there may also be a sixth taste for fats (lipids). Much of what you think is taste when you’re eating is actually smell, which is why food often seems bland or different when you have a cold, and your sense of smell is reduced.

The receptors associated with gustation are located on the tongue. The surface of the tongue, along with the rest of the oral cavity, is lined by a stratified squamous epithelium. Raised bumps called **papillae** (singular = papilla) contain **taste buds**, the structures for taste. There are four types of papillae based on their appearance: circumvallate, foliate, filiform, and fungiform. See Figure 8.39[6] for an illustration of the different types of papillae. Within the structure of the papillae are taste buds that contain specialized **gustatory receptor cells** for taste. These receptor cells are sensitive to the chemicals contained in foods, and they release neurotransmitters based on the amount of the chemical in the food. Neurotransmitters from the gustatory cells can activate sensory neurons in the facial, glossopharyngeal, and vagus cranial nerves.

6. OpenStax College. (2016). *1402_The_Tongue* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1402_The_Tongue.jpg

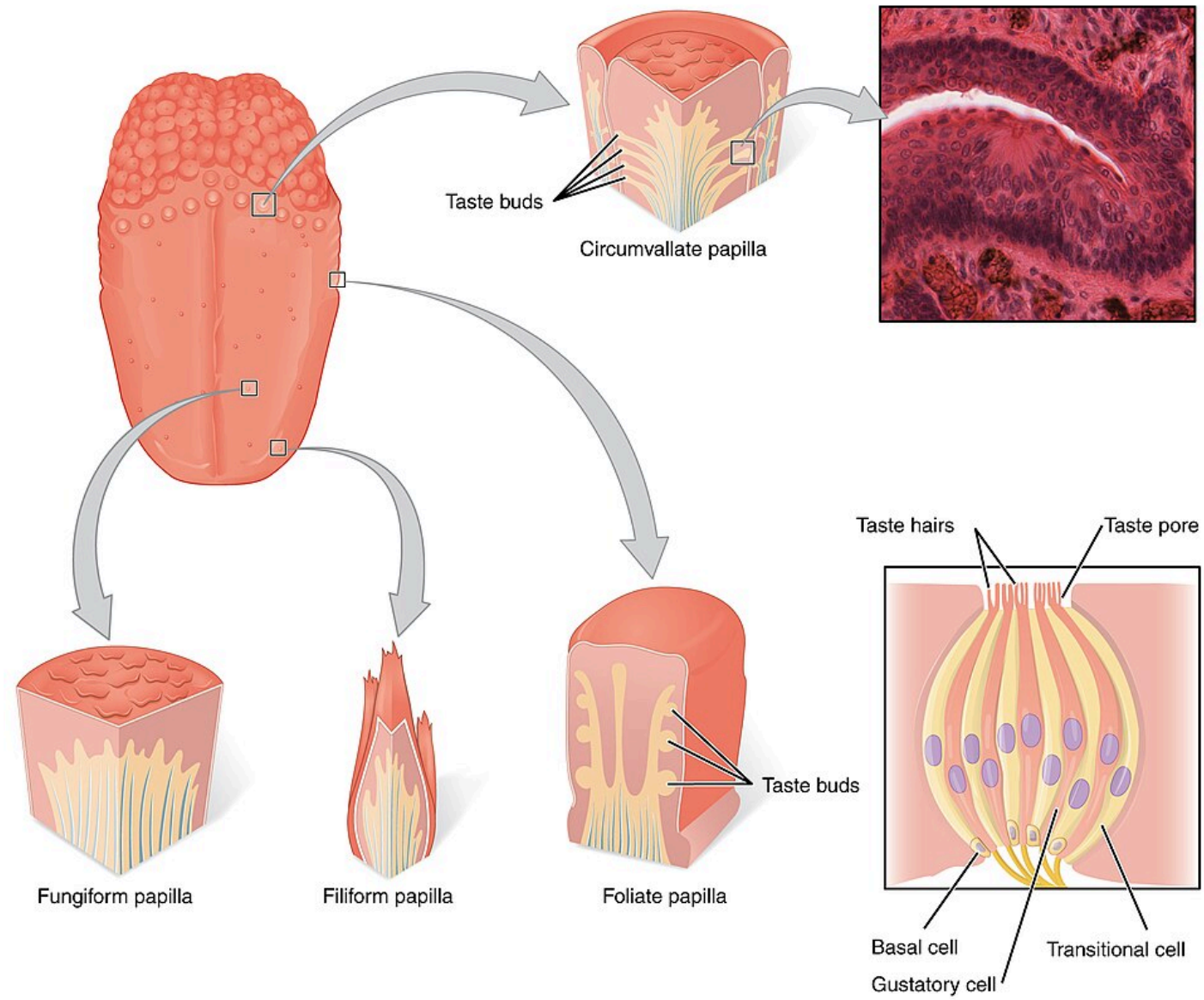


Figure 8.39 Papillae on the Tongue

Audition (Hearing)

Audition

is the sense of hearing, which is made possible by the structures and functions of several regions in the ear.

External (Outer) Ear

The auricle, external auditory canal, and tympanic membrane are often referred to

as the **external (or outer) ear**. The earlobe, a large, fleshy structure on the lateral side of the head, is known as the **auricle** or **pinna**. The C-shaped curves of the auricle direct sound waves toward the external auditory canal. The external auditory canal enters the skull through the **external auditory meatus** of the temporal bone. At the end of the external auditory canal is the **tympanic membrane**, or eardrum, which vibrates when sound waves hit it.

Middle Ear

The **middle ear** consists of a space within the head that contains three small bones called the **auditory ossicles**. The three ossicles are the **malleus**, **incus**, and **stapes**, which are Latin names that roughly translate to hammer, anvil, and stirrup. The malleus is attached to the tympanic membrane and articulates with the incus. The incus, in turn, articulates with the stapes. The middle ear is connected to the pharynx through the **eustachian tube**, which helps equalize air pressure across the tympanic membrane. The tube is normally closed but will "pop" open when the muscles of the pharynx contract during swallowing or yawning. See Figure 8.40[7] for an illustration of the structures of the external, middle, and inner ear.

7. OpenStax College. (2016). *Structures of the ear* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1404_The_Structures_of_the_Ear.jpg

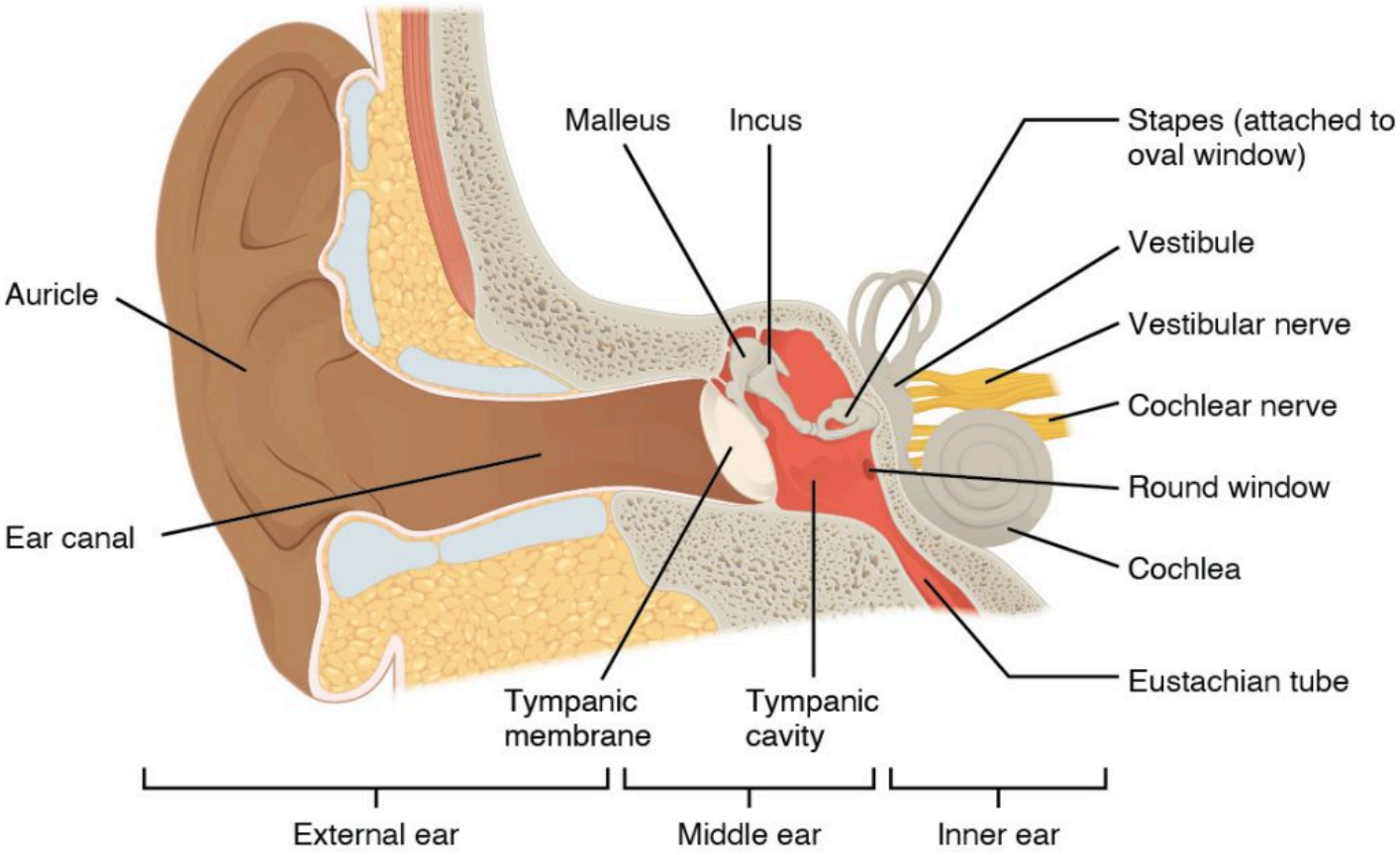


Figure 8.40 Ear

Inner Ear

The inner ear is often described as a bony labyrinth, as it is composed of a series of canals found within the temporal bone. It has two separate regions: the **vestibule**, along with its semicircular canals, which are responsible for balance, and the **cochlea**, which is responsible for hearing.

The **semicircular canals** are three ring-like extensions of the vestibule. One is oriented in the horizontal plane, whereas the other two are oriented in the vertical plane. The base of each semicircular canal, where it meets with the vestibule, connects to an enlarged region known as the ampulla. The ampulla contains the hair cells that respond to rotational movement, such as turning the head while saying "No."

The spiral-shaped **cochlea** is the auditory portion of the inner ear containing structures to transmit sound stimuli. The **cochlear duct** is a space within the auditory portion of the inner ear and contains several **organs of Corti**, structures that change sound waves into neural signals.

The neural signals from the vestibule and the cochlea travel to the brain stem through separate fiber bundles. However, these two distinct bundles travel together from the inner ear to the brain stem as the vestibulocochlear nerve (Cranial Nerve VIII). See Figure 8.40[8] for an illustration of the cochlea, and Figure 8.41[9] for an illustration of sound waves to the cochlea.

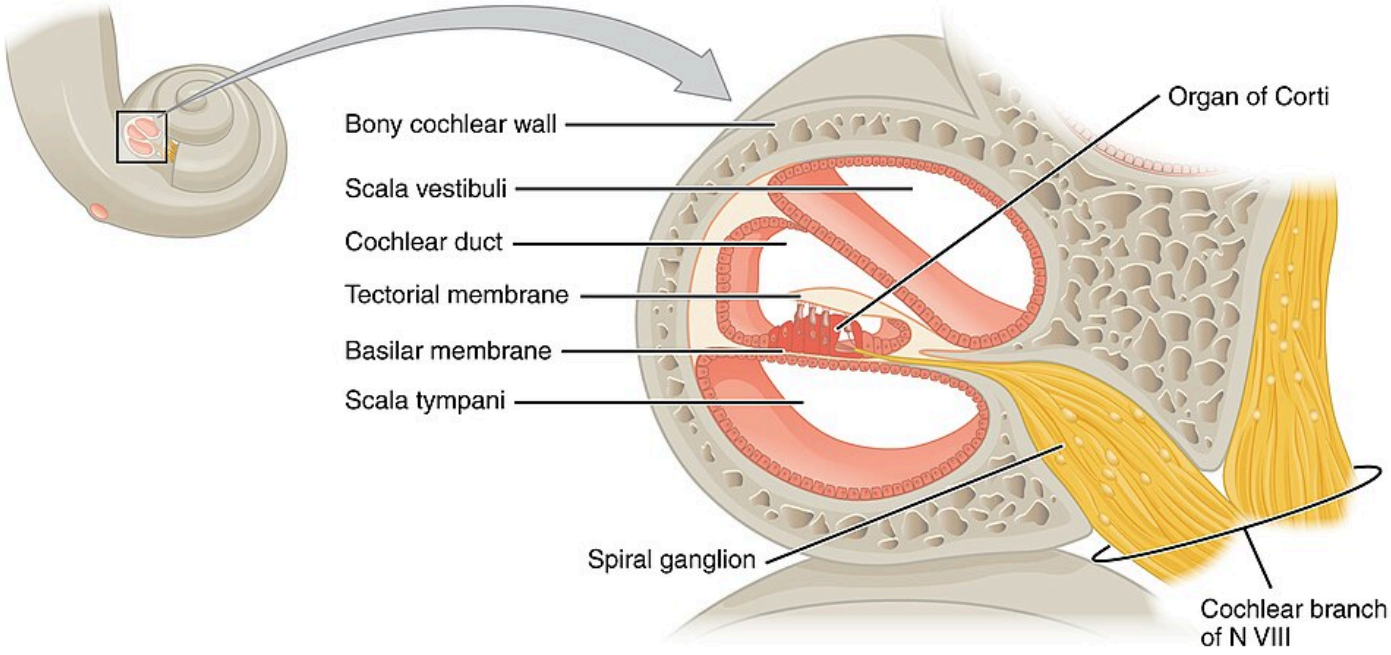


Figure 8.40 Cochlea

8. OpenStax College. (2016). *1406_Cochlea* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1406_Cochlea.jpg

9. OpenStax College. (2016). *1405_Sound_Waves_and_the_Ear* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1405_Sound_Waves_and_the_Ear.jpg

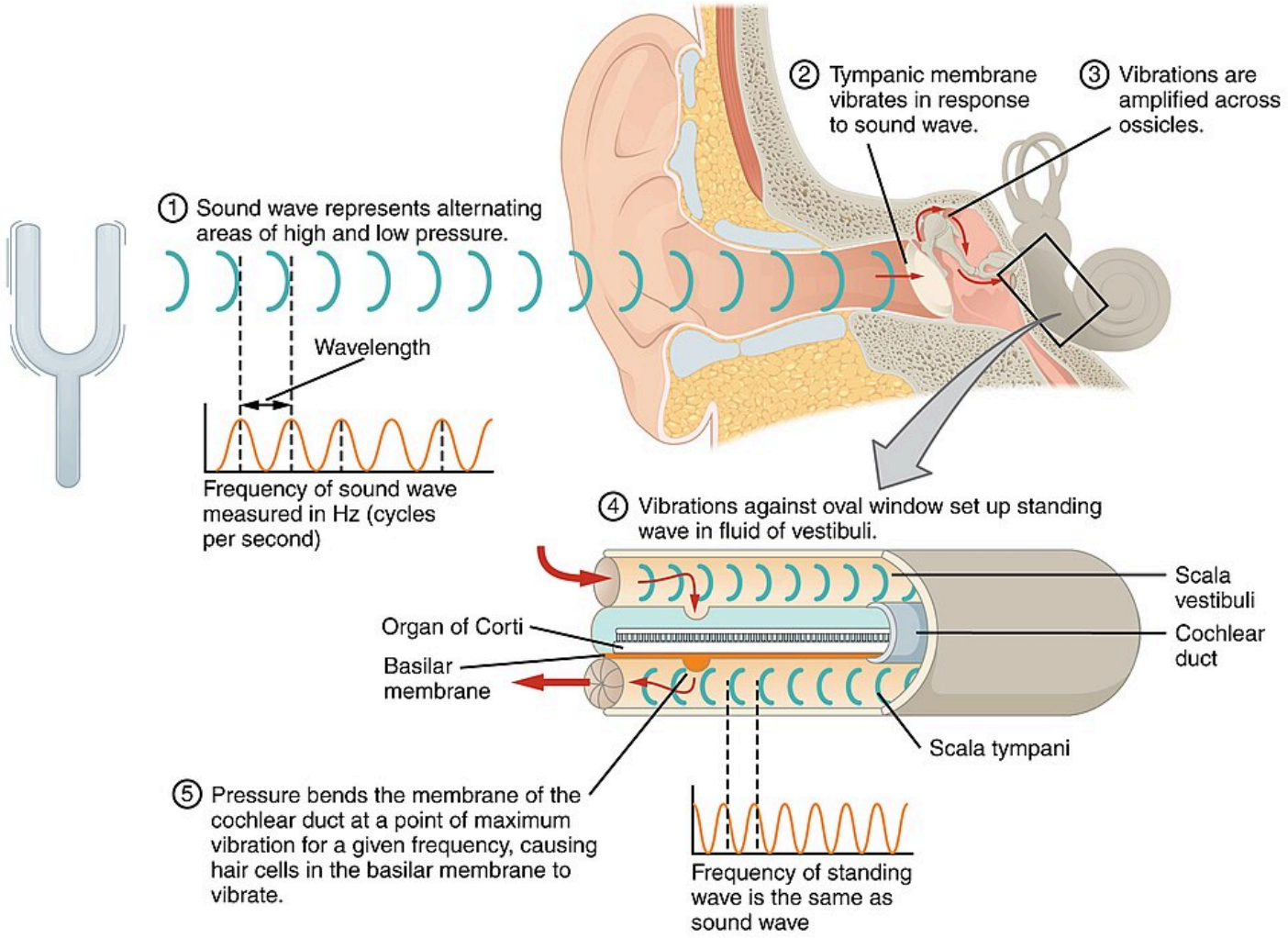


Figure 8.41 Transmission of Sound Waves to Cochlea

Inside each cochlea is a structure called the organ of Corti (or spiral organ). This structure contains mechanoreceptor cells called **hair cells**, which convert sound vibrations into nerve impulses. The hair cells found along the length of the cochlear duct are each sensitive to a particular frequency, allowing the cochlea to separate auditory stimuli by frequency, just as a prism separates visible light into its component colors. Our ability to detect differences in pitch, loudness, and localization of sound can be attributed to the deflections in our hair cells. The cochlea encodes auditory stimuli for frequencies between 20 and 20,000 Hz, which is the range of sound that human ears can detect. These delicate hair cells aren't replaced if they're damaged or lost as we age. See Figure 8.42[10] for an illustration of a hair cell.

10. OpenStax College. (2016). *1407_The_Hair_Cell* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:1407_The_Hair_Cell.jpg

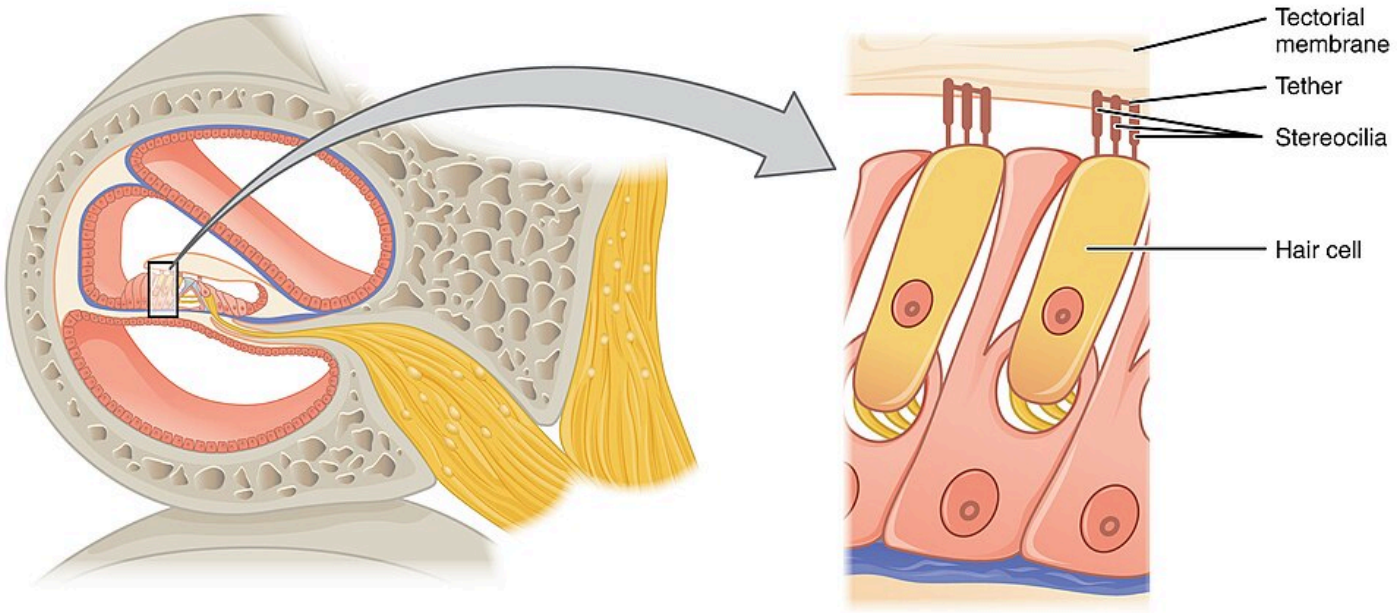


Figure 8.42 Hair Cell

Equilibrium (Balance)

Along with hearing, the inner ear is responsible for **equilibrium**, the sense of balance. A similar mechanoreceptor—hair cells —senses head position, head movement, and whether our bodies are in motion. These cells are located within the vestibule of the inner ear. Head position is sensed by specialized structures called the **utricle** and **saccule**. Movement of the head is detected by the semicircular canals positioned in different planes so they can sense rotational motion in all directions. See Figure 8.43[11] for an illustration of the internal ear and the semicircular canals.

11. Blausen.com staff. (2014). *Blausen_0329_EarAnatomy_InternalEar* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Blausen_0329_EarAnatomy_InternalEar.png

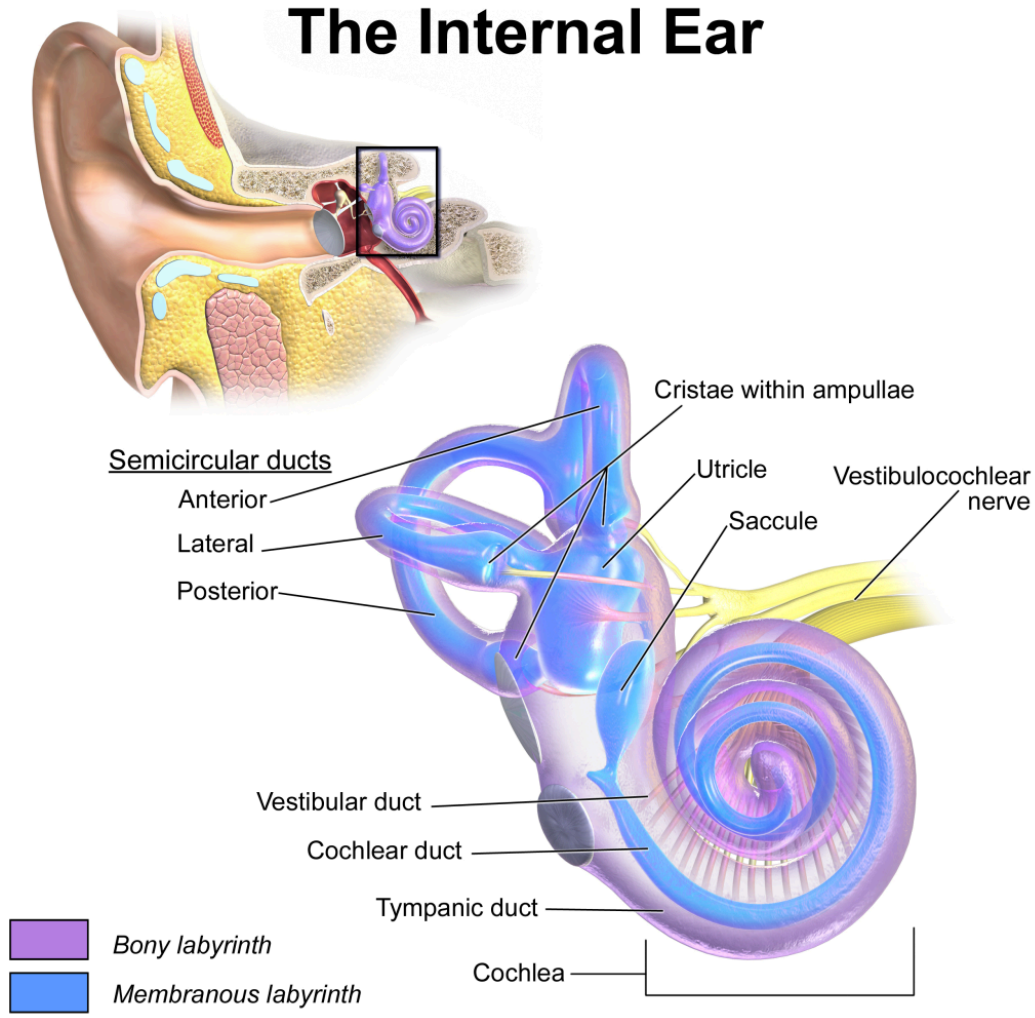


Figure 8.43 Internal Ear and Semicircular Canals

Vision

Vision is the special sense of sight that is based on light stimuli entering through the eyes. The eyes are located within the bony orbits in the skull, which protect and anchor the soft tissues of the eye. See Figure 8.44[12] for an illustration of the eye orbit. The eyelids, with lashes at their leading edges, help to protect the eye from abrasions by blocking dirt and debris that may land on the surface of the eye. The inner surface of each lid is lined with a thin membrane known as the **palpebral conjunctiva**. The conjunctiva extends over the white areas of the eye (the sclera), connecting the eyelids

12. OpenStax College. (2013). *1411_Eye_in_The_Orbit* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1411_Eye_in_The_Orbit.jpg

to the eyeball. Tears are produced by the **lacrimal gland**, located just inside the orbit, superior and lateral to the eyeball. Tears produced by this gland flow over the conjunctiva and exposed surface of the eyeball, washing away foreign particles. The tears then flow into the **lacrimal duct** in the medial corner of the orbit that drains tears into the nasal cavity.

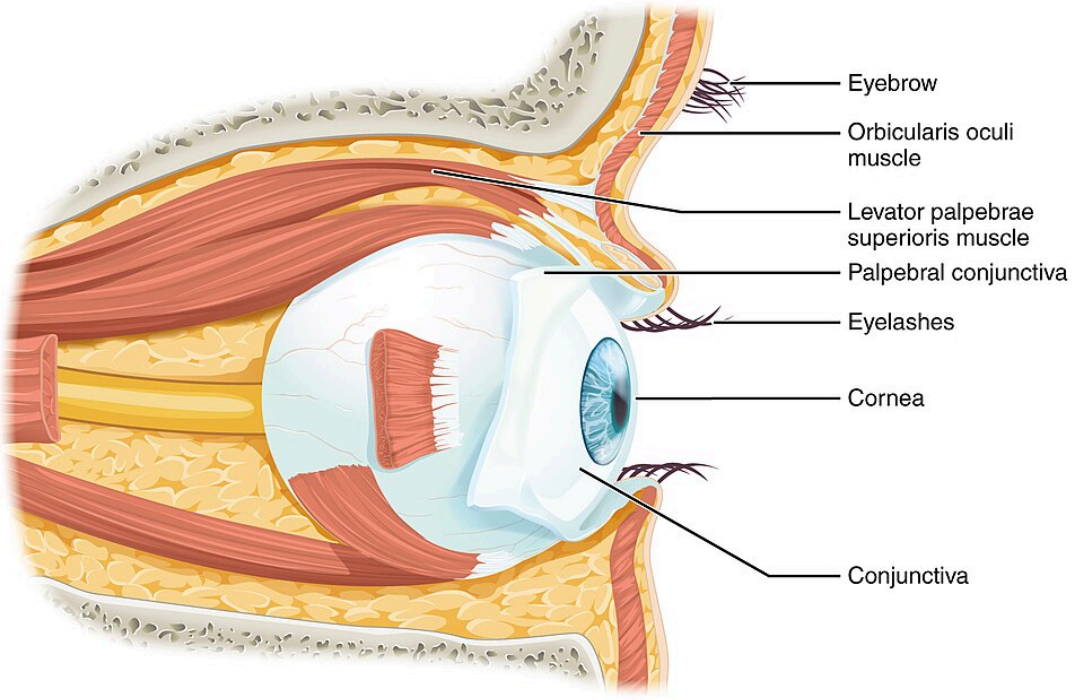


Figure 8.44 Eye Orbit

Movement of the Eye

Movement of the eye within the orbit is accomplished by the contraction of six **extraocular** muscles that originate from the bones of the orbit and insert into the surface of the eyeball. Four of the muscles arranged around the eye are named for their locations. They are the **superior rectus**, **medial rectus**, **inferior rectus**, and **lateral rectus**. The other two are the **inferior oblique** and **superior oblique**. See Figure 8.45[13] for an illustration of the extraocular muscles. When each of these muscles contracts, the eye moves toward the contracting muscle. For example, when the superior rectus contracts, the eye rotates to look up. The extraocular muscles are innervated by three cranial nerves

13. OpenStax College. (2013). *1412_Extraocular_Muscles* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1412_Extraocular_Muscles.jpg

– the abducens, oculomotor, and trochlear nerves. These cranial nerves connect to the brain stem, which coordinates eye movements.

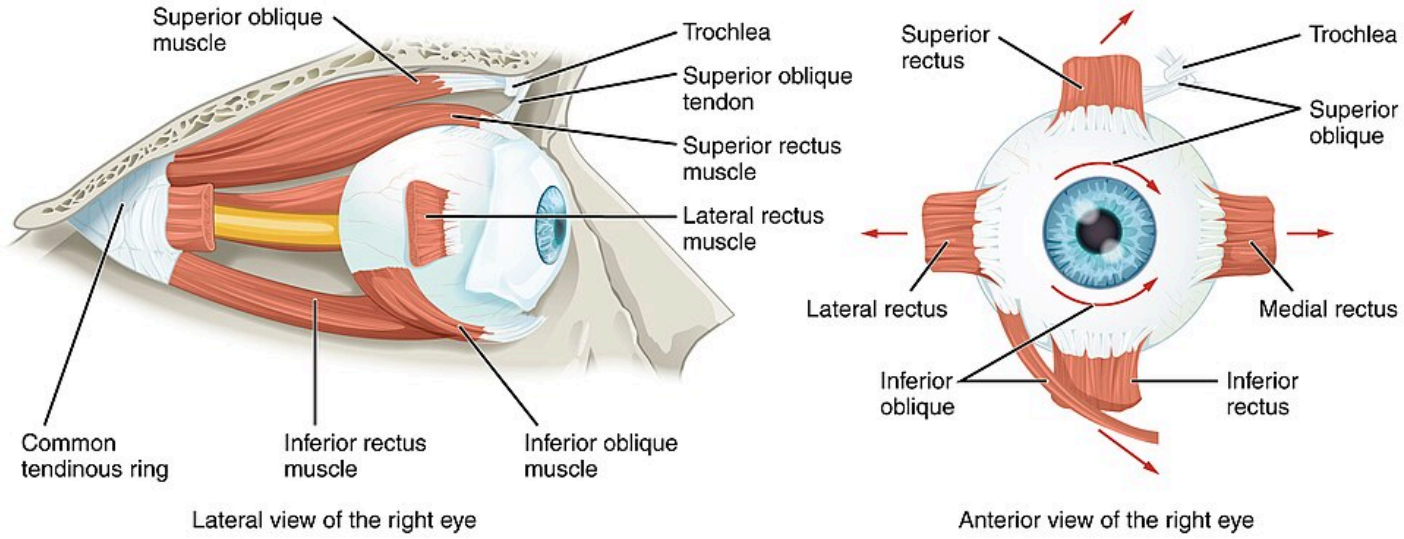


Figure 8.45 Extraocular Muscles

Tunics (Layers) of the Eye

The eye itself is a hollow sphere composed of three layers of tissue. The outermost layer is the **fibrous tunic**, which includes the white **sclera** and clear **cornea**. The transparent cornea covers the anterior part of the eye. It allows light to enter, and along with the **lens**, focuses light onto the retina. The sclera is a tough protective structure. The middle layer of the eye is the **vascular tunic (or uvea)**, which is mostly composed of the choroid, ciliary body, and iris. The **choroid** is a layer of highly vascularized connective tissue that provides a blood supply to the eyeball. The choroid is posterior to the **ciliary body**, a muscular structure that is attached to the lens by suspensory ligaments, or **zonule fibers**. These two structures bend the lens, allowing it to focus light on the back of the eye. Overlaying the ciliary body and visible in the anterior eye is the **iris**—the colored part of the eye. The **iris** is a smooth muscle that dilates or constricts the **pupil**, which is the black hole in the center of the iris that allows light to enter the eye. The iris constricts the pupil in response to bright light and dilates the pupil in response to dim light. The innermost layer of the eye is the **retina** or **neural tunic**, which contains the rods and cones responsible for photoreception.

The eyeball is divided into two cavities: the anterior cavity and the posterior cavity. The anterior cavity is the space between the cornea and lens, including the iris and ciliary body. It is filled with a thin, watery fluid called the **aqueous humor** that is constantly being refreshed. The posterior cavity is the space behind the lens that extends to the

posterior side of the interior eyeball, where the retina is located. The posterior cavity is filled with a more viscous or jelly-like fluid called the **vitreous humor**. The vitreous humor is produced during fetal eye development and is never replaced or refreshed.

The retina is composed of photoreceptors called rods and cones that generate a nerve impulse when stimulated by light energy. These nerve impulses are sent to the brain through the **optic nerve**. The area of the retina where the optic nerve leaves the eye is called the **optic disc** or "blind spot." Because the optic nerve passes through the retina, there are no photoreceptors at the very back of the eye, where the optic nerve begins. This creates a blind spot in the retina and a corresponding blind spot in our visual field. See Figure 8.46[14] for an illustration of the structures of the eye.

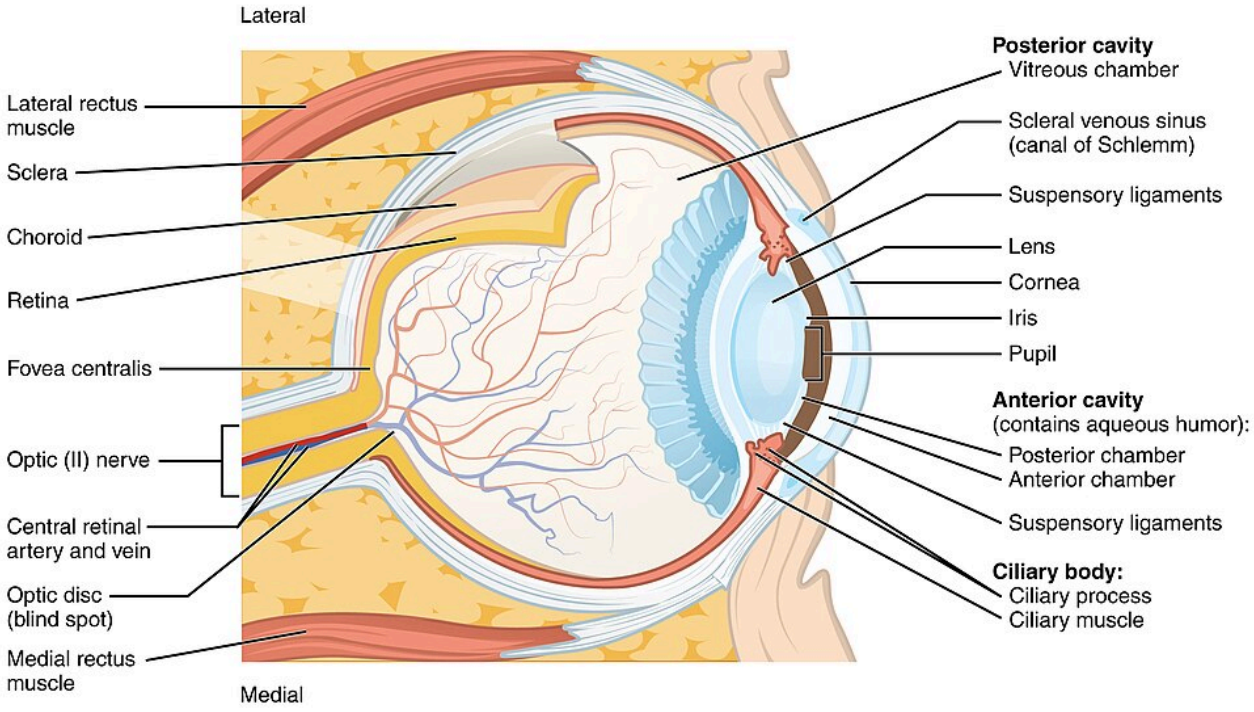


Figure 8.46 Structures of the Eye

Photoreceptors (rods and cones) in the retina are located behind axons, cells, and retinal blood vessels. A significant amount of light is absorbed by these structures before the light reaches the photoreceptor cells. Located in the exact center of the retina is the macula lutea, an area containing a large number of cones providing increased visual clarity. In this, the macula lutea is a small area known as the **fovea** (fovea centralis). At the fovea, the retina only contains cones, and there are no blood vessels. Therefore, visual

14. OpenStax College. (2013). *1413_Structure_of_the_Eye* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1413_Structure_of_the_Eye.jpg

acuity, or the sharpness of vision, is greatest at the fovea. The difference in **visual acuity** between the fovea and peripheral retina is easily evidenced by looking directly at a word in the middle of this paragraph. The visual stimulus in the middle of the field of view falls on the fovea and is in the sharpest focus. Without moving your eyes off that word, notice that words at the beginning or end of the paragraph are not in focus. The images in your peripheral vision are focused by the peripheral retina and have vague, blurry edges and words that are not as clearly identified. As a result, a large part of the neural function of the eyes is concerned with moving the eyes and head so that important visual stimuli are centered on the fovea.

As previously mentioned, there are two types of photoreceptors—rods and cones. **Rods** detect shades of black and grey and do not function in bright light. Therefore, our low-light vision is grayscale. In a dark room, everything appears as a shade of gray. If you think that you can see colors in the dark, it is most likely because your brain knows what color something is and is relying on that memory.

Cones detect color and do function in bright light. In a darkened room, there is not enough light to activate cones, and vision is entirely dependent on rods. The pigments in human eyes are specialized in perceiving three different primary colors: red, green, and blue.

Videos

Watch the video "Special Senses Explained (Vision, Hearing, Taste, Smell)" below to learn more about the special senses and how the body interprets sensory information.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Watch the video “The Sense of Sight” below to learn how the eye detects light and how visual information is processed and transmitted to the brain.[15]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

15. Wisc-Online. (2018, November 15). *The sense of sight* [Video]. YouTube. https://youtu.be/boZRuSB1zNs

8.6 Disorders of the Nervous System and Sense Organs

Age-Related Macular Degeneration

Age-related macular degeneration (AMD) is an eye disease that can blur central vision. It happens when aging causes damage to the macula—the part of the eye that controls sharp, straight-ahead vision. The macula is part of the retina (the light-sensitive tissue at the back of the eye). AMD is a common condition—it's a leading cause of vision loss for older adults. AMD doesn't cause complete blindness, but losing central vision can make it harder to see faces, read, drive, or do close-up work like cooking or fixing things around the house. AMD progresses very slowly in some people and faster in others. People with early AMD may not notice vision loss for a long time, so regular eye exams are important. See Figure 8.47[1] for a simulated image of central vision loss in a person with macular degeneration compared to Figure 8.48[2] of a simulated image of normal vision.[3]

1. National Eye Institute, National Institutes of Health. (n.d.) *Eye disease simulation, age-related macular degeneration* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Eye_disease_simulation,_age-related_macular_degeneration.jpg
2. National Eye Institute, National Institutes of Health. (n.d.) *Eye disease simulation, normal vision* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Eye_disease_simulation,_normal_vision.jpg
3. National Eye Institute. (2021). *Age-related macular degeneration (AMD)*. National Institutes of Health. https://www.nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/age-related-macular-degeneration

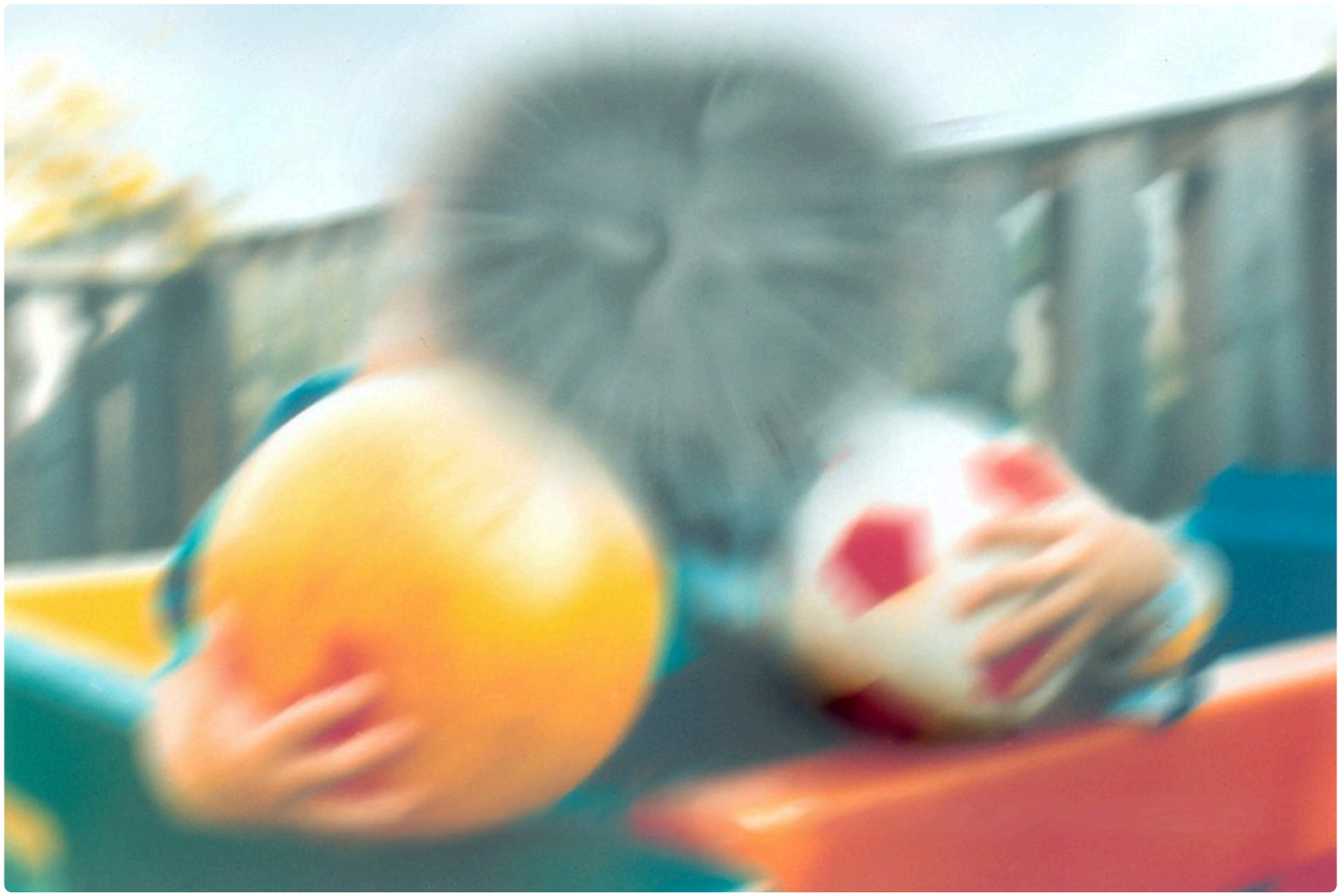


Figure 8.47 Macular Degeneration



Figure 8.48 Simulated Image of Normal Vision

Alzheimer's Disease

Alzheimer's disease is a type of dementia, a progressive brain disorder that slowly destroys memory and thinking skills, and eventually, the ability to carry out the simplest tasks. Alzheimer's is the seventh leading cause of death in the United States, and more than 6 million Americans, most of them age 65 or older, have Alzheimer's disease. The risk for developing Alzheimer's disease increases as a person ages, with people over age 85 at the highest risk. Alzheimer's disease causes abnormal buildup of proteins that form amyloid plaques and tau tangles that damage neurons and impair communication

between neurons, which results in brain shrinkage. See Figure 8.49[4] for an illustration of a healthy brain compared with the brain of a person with severe Alzheimer's disease. Early symptoms of Alzheimer's disease include short-term memory loss, wandering and getting lost, trouble handling money and paying bills, repeatedly asking the same questions, and changes in personality and behavior. There is no cure for Alzheimer's disease, but medications can help slow the progression of the disease.[5]

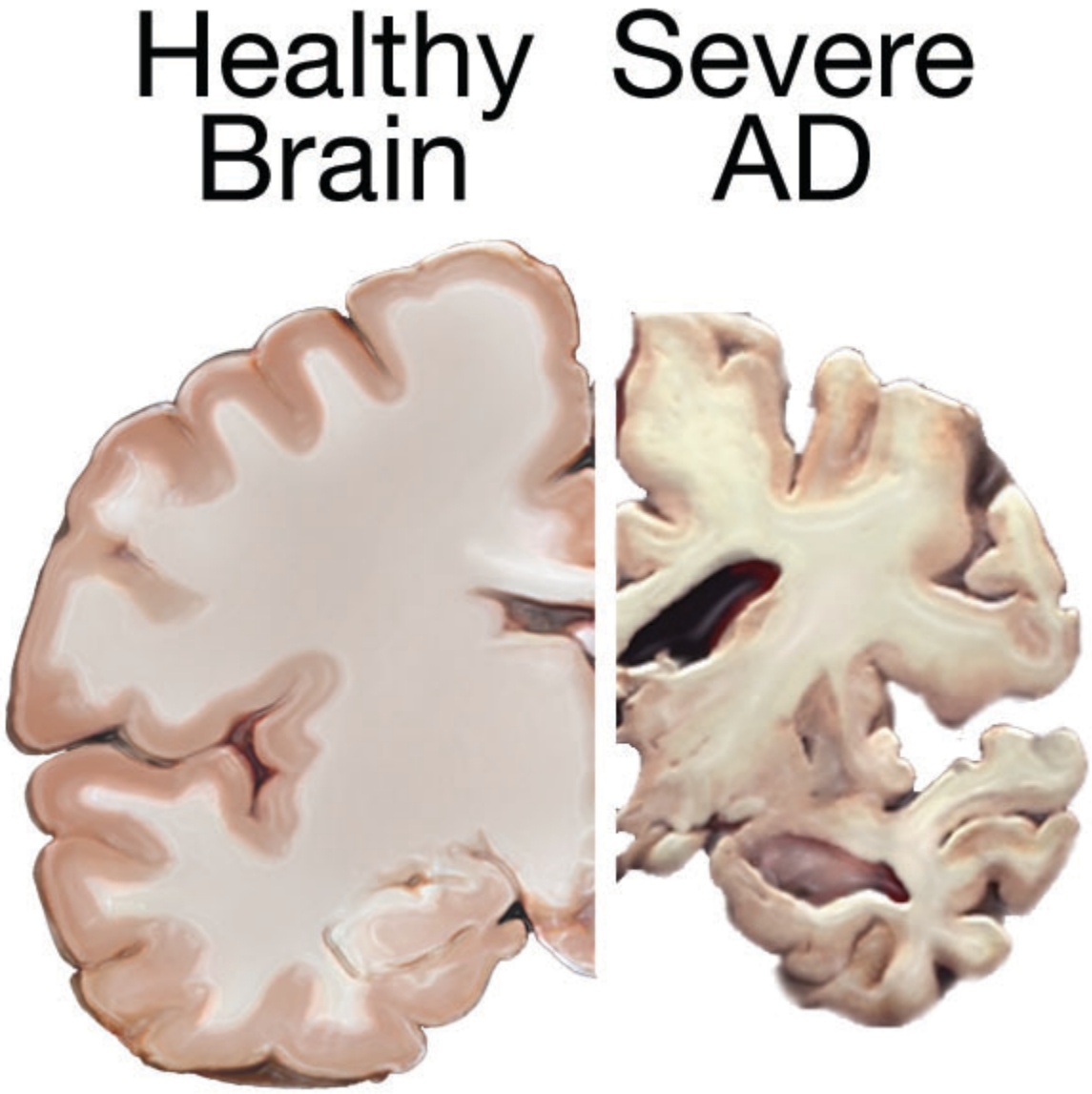


Figure 8.49 Comparison of a Healthy Brain to a Brain with Severe Alzheimer's Disease

4. National Institute on Aging, National Institutes of Health. (2008). *Healthy_Brain_and_Severe_AD_Brain* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Healthy_Brain_and_Severe_AD_Brain_(24239522109).jpg

5. National Institute on Aging. (2023). *Alzheimer's disease fact sheet.* National Institutes of Health. https://www.nia.nih.gov/health/alzheimers-and-dementia/alzheimers-disease-fact-sheet

Anosmia

Anosmia is the loss of the sense of smell that can be caused by many viral respiratory illnesses or the result of the olfactory nerve being severed, usually due to blunt force trauma to the head. The sensory neurons of the olfactory epithelium have a limited life span of approximately one to four months, and new ones are made on a regular basis. The ability of these neurons to be replaced is lost with age. Age-related anosmia is not the result of impact trauma to the head, but rather a slow loss of the sensory neurons with no new neurons formed to replace them. As the replacement of olfactory neurons declines with age, anosmia can set in. Without the sense of smell, many sufferers complain of food tasting bland. Often, the only way to enjoy food is to add seasoning that can be sensed on the tongue, which usually means adding table salt. The problem with this, however, is that this increases sodium intake, which can lead to cardiovascular problems through water retention and the associated increase in blood pressure.

Anxiety

Everyone can feel anxious at times, but people with anxiety disorders often experience fear and worry that is both intense and excessive. These feelings are typically accompanied by physical tension and other behavioral and cognitive symptoms. These symptoms can cause significant distress and interfere with daily activities such as family life, social interactions, and school or work. An estimated 4% of the global population currently experiences an anxiety disorder, making anxiety disorders the most common of all mental disorders. Although effective treatments for anxiety disorders exist, only about one in four people with anxiety receive treatment because of barriers to care. Barriers to care include a lack of awareness that anxiety is a treatable health condition, a lack of investment in mental health services, a lack of trained health care providers, and social stigma.[6]

Ataxia

Ataxia is a neurological condition characterized by the loss of muscle control,

6. World Health Organization. (2023). *Anxiety disorders*. https://www.who.int/news-room/fact-sheets/detail/anxiety-disorders

resulting in difficulties with balance, coordination, and movement. Ataxia is often the result of exposure to external substances, focal lesions, or a genetic disorder. Focal lesions include strokes affecting the cerebellar arteries, tumors that may impinge on the cerebellum, trauma to the back of the head and neck, or multiple sclerosis. Alcohol intoxication or drugs such as ketamine can cause ataxia that is typically reversible. Mercury in fish can cause ataxia as well. Hereditary conditions can lead to degeneration of the cerebellum or spinal cord, as well as malformation of the brain, or the abnormal accumulation of copper seen in Wilson's disease.

Bell's Palsy

Bell's palsy is a neurological disorder that causes paralysis or weakness on one side of the face. Bell's palsy results from a problem in the seventh cranial nerve, also called the facial nerve, which connects the brain to the muscles that control facial expression. The seventh cranial nerve also affects taste and ear sensation.[7] Bell's palsy is the most common cause of facial paralysis. Symptoms of Bell's palsy include sudden weakness or paralysis on one side of the face, a drooping eyebrow and mouth, drooling from one side of the mouth, and difficulty closing one eyelid, which causes eye dryness. Most often, these symptoms lead to significant facial distortions. See Figure 8.50[8] for an image of a person with Bell's palsy.

7. National Institute of Neurological Disorders and Stroke. (2025). *Bell's palsy*. National Institutes of Health. https://www.ninds.nih.gov/health-information/disorders/bells-palsy

8. Heilman, J. (2010). *Bellspalsy* [Photograph]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Bellspalsy.JPG



Figure 8.50 Bell's Palsy

People living with Bell's palsy also may develop facial pain or abnormal sensations, excessive tears in one eye, problems with taste, sensitivity to loud noises, pain around the jaw and behind the ear, and/or problems eating or drinking. In rare cases, Bell's palsy can affect both sides of the face. Symptoms appear suddenly over a 48- to 72-hour period

and generally begin to improve after a few weeks. The symptoms vary from person to person and can be mild to severe. People with Bell's palsy usually recover some or all facial function within a few weeks to 6 months. Sometimes, facial weakness may last longer or be permanent.[9]

Cataract

A **cataract** results when the lens of the eye or its attached membrane becomes cloudy or opaque due to the breakdown of proteins in the lens. When this occurs, light has difficulty passing through the lens and cannot focus on the retina. See Figure 8.51[10] for an image of a cloudy lens that occurs in people with cataracts.

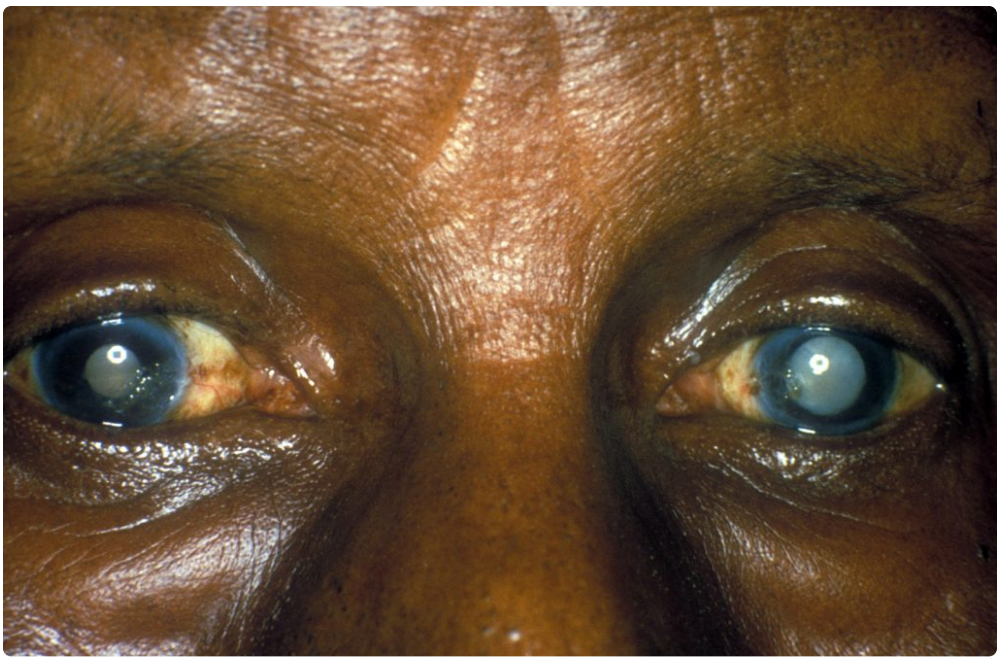


Figure 8.51 Cloudy Lens in Bilateral Cataracts

Although cataracts primarily affect older adults, they can affect those of all ages. In younger clients, cataract development is often associated with trauma to the eye. Other than age, other risk factors for the development of a cataract are dietary deficiencies,

9. National Institute of Neurological Disorders and Stroke. (2025). *Bell's palsy.* National Institutes of Health. https://www.ninds.nih.gov/health-information/disorders/bells-palsy
10. Community Eye Health. (1998). *Bilateral advanced cataracts* [Photograph]. Flickr. CC BY-NC 2.0. https://www.flickr.com/photos/communityeyehealth/8407832849

the use of alcohol or tobacco, the presence of diabetes mellitus, or other ocular disorders such as glaucoma.

One eye or both can be affected, and the severity of vision loss can vary. However, a cataract is a progressive disease that will eventually lead to blindness once the cataract matures (the lens of the eye becomes completely obscured). See Figure 8.52[11] for a simulated image of blurred vision of a person with cataracts.



Figure 8.52 Cataracts

11. National Eye Institute, National Institutes of Health. (2010). *Eye_disease_simulation,_cataract* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Eye_disease_simulation,_cataract.jpg

Other signs and symptoms that may be present, depending on cataract severity, are as follows:

- Decreased visual acuity
- Blurred and/or double vision
- Rainbow colored halos are seen around objects
- Increased effects of glare (from headlights or sunlight) on vision
- Changes in color vision in which objects appear faded or yellowish
- Visible clouding of the lens

Treatment of a cataract depends on the severity of the disorder. In early stages, treatment may consist of corrective lenses and/or medications, but once the opacity of the cataract starts to interfere with activities of daily living, surgery is usually recommended.[12]

Color Blindness

Color blindness, also known as color deficiency, is when colors are seen abnormally. Color blindness is usually a genetic condition that is present at birth, in which cones in the retina are completely or partially absent. Color blindness can also be acquired from trauma to the eye and is also associated with specific disorders such as alcoholism and diabetes.

Symptoms can range in severity and include the following:

- Issues with seeing colors or color brightness
- Inability to distinguish between similar shades of colors, such as red and green or blue and yellow
- Difficulty learning colors in children

Color blindness can be diagnosed by a test where clients are shown patterns consisting of dots in a variety of colors. Clients with color blindness are unable to

12. Nizami, A. A., Gurnani, B., & Gulani, A.C. (2024). *Cataract.* StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK539699/

decipher the number or shape that is present in the dots. See Figure 8.53[13] for an example of this type of test.

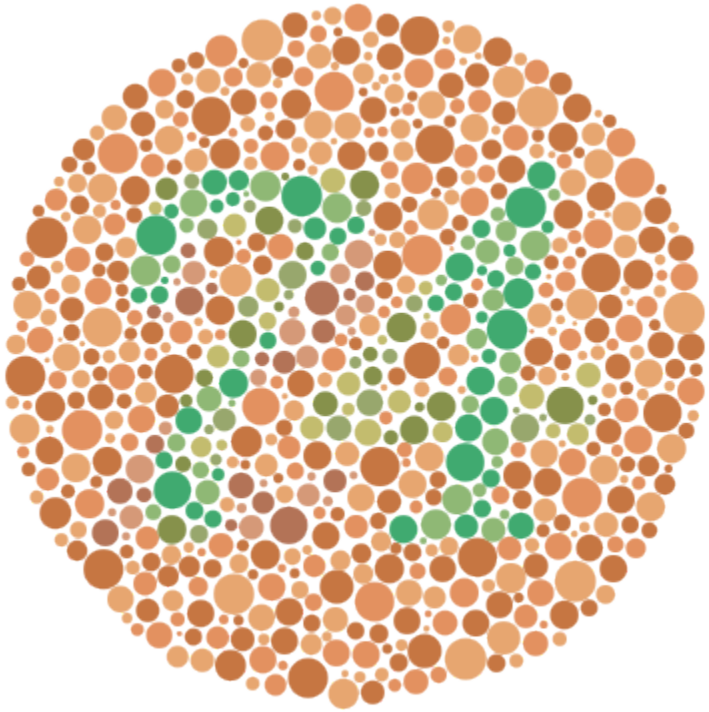


Figure 8.53 The Ishihara Test Is Used to Diagnose Color Blindness

Congenital color blindness cannot be cured. However, special lenses are available to help the client distinguish colors. If color blindness is an acquired condition, treating the underlying condition may improve color vision.[14]

Concussion

A **concussion** is a mild traumatic brain injury that affects brain function. Effects are often short-term and can include headaches and trouble with concentration, memory, balance, mood, and sleep. Concussions are usually caused by an impact to the head or body that is associated with a change in brain function. Not everyone who experiences

13. Pbrks. (2021). *Ishihara_9* [Image]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Ishihara_9.svg

14. Turbert, D. (2024). *What is color blindness?* American Academy of Ophthalmology. https://www.aao.org/eye-health/diseases/what-is-color-blindness

a blow to the body or head has a concussion. Some concussions cause the person to lose consciousness, but most do not. Falls are the most common cause of concussions. Concussions are also common among athletes who play contact sports, such as football or soccer. Most people recover fully after a concussion.[15]

Deafness

Hearing loss affects people of all ages and can be caused by many different factors. The three basic categories of hearing loss are sensorineural hearing loss, conductive hearing loss, and mixed hearing loss, which is a combination of both types:[16]

Sensorineural Hearing Loss: Sensorineural hearing loss occurs when the inner ear or the vestibulocochlear nerve becomes damaged. This loss generally occurs when some of the hair cells within the cochlea are damaged. Sensorineural loss is the most common type of hearing loss. It can be a result of aging, exposure to loud noise, injury, disease, certain drugs, or an inherited condition. Hearing aid devices can be beneficial for people with sensorineural hearing loss. Individuals with moderate to severe sensorineural hearing loss who do not have adequate benefit from hearing aids may have cochlear implant surgery. A cochlear implant electrically stimulates the cochlea, which stimulates the nerve that carries sound to the brain.[17]

Conductive Hearing Loss: Conductive hearing loss occurs in the outer or middle ear, where sound waves are not able to carry all the way through to the inner ear. Sound may be blocked by earwax or a foreign object located in the ear canal; the middle ear space may be impacted with fluid, infection, or a bone abnormality; or the eardrum may have been injured. In some people, conductive hearing loss may be reversed through medical or surgical intervention. Conductive hearing loss is most common in children who may have recurrent ear infections or who insert foreign objects into their ear canals.

15. Mayo Clinic. (2024). *Concussion.* https://www.mayoclinic.org/diseases-conditions/concussion/symptoms-causes/syc-20355594
16. Johns Hopkins Medicine. (n.d.). *Types of hearing loss*. https://www.hopkinsmedicine.org/health/conditions-and-diseases/hearing-loss/types-of-hearing-loss
17. Bowditch, S. (n.d.). *Cochlear implants*. John Hopkins Medicine. https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/cochlear-implants

Depression

Depression is a serious mental illness that causes persistent feelings of sadness and affects how the person acts and perceives the world. Nearly three out of ten people have been diagnosed with major depressive disorder. Symptoms of depression can appear differently in each person and can vary from mild to severe. These symptoms can include the following:[18]

- Feeling sad, irritable, empty, and/or hopeless
- Losing interest or pleasure in activities formerly enjoyed
- A significant change in appetite (eating much less or more than usual) and/or weight (notable loss or gain unrelated to dieting)
- Sleeping too little or too much
- Decreased energy or increased tiredness or fatigue
- Increase in purposeless physical activity (e.g., inability to sit still, pacing, hand-wringing) or slowed movements or speech that are severe enough to be observable by others
- Feeling worthless or excessively guilty
- Difficulty thinking or concentrating, forgetfulness, and/or difficulty making minor decisions
- Thoughts of death, suicidal ideation, or suicide attempts

Most people diagnosed with depression can benefit from medication, psychotherapy, or both.[19]

If you or someone you know is experiencing symptoms of depression and needs help, call or text 988, or visit the **988 Suicide & Crisis Lifeline website**.

18. Onyemaechi, C. (n.d.). *Depression*. American Psychiatric Association. https://www.psychiatry.org/patients-families/depression

19. Mayo Clinic. (2022). *Depression*. https://www.mayoclinic.org/diseases-conditions/depression/symptoms-causes/syc-20356007

Guillain-Barré Syndrome

Guillain-Barré (pronounced gee-YAN bah-RAY) syndrome is an autoimmune disorder where the immune system mistakenly attacks some peripheral nerves. This damage interferes with the transmission of signals, leading to muscle weakness and other symptoms. Symptoms typically last a few weeks, with most individuals recovering without long-term, severe neurological complications. The first symptoms of Guillain-Barré syndrome include weakness or tingling sensations that start in the legs and can spread to the arms and face. For some people, these symptoms can lead to paralysis of the legs, arms, or muscles in the face. In approximately one-third of people, the chest muscles are affected, making it hard to breathe. Most people recover fully from even the most severe cases of Guillain-Barré syndrome, although some continue to experience weakness.[20]

Encephalitis

Encephalitis is inflammation of the brain that can be caused by viral or bacterial infections, or by a person's immune system mistakenly attacking brain cells. Viruses that can lead to encephalitis can be spread by insects such as mosquitoes and ticks. When inflammation is caused by an infection in the brain, it's known as infectious encephalitis, and when it's caused by the immune system attacking the brain, it's known as autoimmune encephalitis. Most people with infectious encephalitis initially have flu-like symptoms, such as headache, fever, achy muscles or joints, fatigue, or weakness. These symptoms are followed by more serious symptoms over a period of hours to days, such as stiff neck, confusion, agitation or hallucinations, seizures, loss of feeling or the ability to move certain areas of the face or body, trouble with speech or hearing, and loss of consciousness, including coma. Encephalitis can be deadly, so early diagnosis and treatment are important.[21]

20. World Health Organization. (2023). *Guillian-Barré syndrome*. https://www.who.int/news-room/fact-sheets/detail/guillain-barr%C3%A9-syndrome

21. Mayo Clinic. (2024). *Encephalitis*. https://www.mayoclinic.org/diseases-conditions/encephalitis/symptoms-causes/syc-20356136

Epilepsy

Epilepsy is a neurological disorder characterized by recurrent seizures that are caused by abnormal electrical activity in the brain. There is a wide variety of symptoms associated with seizures, ranging from the person staring blankly, rapid jerking of their arms or legs, or losing consciousness. Epilepsy is diagnosed in people who have had at least two unprovoked seizures at least 24 hours apart. Seizures are treated with medications, medical procedures, and sometimes surgery. In some cases, epilepsy resolves on its own.[22]

Glaucoma

Glaucoma is a chronic, progressive eye disease that leads to vision loss due to damage to the optic nerve. A major risk factor for glaucoma is excessive eye pressure caused by an abnormality in the eye's drainage system that causes fluid to build up inside the eye, resulting in excessive pressure that damages the optic nerve. Damage to the optic nerve causes loss of peripheral vision that, if left untreated, slowly impacts central vision. Once vision is lost, it cannot be recovered. See Figure 8.54[23] for a simulated image of peripheral vision loss in a person with glaucoma.[24]

22. Mayo Clinic. (2023). *Epilepsy*. https://www.mayoclinic.org/diseases-conditions/epilepsy/symptoms-causes/syc-20350093

23. National Eye Institute, National Institutes of Health. (2010). *Eye disease simulation, glaucoma* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Eye_disease_simulation,_glaucoma.jpg

24. Johns Hopkins Medicine. (n.d.). *Glaucoma*. https://www.hopkinsmedicine.org/health/conditions-and-diseases/glaucoma



Figure 8.54 Glaucoma

Huntington's Disease

Huntington's disease is a rare, progressive, genetic disease that causes deterioration of neurons in the brain and affects a person's movements, thinking ability, and mental health. Huntington's disease symptoms can develop at any time, but they often begin when people are in their 30s or 40s. If the disease develops before age 20, it's called juvenile Huntington's disease. When Huntington's develops early, symptoms can be different, and the disease may have a faster progression. Medications are available to help manage the symptoms of Huntington's disease, but cannot prevent the physical, mental, and behavioral decline caused by the disease.[25]

25. Mayo Clinic. (2024). *Huntington's disease*. https://www.mayoclinic.org/diseases-conditions/huntingtons-disease/symptoms-causes/syc-20356117

Meningitis

Meningitis is an inflammation of the meninges, the three layers of fibrous membranes that surround the CNS. Meningitis can be caused by infection, bacteria, or viruses. Bacterial meningitis is often more severe than viral meningitis and can be fatal. Fatality occurs in 5 to 40% of children and 20 to 50% of adults with bacterial meningitis. Symptoms of meningitis include fever, chills, nausea, vomiting, light sensitivity, neck stiffness, severe headache, and confusion. Some types of meningitis can be prevented with the administration of vaccines.

A lumbar puncture is used to test for meningitis. During a lumbar puncture, a needle is inserted into the lumbar region of the spinal column, through the dura mater and arachnoid membrane, and into the subarachnoid space so that cerebrospinal fluid can be withdrawn for laboratory testing. Bacterial meningitis is treated with antibiotics. A serious risk of meningitis is damage to peripheral structures because of the nerves that pass through the meninges. For example, hearing loss is a common result of meningitis.

Migraine

A **migraine** is a neurological condition consisting of recurrent headaches that are moderate to severe in intensity. A migraine can last for hours to days and can have a great impact on quality of life and the ability to complete activities of daily living. The exact pathology of migraines is complex and not completely understood, but it is thought to involve inflammatory mediators acting on pain receptors. Migraines can be triggered by a variety of factors, with some common triggers being stress, changes in hormone levels, changes in sleep, strong odors, changes in weather or temperature, missing meals, or eating foods with high levels of aspartame or tyramine. Additionally, migraines have a genetic link and are seen more commonly in women.

Migraines are classified into two main categories: migraine with and without aura. An **aura** is a change in function or onset of symptoms that precedes a migraine. Although there are a variety of auras that may be experienced by those with migraines, some potential auras are changes in vision, the presence of **paresthesia** (tingling sensations), or the loss of bodily functions such as hearing, movement, or language. The pain of a migraine is usually located on one side of the head and is usually described as pulsating or throbbing. Other common symptoms during a migraine are nausea, vomiting, and sensitivity to light and sound. After the migraine passes, most clients are fatigued and may be unable to concentrate.

Diagnosis of migraine can be done by taking a client history, completing a physical exam, and comparing signs and symptoms to established diagnostic criteria. In some instances, imaging of the brain may be completed.

The treatment of migraines consists of medications and lifestyle changes. Medications may be used to relieve pain during a migraine, relieve nausea and vomiting, or prevent migraines from occurring in the first place. Some alternative treatments are consistent exercise, yoga, avoiding triggers, and cognitive-behavioral therapy.[26]

Multiple Sclerosis

Multiple sclerosis (MS) is an autoimmune disease that causes inflammation and destruction of the myelin in the central nervous system. As the insulation around axons is destroyed, scarring in the white matter of the brain and spinal cord occurs, referred to as sclerosis. The loss of myelin disrupts the transmission of nerve impulses, leading to a variety of symptoms, ranging from mild to severe. Symptoms of MS depend on the person, the location of the damage in their nervous system, and the severity of damage to the nerve fibers. Symptoms include numbness and tingling, weakness, vision loss, loss of bladder and bowel control, and loss of the ability to walk. Many individuals with MS experience flare-ups of symptoms, followed by remissions. There is no cure for MS, but medications are used to slow the progression, prevent flare-ups, and manage the symptoms.[27]

Orthostatic Hypotension

Orthostatic hypotension, also known as postural hypotension, is a condition where blood pressure drops significantly when a person stands up, often causing dizziness, lightheadedness, or fainting. This condition can occur due to a malfunction of the autonomic nervous system that regulates involuntary body functions like heart rate and blood vessel constriction. When standing, the body normally responds to changes in blood pressure by constricting blood vessels and increasing heart rate to maintain adequate blood flow to the brain. However, in orthostatic hypotension, this

26. Pescador Ruschel, M. A., & De Jesus, O. (2024). *Migraine headache*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK560787/

27. Mayo Clinic. (2024). *Multiple sclerosis*. https://www.mayoclinic.org/diseases-conditions/multiple-sclerosis/symptoms-causes/syc-20350269

compensatory mechanism is impaired, causing blood to pool in the lower extremities and reducing blood flow to the brain. Individuals with orthostatic hypotension must take extra time when standing to allow the blood flow to their brain to adjust and prevent falls.

Otitis Media

Otitis media is inflammation or infection of the middle ear that is often caused by an upper respiratory infection (e.g., a "cold"), resulting in fluid build-up in the eustachian tubes, fever, and ear pain. Children are more likely than adults to get otitis media because their eustachian tubes are shorter, narrower, and more horizontal. Otitis media often resolves on its own, but if it does not resolve in a few days, antibiotics may be prescribed. Some children are prone to multiple ear infections that can cause hearing problems. Surgery may be performed to place a small tube through the eardrum to help drain the excess fluid and prevent recurrent infections.[28]

Parkinson's Disease

Parkinson's disease is a progressive neurological disorder that affects an individual's ability to move. It is caused by the deterioration of neurons in the brain that produce dopamine, a neurotransmitter that coordinates movement. Symptoms of Parkinson's disease include hand tremors, muscle stiffness, balance problems, slurred speech, and a slow, shuffling walk. While there's no cure for Parkinson's disease, medications can help manage symptoms. In some cases, brain surgery may be performed to help lessen symptoms.[29]

Peripheral Neuropathy

Peripheral neuropathy is weakness, numbness, and pain caused by peripheral nerve

28. Mayo Clinic. (2025). *Ear infection (middle ear)*. https://www.mayoclinic.org/diseases-conditions/ear-infections/symptoms-causes/syc-20351616

29. Mayo Clinic. (2024). *Parkinson's disease*. https://www.mayoclinic.org/diseases-conditions/parkinsons-disease/symptoms-causes/syc-20376055

damage. Common causes of peripheral neuropathy are diabetes and peripheral vascular disease. Symptoms include pain, pins-and-needles sensations, numbness, and weakness. Peripheral neuropathy decreases sensation, especially in the feet and legs, which affects a person's ability to walk and increases their risk for falls. It also makes them prone to injuries in the toes and feet that can lead to advanced infections requiring amputation. There is no cure for peripheral neuropathy, but controlling underlying conditions (like diabetes) may prevent the condition from worsening. Symptoms are managed with medications.[30]

Refractive Errors

Refractive errors are a common type of vision problem that occurs when the shape of a person's eye prevents light from focusing correctly on their retina. Refractive errors are the most common type of vision problem, with more than 150 million Americans having a refractive error. There are four common types of refractive errors: myopia, hyperopia, astigmatism, and presbyopia.[31]

Myopia (Nearsightedness)[32]: Nearsightedness makes far-away objects look blurry. It happens when the eyeball grows too long from front to back, or when there are problems with the shape of the cornea or the lens. These problems make the light focus in front of the retina, instead of on it. Nearsightedness usually starts between the ages of 6 and 14. See Figure 8.55[33] for an illustration of myopia.

30. Yale Medicine. (n.d.). *Peripheral neuropathy*. https://www.yalemedicine.org/conditions/peripheral-neuropathy
31. National Eye Institute. (2024). *Refractive errors*. https://www.nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/refractive-errors
32. National Eye Institute. (2024). *Nearsightedness (Myopia)*. https://www.nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/nearsightedness-myopia
33. National Eye Institute, National Institutes of Health. (2012). *Myopia_Diagram* [Diagram]. Wikimedia Commons. CC BY 2.0. https://commons.wikimedia.org/wiki/File:Myopia_Diagram.jpg

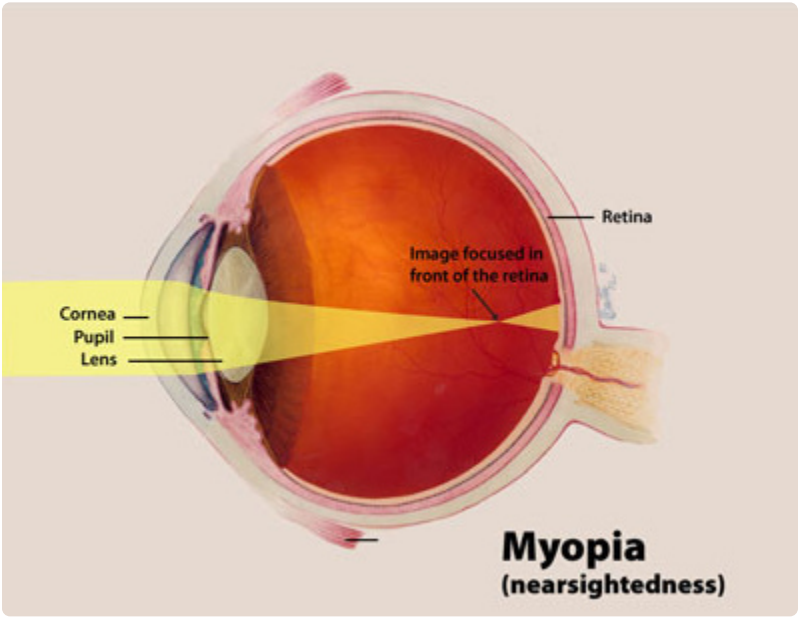


Figure 8.55 Myopia

Hyperopia (Farsightedness)[34]: Farsightedness makes nearby objects look blurry. It happens when the eyeball grows too short from front to back, or when there are problems with the shape of the cornea or lens. These problems make light focus behind the retina, instead of on it. People with farsightedness are usually born with it. See Figure 8.56[35] for an illustration of hyperopia.

34. National Eye Institute. (2024). *Farsightedness (Hyperopia).* https://www.nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/farsightedness-hyperopia

35. National Eye Institute, National Institutes of Health. (2005). *Hyperopia* [Diagram]. Wikimedia Commons. CC BY 2.0. https://commons.wikimedia.org/wiki/File:Hyperopia.gif

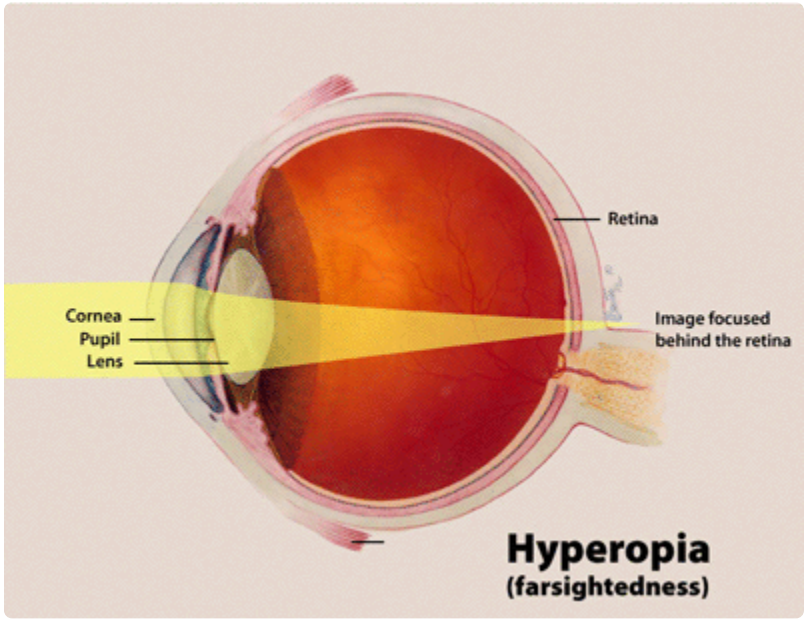


Figure 8.56 Hyperopia

Astigmatism[36] can make objects look blurry or distorted. It happens when the cornea or lens has a different shape than normal, which makes light bend differently as it enters the eye. Some people with astigmatism are born with it, but many people develop it as children or young adults. People with astigmatism often have another refractive error, like nearsightedness or farsightedness.

Presbyopia[37] makes it hard for middle-aged and older adults to see things up close. As you age, the lens in your eye gets harder and less flexible and stops focusing light correctly on the retina. Everyone gets presbyopia as they get older, usually after age 45. See Figure 8.57[38] for a simulated image of what a person with presbyopia sees without corrective lenses.

36. National Eye Institute. (2024). *Astigmatism*. https://www.nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/astigmatism

37. National Eye Institute. (2024). *Presbyopia*. https://www.nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/presbyopia

38. Colin. (2014). *Pesto ingredients – blurred* [Photograph]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Pesto_ingredients_-_blurred.jpg



Figure 8.57 Simulated Vision of a Person With Presbyopia

Schizophrenia

Schizophrenia is a serious mental illness caused by genetics, imbalanced neurotransmitters in the brain, and environmental factors. People with schizophrenia may hallucinate, meaning they see things or hear voices that aren't present. They may feel paranoid and think other people are trying to hurt them, or they may not make sense when they talk. Some people with schizophrenia lack insight or awareness of their disorder and do not think they need treatment. If untreated, this disorder can make it hard for a person to take care of themselves or keep a job and may result in homelessness. Symptoms of schizophrenia usually start between the ages of 16 and 30. There is no cure for schizophrenia, but medications can help control many of the symptoms. Additional treatments include psychotherapy and skills teaching.[39]

39. MedlinePlus [Internet]. (2024). *Schizophrenia*. https://medlineplus.gov/schizophrenia.html

Sciatica

Sciatica refers to pain that travels along the sciatic nerve from the buttocks and down the back of the leg. Sciatica most often happens when a herniated disk or an overgrowth of bone puts pressure on the lumbar spine nerve roots, causing inflammation, pain, and possible numbness in the affected leg. Pain often resolves with self-care measures, medications, and physical therapy. However, severe sciatica associated with leg weakness or bowel or bladder changes may require surgery.[40]

Stroke (Cerebrovascular Accident)

The supply of blood to the brain is crucial to its ability to perform many functions. Without a steady supply of oxygen and blood glucose, the nervous tissue in the brain cannot maintain its extensive electrical activity, and neurological function is compromised. The medical term for disruption of blood supply to the brain is a **cerebrovascular accident (CVA)**, commonly called a **stroke**. There are two main types of strokes: ischemic and hemorrhagic. **Ischemic strokes** are caused by a blockage in an artery in the brain from a blood clot or embolism. When blood cannot travel through the artery, the affected brain tissue is deprived of oxygen and glucose. **Hemorrhagic strokes** result from bleeding in the brain due to a ruptured blood vessel. A third type, a transient ischemic attack (TIA), also known as a "mini-stroke," involves a temporary interruption of blood flow to the brain without causing permanent damage. Although temporary, TIAs are warning signs of an impending stroke.

A stroke results in loss of very specific functions based on the location of the blocked artery or ruptured blood vessel. For example, loss of blood flow to specific regions of the cerebral cortex can cause a person to lose the ability to voluntarily move a specific region of the body, speak, swallow, or recognize faces. The mnemonic "**BE FAST**" helps people remember what to look for in someone who is having symptoms of a stroke:

- Balance: Is the person having sudden issues with balance or coordination?
- Eyes: Does the person have sudden changes in vision, such as blurred vision, double vision, or loss of vision?
- Face: Look at the person's face. Is one side of their face drooping? Can they make

40. Mayo Clinic. (2024). *Sciatica*. https://www.mayoclinic.org/diseases-conditions/sciatica/symptoms-causes/syc-20377435

regular facial expressions, or is one side not moving effectively?

- Arms: Ask the person to raise their arms above their head. Can the person lift one arm but not the other?
- Speech: Has the person's speech changed? Are they slurring words or having trouble saying things?
- Time: If any of these things are happening, then it is time to call for help.

A stroke can be fatal or cause a variety of long-term deficits affecting motor function, speech and language, cognitive abilities, and emotional and behavioral changes. These deficits can impact a person's ability to perform daily tasks and can significantly affect quality of life. Recovery from a stroke depends on the speed of treatment and severity of the blockage or bleed. Treatment is based on the cause of the stroke. An ischemic stroke may be treated with medications to break up the clot or surgery to remove the clot. Treatment for a hemorrhagic stroke may include surgical procedures to stop the bleeding. With fast treatment, a person having a stroke has increased chances for survival. Physical, occupational, and speech therapy can help victims of strokes recover and relearn many functions that were lost due to brain injury.[41]

Traumatic Brain Injuries

Head injuries, known as **traumatic brain injuries (TBIs)**, can range from mild concussions to severe brain injuries causing death. TBIs can result from various causes, including falls, motor vehicle accidents, sports injuries, and violence. Falls are most common among young children (ages 0–4 years), adolescents (15–19 years), and older adults (over 65 years). Symptoms of TBI include headache, dizziness, confusion, nausea, and loss of consciousness.

Strong blows to the skull can cause a skull fracture that may result in bleeding inside the skull with subsequent injury to the brain. The most common is a linear skull fracture, in which fracture lines radiate from the point of impact. Other fracture types include a comminuted fracture, in which the bone is broken into several pieces at the point of impact, or a depressed fracture, in which the fractured bone is pushed inward. In a contrecoup (counterblow) fracture, the bone at the point of impact is not broken; instead, a fracture occurs on the opposite side of the skull. Fractures of the occipital bone

41. American Stroke Association. (n.d.). *About stroke*. American Heart Association. https://www.stroke.org/en/about-stroke

at the base of the skull can occur in this manner, producing a basilar fracture that can damage the artery that passes through the carotid canal.

A blow to the lateral side of the head may fracture the bones of the pterion. The pterion is an important clinical landmark because a major branch of an artery that supplies blood to the layers of the brain is located underneath it. If the underlying artery is damaged, bleeding can cause the formation of a hematoma (a collection of blood) between the brain and the interior of the skull. As blood accumulates, it puts pressure on the brain. Symptoms associated with a hematoma may not be apparent immediately following the injury, but if untreated, blood accumulation continues to exert increasing pressure on the brain, which can result in death within a few hours.

Subdural Hemorrhage/Hematoma

A **subdural hematoma** occurs when a blood vessel near the surface of the brain bursts, causing blood to build up between the brain and the brain's tough outer lining called the dura mater. A subdural hematoma is a life-threatening problem because it causes increased pressure that compresses the brain and can result in loss of consciousness, paralysis, or death. Most subdural hemorrhages result from trauma to the head, such as a motor vehicle accident or severe sports injury, that damages tiny veins within the meninges. However, older adults may bleed after minor trauma like a fall, especially if they are taking medications that prevent blood from clotting.[42]

42. LeWine, H. E. (2024). *Subdural hematoma*. Harvard Health Publishing. https://www.health.harvard.edu/a_to_z/subdural-hematoma-a-to-z

8.7 Career Connections Related to the Nervous System

The nervous system includes the brain, spinal cord, nerves, and sense organs. It controls body movement, processes sensory information, supports communication, regulates many body functions, and influences thoughts, emotions, and behavior. When the nervous system is injured, affected by disease, or impacted by substance use or mental health conditions, many different professionals may help with testing, treatment, rehabilitation, and support. Careers related to the nervous system can include neurodiagnostic technologists, occupational therapy assistants, physical therapist assistants, substance use disorder counselors, and medical assistants.

Neurodiagnostic Technologist

Neurodiagnostic technologists are health care professionals who perform tests that help providers evaluate the brain, spinal cord, nerves, and muscles. They may assist with procedures such as electroencephalograms, which record electrical activity in the brain. These tests can help identify conditions such as seizures, sleep disorders, nerve problems, or other nervous system disorders.

Occupational Therapy Assistant

Occupational therapy assistants work with occupational therapists to help people participate in daily activities after injury, illness, disability, or age-related changes. This career connects to the nervous system because occupational therapy assistants may help patients recover or adapt after strokes, brain injuries, spinal cord injuries, nerve damage, or conditions that affect coordination, sensation, memory, or thinking.

Physical Therapist Assistant

Physical therapist assistants work under the direction and supervision of physical

therapists to help patients improve movement, balance, strength, and function. This career connects to the nervous system because physical therapist assistants may work with people recovering from strokes, spinal cord injuries, nerve injuries, or neurological conditions that affect walking, posture, coordination, and mobility.

Substance Use Disorder Counselor

Substance use disorder counselors support individuals who are experiencing challenges related to alcohol or drug use. This career connects to the nervous system because substances can affect brain function, behavior, decision-making, mood, and physical health. Substance use disorder counselors may provide education, support recovery planning, lead individual or group counseling sessions, and connect clients with additional services.

Medical Assistant

Medical assistants work in clinics and other health care settings where they support patient care and office procedures. In neurology, psychiatry, primary care, or rehabilitation settings, medical assistants may help room patients, collect health information, record symptoms, prepare patients for examinations, assist with basic procedures, support documentation, and communicate follow-up instructions.

Take a Closer Look

Explore careers related to the human body's nervous system on these websites.

- Neurodiagnostic technologist from ASET – The Neurodiagnostic Society
- Occupational therapy assistant from the American Occupational Therapy Association
- Physical therapist assistant from the American Physical Therapy Association
- Substance use disorder counselor from the U.S. Bureau of Labor Statistics
- Addiction counseling from NAADAC, the Association for Addiction Professionals

- Medical assistant from the American Association of Medical Assistants

8.8 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

8.9 Glossary

Abducens nerve (CN VI): Responsible for controlling the lateral rectus muscle, which moves the eye outward (abduction). (**Chapter 8.3**)

Age-related macular degeneration (AMD): An eye disease that can blur central vision. It happens when aging causes damage to the macula, the part of the eye that controls sharp, straight-ahead vision. (**Chapter 8.6**)

Alzheimer's disease: A type of dementia; a progressive brain disorder that causes abnormal buildup of proteins that form amyloid plaques and tau tangles that damage neurons and impair communication between neurons, which results in brain shrinkage. (**Chapter 8.6**)

Amygdala: Involved in long-term memory formation and emotional responses. (**Chapter 8.3**)

Anosmia: The loss of the sense of smell. (**Chapter 8.6**)

Anterior columns: Area of white matter in the spinal column between the two anterior horns of gray matter. (**Chapter 8.3**)

Anterior horn: Area of gray matter within the spinal cord that sends out motor signals to the skeletal muscles. (**Chapter 8.3**)

Anterior median fissure: The anterior midline of the spinal cord. (**Chapter 8.3**)

Aqueous humor: A thin, watery fluid found between the cornea and lens of the eye. (**Chapter 8.5**)

Arachnoid mater: A membrane of thin fibrous tissue that forms a loose sac around the CNS and is found in the middle layer of the meninges. (**Chapter 8.3**)

Arachnoid trabeculae: A thin, filamentous mesh deep to the arachnoid. (**Chapter 8.3**)

Ascending tracts: Nervous system fibers within the spinal cord columns that carry sensory information up to the brain. (**Chapter 8.3**)

Association areas: Areas of the brain's cortex found in the spaces between the primary areas for sensory and motor functions, and integrate multisensory information. (**Chapter 8.3**)

Astigmatism: A type of refractive error that causes objects to look blurry or distorted.

It happens when the cornea or lens has a different shape than normal, which makes light bend differently as it enters the eye. (Chapter 8.6)

Astrocyte: A type of neuroglia of the central nervous system. (Chapter 8.3)

Ataxia: A neurological condition characterized by the loss of muscle control, resulting in difficulties with balance, coordination, and movement; often the result of exposure to external substances, focal lesions, or a genetic disorder. (Chapter 8.6)

Audiologists: Health care professionals who diagnose, manage, and treat hearing, balance, or ear problems. (Chapter 8.7)

Audition: The sense of hearing. (Chapter 8.5)

Auditory ossicles: Three small bones in the middle called the malleus (hammer), incus (anvil), and stapes (stirrups). (Chapter 8.5)

Aura: A change in function or onset of symptoms that can precede a migraine. (Chapter 8.6)

Auricle: A large, fleshy structure on the lateral side of the head; also called the pinna or earlobe. (Chapter 8.5)

Autonomic nervous system (ANS): Responsible for involuntary control of the body to maintain homeostasis. (Chapter 8.3)

Autonomic tone: Balance between the sympathetic and parasympathetic nervous systems. (Chapter 8.4)

Axon: A fiber that emerges from the cell body and sends an electrical nerve impulse to target cells. (Chapter 8.3)

Axon terminals: Ends of axons. (Chapter 8.3)

Baroreceptors: A type of receptor that senses an increase in blood pressure in the aorta or carotid sinus. (Chapter 8.5)

Basal forebrain: Contains nuclei that are important in learning and memory. Alzheimer's disease is associated with a loss of neurons in this area. (Chapter 8.3)

Basal nuclei: Responsible for planning and coordinating movements, along with preventing or suppressing unwanted movements and regulating muscle tone. (Chapter 8.3)

BE FAST: A mnemonic to help people remember what to look for in someone who is having symptoms of a stroke; it stands for Balance, Eyes, Face, Arms, and Speech. (Chapter 8.6)

Bell's palsy: A neurological disorder that causes paralysis or weakness on one side of the face. (Chapter 8.6)

Bipolar neurons: Have two processes, which extend from each end of the cell body, opposite to each other. One is the axon, and one is the dendrite. (Chapter 8.3)

Blood-brain barrier (BBB): A physical barrier that restricts what can cross from the blood into the brain. (Chapter 8.3)

Brachial plexus: Spinal nerves C4 through T1 reorganize through this plexus to give rise to the nerves of the arms. (Chapter 8.3)

Broca's area: Responsible for the production of language or controlling the movements of muscles responsible for speech. In most people, it is located in the left frontal lobe. (Chapter 8.3)

Brodmann's areas: A system of classification developed in the early 1900s by Korbinian Brodmann to describe the anatomical distinctions within the cortex. (Chapter 8.3)

Cardiovascular control center: Heart rate, force of the heart's contraction, and blood pressure are controlled by the medulla oblongata. (Chapter 8.3)

Cataract: Results when the lens of the eye or its attached membrane becomes cloudy or opaque due to the breakdown of proteins in the lens. (Chapter 8.6)

Cauda equina: A long bundle of nerves that emerges from the end of the spinal cord and resembles a horse's tail. (Chapter 8.3)

Cell body: The main part of a neuron that contains the nucleus and most of the major organelles. (Chapter 8.3)

Central nervous system (CNS): Includes the brain and spinal cord. (Chapter 8.3)

Central sulcus: Separates the parietal lobes and the frontal lobes of the brain. (Chapter 8.3)

Cerebellum: An area of the brain attached to the brain stem; accounts for 10 percent of the brain's mass and is covered in folds and grooves like the cerebrum, and looks like a miniature version of that part of the brain. (Chapter 8.3)

Cerebral aqueduct: Area of the brain where the third ventricle opens into and then passes through the midbrain. (Chapter 8.3)

Cerebral cortex: The wrinkled outer portion of the cerebrum. (Chapter 8.3)

Cerebral hemisphere: The right and left halves (hemispheres) of the cerebrum. (Chapter 8.3)

Cerebrospinal fluid (CSF): The fluid that circulates through and around the brain and spinal cord. (Chapter 8.3)

Cerebrovascular accident (CVA): The medical term for disruption of blood supply to the brain; commonly called a stroke. (Chapter 8.3, Chapter 8.6)

Cerebrum: The iconic gray structure of the human brain that makes up most of the mass of the brain; responsible for higher neurological functions such as memory, emotion, and consciousness. (Chapter 8.3)

Cervical plexus: Composed of axons from spinal nerves C1 through C5 and branches into nerves in the posterior neck and head, as well as the phrenic nerve. (Chapter 8.3)

Chemoreceptor: A type of receptor cells that respond to chemical stimuli, such as changes in oxygen levels in the blood or molecules associated with taste and smell. (Chapter 8.5)

Choroid: A layer of highly vascularized connective tissue that provides a blood supply to the eyeball. (Chapter 8.5)

Choroid plexus: A specialized structure in the ventricles where ependymal cells come in contact with blood vessels and filter and absorb components of the blood to produce cerebrospinal fluid. (Chapter 8.3)

Ciliary body: A muscular structure that is attached to the lens of the eye by suspensory ligaments or zonule fibers. (Chapter 8.5)

Cochlea: The auditory portion of the inner ear containing structures to transmit sound stimuli. (Chapter 8.5)

Cochlear duct: A space within the auditory portion of the inner ear. (Chapter 8.5)

Cognitive abilities: Higher mental functions, such as orientation and memory, language and speech, sensorium, and judgment and abstract reasoning, occur across regions of the cerebral cortex. If a particular area of the brain becomes injured or diseased, specific cognitive abilities are affected. (Chapter 8.3)

Color blindness: Also known as color deficiency; occurs when colors are seen abnormally and is usually a genetic condition that is present at birth, in which cones in the retina are completely or partially absent. (Chapter 8.6)

Concussion: A mild traumatic brain injury that affects brain function and can include

headaches and trouble with concentration, memory, balance, mood, and sleep; usually caused by an impact to the head or body. (**Chapter 8.6**)

Conductive hearing loss: Occurs in the outer or middle ear, where sound waves are not able to carry all the way through to the inner ear. (**Chapter 8.6**)

Cones: Part of the eye that detects color and functions in bright light. (**Chapter 8.5**)

Cornea: Covers the anterior part of the eye. It allows light to enter, and along with the lens, focuses light onto the retina. (**Chapter 8.5**)

Corpus callosum: White matter deep within the cerebrum that provides the major pathway for communication between the two hemispheres of the cerebrum. (**Chapter 8.3**)

Cranial nerves: Twelve pairs of nerves attached to the brain and primarily responsible for the sensory and motor functions of the head and neck. (**Chapter 8.3**)

Craniosacral system: Another name for the parasympathetic system. (**Chapter 8.4**)

Dendrites: Receive information from other neurons at synapses. (**Chapter 8.3**)

Depression: A serious mental illness that causes persistent feelings of sadness and affects how the person acts and perceives the world. (**Chapter 8.6**)

Descending tracts: Nervous system fibers within the spinal cord columns that carry motor commands down from the brain. (**Chapter 8.3**)

Dorsal (posterior) nerve root: The posterior area of the spinal cord where axons responsible for sensory functions enter. (**Chapter 8.3**)

Dorsal (posterior) root ganglion: The most common type of sensory ganglion that has sensory endings in the periphery, such as the skin, and extends into the CNS through the dorsal nerve root. (**Chapter 8.3**)

Dura mater: The outermost layer of the meninges. (**Chapter 8.3**)

Electroconvulsive therapy (ECT): The application of electrical currents to the brain, which is typically used to treat severe depression that has not responded to other treatments. (**Chapter 8.7**)

Encapsulated ending: Refers to a type of neuron that has sensory nerve endings surrounded in connective tissue to enhance their sensitivity. (**Chapter 8.5**)

Encephalitis: An inflammation of the brain that can be caused by viral or bacterial infections or by a person's immune system mistakenly attacking brain cells. (**Chapter 8.6**)

Endoneurium: Loose connective tissue that surrounds individual axons. (Chapter 8.3)

Enteric nervous system (ENS): A division of the nervous system that controls the smooth muscle and glandular tissue in the digestive system. (Chapter 8.3)

Ependymal cell: A neuroglial cell that filters blood to make cerebrospinal fluid. (Chapter 8.3)

Epidural space: Space between the dura and the vertebrae. (Chapter 8.3)

Epilepsy: A neurological disorder characterized by recurrent seizures that are caused by abnormal electrical activity in the brain. (Chapter 8.6)

Epineurium: A layer of fibrous connective tissue that surrounds the outer surface of a nerve. (Chapter 8.3)

Equilibrium: The sense of balance. (Chapter 8.5)

Eustachian tube: Connects the middle ear to the pharynx and helps equalize air pressure across the tympanic membrane. (Chapter 8.5)

Expressive aphasia: A condition in which there is difficulty in producing speech sounds; it often leads to broken or halting speech. (Chapter 8.3)

External (outer ear): Consists of the auricle, external auditory canal, and tympanic membrane. (Chapter 8.5)

External auditory meatus: The location where the external auditory canal enters the skull. (Chapter 8.5)

Exteroceptor: A receptor that is located near a stimulus in the external environment. (Chapter 8.5)

Extraocular muscles: Eye muscles that cause movement of the eye within the orbit. (Chapter 8.5)

Facial nerve (CN VII): Controls the muscles of facial expression and taste sensations on the anterior two-thirds of the tongue and also plays a role in saliva and tear production. (Chapter 8.3)

Fascicles: Groups of axons bundled within a nerve. (Chapter 8.3)

Femoral nerve: One of the major nerves from the lumbar plexus. (Chapter 8.3)

Fibrous tunic: The outermost layer of tissue of the eye. (Chapter 8.5)

Fight-or-flight response: Controlled by the sympathetic division of the autonomic nervous system. (Chapter 8.4)

Fourth ventricle: The space between the cerebellum and the pons and upper medulla oblongata; it narrows into the central canal of the spinal cord. (Chapter 8.3)

Fovea: A small area in the macula lutea of the eye; visual acuity is greatest at this point. (Chapter 8.5)

Free nerve ending: A neuron that has dendrites embedded in tissue that receives a sensation. (Chapter 8.5)

Frontal lobes: Regions of the cerebral cortex deep to the frontal bone, which is also superior to the lateral sulcus. (Chapter 8.3)

Ganglion: In the PNS, a collection of neuron cell bodies. (Chapter 8.3)

General sense: A sense that is distributed throughout the body, such as touch or pain. (Chapter 8.5)

Glaucoma: A chronic, progressive eye disease that leads to vision loss due to damage to the optic nerve. (Chapter 8.6)

Glossopharyngeal nerve (CN IX): Responsible for taste on the posterior one-third of the tongue, sensations from the pharynx and tonsils, and helps with swallowing and saliva production. (Chapter 8.3)

Gray matter: Regions within the nervous system structures with many cell bodies and dendrites. (Chapter 8.3)

Guillain-Barré syndrome: An autoimmune disorder where the immune system mistakenly attacks some peripheral nerves. This damage interferes with the transmission of signals, leading to muscle weakness and other symptoms. (Chapter 8.6)

Gustation: The sense of taste. (Chapter 8.5)

Gustatory receptor cells: Cells found in taste buds that are responsible for taste. (Chapter 8.5)

Gyrus: A ridge on a wrinkle of the cerebral cortex. (Chapter 8.3)

Hair cells: Mechanoreceptor cells found in the ear that convert sound vibrations into nerve impulses. (Chapter 8.5)

Hemorrhagic strokes: Result from bleeding in the brain due to a ruptured blood vessel. (Chapter 8.6)

Hippocampus: Involved in long-term memory formation and emotional responses. (Chapter 8.3)

Huntington's disease: A rare, progressive genetic disease that causes deterioration

of neurons in the brain and affects a person's movements, thinking ability, and mental health. (Chapter 8.6)

Hyperopia (farsightedness): Makes nearby objects look blurry. It happens when the eyeball grows too short from front to back, or when there are problems with the shape of the cornea or lens. (Chapter 8.6)

Hypoglossal nerve (CN XII): Controls the muscles of the tongue, which are important for speech, swallowing, and food manipulation in the mouth. (Chapter 8.3)

Hypothalamus: A major region of the diencephalon; the major regulator of homeostasis and also controls temperature, appetite, thirst, and sleep. (Chapter 8.3)

Incus: Latin term for a small bone in the middle ear; also called the anvil. (Chapter 8.5)

Inferior colliculus: Inferior pair of colliculi of the midbrain's tectum; neurons within the inferior colliculus project to the thalamus, which then sends auditory information to the cerebrum for the conscious perception of sound. (Chapter 8.3)

Inferior oblique: An extraocular eye muscle that coordinates eye movements. (Chapter 8.5)

Inferior rectus: An extraocular eye muscle that coordinates eye movements. (Chapter 8.5)

Integration: The process of the central nervous system that requires the analysis of sensory information and the development of thoughts, emotions, and conscious experiences in the brain. (Chapter 8.2, Chapter 8.3)

Interneurons: Connect sensory neurons to motor neurons and are responsible for interpreting sensory information, storing information, and making decisions. Most neurons in the central nervous system are interneurons, also referred to as association neurons. (Chapter 8.3)

Interoceptor: A receptor that interprets stimuli from internal organs and tissues. (Chapter 8.5)

Iris: The colored part of the eye. (Chapter 8.5)

Ischemic strokes: Caused by a blockage in an artery in the brain from a blood clot or embolism. (Chapter 8.6)

Judgment and abstract reasoning: Refers to making sense of concepts and making appropriate decisions. (Chapter 8.3)

Kinesthesia: A general sense referring to body movement. (Chapter 8.5)

Lacrimal duct: Area of the eye responsible for draining tears into the nasal cavity. (Chapter 8.5)

Lacrimal gland: A gland that produces tears in the eye. (Chapter 8.5)

Lateral columns: The white matter on either side of the spinal cord, between the posterior horn and the anterior horn. (Chapter 8.3)

Lateral horn: Area of gray matter found in the thoracic, upper lumbar, and sacral regions; contains cell bodies of motor neurons of the autonomic nervous system. (Chapter 8.3)

Lateral rectus: An extraocular eye muscle that coordinates eye movements. (Chapter 8.5)

Lateral sulcus: Separates the temporal lobe from the other regions of the brain. (Chapter 8.3)

Lateral ventricles: Two ventricles within each cerebral hemisphere of the brain. (Chapter 8.3)

Lens: A part of the eye that focuses light rays. (Chapter 8.3)

Limbic cortex: The region of the cerebral cortex that is part of the limbic system. (Chapter 8.3)

Limbic lobe: Includes structures that are involved in emotional responses, as well as structures that contribute to memory; it has strong connections with the hypothalamus and influences the state of its activity on the basis of emotional state. (Chapter 8.3)

Limbic system: A collection of structures involved in emotion, memory, and behavior. (Chapter 8.3)

Longitudinal fissure: The large groove between the two sides of the cerebrum that separates the cerebrum into two distinct halves. (Chapter 8.3)

Lumbar plexus: Arises from all the lumbar spinal nerves and gives rise to nerves innervating the pelvic region and the anterior leg. (Chapter 8.3)

Lumbar puncture: A procedure in which a needle is inserted through the dura and arachnoid layers to withdraw cerebrospinal fluid. (Chapter 8.3)

Malleus: Latin term for a small bone in the middle ear; also called the hammer. (Chapter 8.5)

Mechanoreceptor: Senses physical stimuli, such as pressure and vibration, as well as the sensation of sound and body position (balance). (Chapter 8.5)

Medial rectus: An extraocular eye muscle that coordinates eye movements. (Chapter 8.5)

Medulla oblongata: The most inferior part of the brain stem before it transitions into the spinal cord. (Chapter 8.3)

Memory: Refers to how the brain stores and remembers information. It is a function of the temporal lobe. (Chapter 8.3)

Meninges: Membranes of the outer surface of the CNS that are composed of connective tissues. (Chapter 8.3)

Meningitis: An inflammation of the meninges; can be caused by infection, bacteria, or viruses. (Chapter 8.6)

Microglia: A type of macrophage, but they are smaller than most other neuroglia. When macrophages encounter diseased or damaged cells, they ingest and digest those cells or the pathogens that cause disease. (Chapter 8.3)

Middle ear: Part of the ear separated from the outer ear by the tympanic membrane and transmits sound waves from the tympanic membrane to the partition between the middle and inner ears through a chain of tiny bones. (Chapter 8.5)

Migraine: A neurological condition consisting of recurrent headaches that are moderate to severe in intensity. (Chapter 8.6)

Motor neurons: Neurons found in the PNS that carry information to other motor neurons, muscles, or glands; also known as efferent neurons. (Chapter 8.3)

Multiple sclerosis (MS): An autoimmune disease that causes inflammation and destruction of the myelin in the central nervous system. (Chapter 8.6)

Multipolar neurons: Any neurons that are not unipolar or bipolar. They have one axon and two or more dendrites. Most neurons in the human body are multipolar. (Chapter 8.3)

Myelin: A lipid-rich, insulating substance made from neuroglia within some axons. (Chapter 8.3)

Myelin sheath: Composed of myelin that surrounds an axon and helps increase the speed of electrical signals along the axon. (Chapter 8.3)

Myopia (nearsightedness): Makes faraway objects look blurry. It happens when the eyeball grows too long from front to back, or when there are problems with the shape of the cornea or the lens. (Chapter 8.6)

Nerve: A bundle of axons in the PNS. (Chapter 8.3)

Nerve plexus: Axons from different spinal nerves that come together and form networks of nerve fibers. (**Chapter 8.3**)

Neural tunic: Another name for the eye's retina; it contains the rods and cones responsible for photoreception. (**Chapter 8.5**)

Neuroglia: Includes a variety of cells that support the neurons in their communication activities. (**Chapter 8.3**)

Neurologist: A physician who specializes in the diagnosis and treatment of disorders and conditions related to the brain, spinal cord, nerves, and muscles. (**Chapter 8.7**)

Neurology: The study of the nervous system and the structure and function of all of its parts. (**Chapter 8.1**)

Neurons: The communicating cells of the nervous system. (**Chapter 8.3**)

Neurosurgeon: A physician who specializes in diagnosing and treating conditions that affect the nervous system. They also perform surgery and prescribe nonsurgical treatments. (**Chapter 8.7**)

Nociceptors: A type of neuron that perceives pain. (**Chapter 8.5**)

Node of Ranvier: A gap within the myelin covering an axon. (**Chapter 8.3**)

Nucleus: A collection of neuron cell bodies in the CNS. (**Chapter 8.3**)

Obturator nerve: A major peripheral nerve of the lower lumbar plexus that provides both motor and sensory innervation to the medial compartment of the thigh. (**Chapter 8.3**)

Occipital lobes: Regions of the cerebral cortex deep to the occipital bone. (**Chapter 8.3**)

Oculomotor nerve (CN III): Responsible for controlling most of the eye's movements, including pupil constriction and eyelid elevation. (**Chapter 8.3**)

Olfaction: The sense of smell. (**Chapter 8.5**)

Olfactory bulb: Part of the frontal lobe of the brain that receives impulses related to smell. (**Chapter 8.5**)

Olfactory nerve (CN I): The first cranial nerve responsible for the sense of smell. (**Chapter 8.3**)

Oligodendrocyte: The neuroglia that insulate axons with myelin in the central nervous system. (**Chapter 8.3**)

Optic disc: An area at the back of the eye in the retina where there are no photoreceptors; commonly called a “blind spot.” (Chapter 8.5)

Optic nerve (CN II): The area where nerve impulses generated by rods and cones of the eye are sent to the brain. (Chapter 8.3, Chapter 8.5)

Organs of Corti: Structures in the ear that change sound waves into neural signals. (Chapter 8.5)

Orientation: Being aware of your immediate circumstances, such as your name, date, and location; this ability occurs in the prefrontal cortex. (Chapter 8.3)

Orthostatic hypotension: Also known as postural hypotension, a condition where blood pressure drops significantly when a person stands up, often causing dizziness, lightheadedness, or fainting. (Chapter 8.6)

Osmoreceptor: Senses solute concentrations of body fluids. (Chapter 8.5)

Otitis media: An inflammation or infection of the middle ear that is often caused by an upper respiratory infection, resulting in fluid build-up in the eustachian tubes, fever, and ear pain. (Chapter 8.6)

Palpebral conjunctiva: A thin membrane that lines the inner surface of each eyelid. (Chapter 8.5)

Papillae: Raised bumps on the tongue that contain taste buds. (Chapter 8.5)

Parasympathetic division: A division of the autonomic nervous system associated with the “rest and digest” response. This division increases activities like digestion and decreases others like heart rate and blood pressure. (Chapter 8.4)

Paresthesia: Tingling sensations. (Chapter 8.6)

Parietal lobes: Regions of the cerebral cortex deep to the parietal bones. They are superior to the lateral sulcus and are directly behind the frontal lobe. (Chapter 8.3)

Parieto-occipital sulcus: Separates the parietal and occipital lobes of the brain. (Chapter 8.3)

Parkinson’s disease: A progressive neurological disorder that affects an individual’s ability to move. It is caused by the deterioration of neurons in the brain that produce dopamine. (Chapter 8.6)

Perception: Refers to the central processing of sensory stimuli into a meaningful pattern. Perception is dependent on sensation, but not all sensations are perceived. (Chapter 8.5)

Perineurium: Fibrous connective tissue that surrounds a group of axons or fascicles. (Chapter 8.3)

Peripheral nervous system (PNS): Includes all of the parts of the nervous system found outside of the brain and spinal cord. (Chapter 8.3)

Peripheral neuropathy: Weakness, numbness, and pain caused by peripheral nerve damage and commonly a result of diabetes and peripheral vascular disease. (Chapter 8.6)

Photoreceptors: Specialized receptor cells in the retina that respond to light stimuli. (Chapter 8.5)

Phrenic nerve: A nerve that connects to the diaphragm at the base of the thoracic cavity. (Chapter 8.3)

Pia mater: A thin fibrous membrane that follows the bumps and grooves of the gyri and sulci. (Chapter 8.3)

Pinna: A large, fleshy structure on the lateral side of the head; also called the auricle or earlobe. (Chapter 8.5)

Pons: The main connection between the cerebellum and the brain stem, with the medulla oblongata, it regulates respiration. (Chapter 8.3)

Postcentral gyrus: The primary somatosensory area; all the tactile senses, as well as more general senses of the body, such as proprioception (body position) and kinesthesia (movement), are processed in this area. (Chapter 8.3)

Posterior columns: Area of white matter in the spinal column between the two posterior horns of gray matter. (Chapter 8.3)

Posterior horn: Area of gray matter within the spinal cord responsible for sensory processing. (Chapter 8.3)

Posterior median sulcus: The posterior middle of the spinal cord. (Chapter 8.3)

Precentral gyrus: Found in the frontal lobe and contains the primary motor cortex. The primary motor cortex has voluntary control over skeletal muscles. (Chapter 8.3)

Presbyopia: A type of refractive error that makes it hard for middle-aged and older adults to see things up close because the lens in the eye gets harder and less flexible and stops focusing light correctly on the retina. (Chapter 8.6)

Proprioception: A general sense referring to body movement. (Chapter 8.5)

Proprioceptor: A receptor located near a moving part of the body, such as a muscle, that interprets position and movement. (**Chapter 8.5**)

Psychiatrist: A physician who specializes in mental health and substance use disorders. (**Chapter 8.7**)

Psychologists: Mental health professionals with graduate or doctoral degrees who help people cope with stress, overcome substance misuse, manage mental health disorders, and perform psychological testing. (**Chapter 8.7**)

Pupil: The black hole in the center of the iris that allows light to enter the eye. (**Chapter 8.5**)

Pyramids: Two large white matter lateral bulges formed from the descending motor tracts of the medulla oblongata. (**Chapter 8.3**)

Pyramidal decussation: The defining landmark of the medullary-spinal border, where motor tracts cross over to the opposite side of the brain, explaining why the right side of the brain controls the left side of the body and vice versa. (**Chapter 8.3**)

Receptive aphasia: Aphasia associated with Wernicke's area, where there is a loss of understanding of what is being spoken. (**Chapter 8.3**)

Reflex: A quick, predictable, automatic response to a stimulus that occurs without a conscious decision by the brain to perform it. (**Chapter 8.3**)

Refractive errors: A common type of vision problem that occurs when the shape of a person's eye prevents light from focusing correctly on their retina. (**Chapter 8.6**)

Response: A reaction to a stimulus perceived by our senses; responses can be voluntary or involuntary. (**Chapter 8.2**)

Rest and digest response: Controlled by the parasympathetic division of the autonomic nervous system. (**Chapter 8.4**)

Reticular formation: Area of gray matter throughout the brain stem that is related to sleep and wakefulness, general brain activity, and attention. (**Chapter 8.3**)

Retina: The innermost layer of the eye, which contains the rods and cones responsible for photoreception. (**Chapter 8.5**)

Rods: Part of the eye that detects shades of black and grey but does not function in bright light. (**Chapter 8.5**)

Saccule: Specialized structures in the ear responsible for sensing head position. (**Chapter 8.5**)

Sacral plexus: Comes from the lower lumbar nerves L4 and L5 and the sacral nerves S1 to S4 to supply nerves to the posterior leg. (**Chapter 8.3**)

Satellite cells: A type of neuroglia in the peripheral nervous system that provides support to neurons. (**Chapter 8.3**)

Schizophrenia: A serious mental illness caused by genetics, imbalanced neurotransmitters in the brain, and environmental factors. (**Chapter 8.6**)

Schwann cell: A type of neuroglia in the peripheral nervous system that insulates axons with myelin. (**Chapter 8.3**)

Sciatica: Refers to pain that travels along the sciatic nerve from the buttocks and down the back of the leg; most often happens when a herniated disk or an overgrowth of bone puts pressure on the lumbar spine nerve roots, causing inflammation, pain, and possible numbness in the affected leg. (**Chapter 8.3**, **Chapter 8.6**)

Sciatic nerve: The most significant nerve to come from the sacral plexus and extends across the hip joint, and is most commonly associated with sciatica. (**Chapter 8.3**)

Sclera: A tough protective structure that is part of the fibrous tunic of the eye. (**Chapter 8.5**)

Semicircular canals: Three ring-like extensions adjacent to the vestibule of the eye and responsible for sensing movement. (**Chapter 8.5**)

Sensation: Refers to receiving information from the environment that activates sensory receptor cells; a major function of the nervous system. (**Chapter 8.2**, **Chapter 8.5**)

Sensorineural hearing loss: Occurs when the inner ear or the vestibulocochlear nerve becomes damaged. It is the most common type of hearing loss and can be a result of aging, exposure to loud noise, injury, disease, certain drugs, or an inherited condition. (**Chapter 8.6**)

Sensorium: Refers to the interpretation of sensory stimuli. (**Chapter 8.3**)

Sensory neurons: Neurons found in the PNS that carry sensory information to the spinal cord or brain; also known as afferent neurons. (**Chapter 8.3**)

SLUDD: An acronym associated with some functions of the parasympathetic nervous system and stands for Salivation, Lacrimation, Urination, Digestion, and Defecation. (**Chapter 8.4**)

Somatic nervous system (SNS): Responsible for conscious perception of the environment (senses) and voluntary motor responses to that perception by the contraction of skeletal muscles. (**Chapter 8.3**)

Somatosensation: The general sense of touch. (Chapter 8.5)

Speech-language pathologist: A healthcare professional who diagnoses and treats communication and swallowing disorders in people of all ages caused by developmental, neurological, or injury-related conditions. (Chapter 8.7)

Special sense: Any sensory system that is localized to a specific organ structure, namely, the senses of smell, taste, sight, hearing, and balance. (Chapter 8.5)

Spinal accessor (or accessory) nerve (CN XI): Controls the sternocleidomastoid and trapezius muscles, enabling movements of the head, neck, and shoulders. (Chapter 8.3)

Spinal nerves: Nerves connected to the spinal cord; all spinal nerves are mixed nerves with combined sensory and motor axons that separate into two nerve roots. (Chapter 8.3)

Stapes: Latin term for a small bone in the middle ear; also called the stirrup. (Chapter 8.5)

Stimulus: An agent that causes a change in homeostasis or the environment. (Chapter 8.2)

Stroke: The medical term for disruption of blood supply to the brain; also called a cerebrovascular accident (CVA). (Chapter 8.6)

Subarachnoid space: Area containing the trabeculae and is filled with circulating cerebrospinal fluid. (Chapter 8.3)

Subdural hematoma: Occurs when a blood vessel near the surface of the brain bursts, causing blood to build up between the brain and the brain's tough outer lining. It is a life-threatening problem because it causes increased pressure that compresses the brain and can result in loss of consciousness, paralysis, or death. (Chapter 8.6)

Subdural space: The space between the dura and the middle layer or arachnoid mater. (Chapter 8.3)

Substantia nigra: Structure found in the midbrain that is responsible for regulating automatic skeletal muscle movements, such as swinging your arms when you walk. (Chapter 8.3)

Substance use and mental health counselors: Healthcare professionals who provide advice and treatment for people with issues like alcoholism, substance use disorders, or depression, with varying education requirements by state. (Chapter 8.7)

Sulcus: A groove between two gyri of the cerebral cortex. (Chapter 8.3)

Superior colliculus: Superior pair of colliculi of the midbrain's tectum; activity in the

superior colliculus is related to orienting the eyes to a sound or touch stimulus. (**Chapter 8.3**)

Superior oblique: An extraocular eye muscle that coordinates eye movements. (**Chapter 8.5**)

Superior rectus: An extraocular eye muscle that coordinates eye movements. (**Chapter 8.5**)

Sympathetic division: A division of the autonomic nervous system associated with the "fight-or-flight" response; it increases body activities that are crucial for survival in a potentially dangerous situation and will decrease body activities that aren't essential. (**Chapter 8.4**)

Synapse: Where two neurons (or a neuron and muscle) meet. (**Chapter 8.3**)

Synaptic end bulb: An enlarged tip of an axon terminal that makes a connection with the target at the synapse. (**Chapter 8.3**)

Taste buds: The structures responsible for taste. (**Chapter 8.5**)

Tectum: Region of the midbrain composed of four nuclei or "bumps" known as the colliculi. (**Chapter 8.3**)

Temporal lobes: Regions of the cerebral cortex deep to the temporal bones and located on each side of the brain. (**Chapter 8.3**)

Thalamus: Relays information between the cerebral cortex and the brain stem, spinal cord, and nerves; all sensory information, except for the sense of smell, passes through and is processed within the thalamus. (**Chapter 8.3**)

Thermoreceptors: A type of neuron that perceives temperature. (**Chapter 8.5**5)

Third ventricle: Connected to the lateral ventricles and is the space between the left and right sides of the diencephalon. (**Chapter 8.3**)

Thoracolumbar system: Another name for the sympathetic nervous system. (**Chapter 8.4**)

Tract: A bundle of axons, or fibers, found in the CNS. (**Chapter 8.3**)

Traumatic brain injuries (TBIs): Head injuries that can range from mild concussions to severe brain injuries causing death, are often due to falls, motor vehicle accidents, sports injuries, or violence. (**Chapter 8.6**)

Trigeminal nerve (CN V): The largest cranial nerve; it has three branches: ophthalmic

(sensory), maxillary (sensory), and mandibular (both sensory and motor). It provides sensation to the face and controls muscles for chewing. (Chapter 8.3)

Trochlear nerve (CN IV): The smallest cranial nerve; it controls the superior oblique muscle, which helps in downward and inward eye movement. (Chapter 8.3)

Tympanic membrane: Eardrum; vibrates when sound waves hit it. (Chapter 8.5)

Umami: A Japanese word that means "delicious taste" and is often translated to mean savory; recently discovered as a fifth taste. (Chapter 8.5)

Unipolar neurons: Have only one process emerging from the cell. True unipolar cells are only found in invertebrate animals. (Chapter 8.3)

Utricle: Specialized structures in the ear responsible for sensing head position. (Chapter 8.5)

Vagus nerve (CN X): The longest cranial nerve; it controls parasympathetic functions like heart rate, digestion, and respiratory rate. (Chapter 8.3)

Vascular tunic (uvea): The middle layer of the eye is mostly composed of the choroid, ciliary body, and iris. (Chapter 8.5)

Ventral (anterior) nerve root: Anterior area of the spinal cord where axons responsible for motor functions enter. (Chapter 8.3)

Ventricles: Open spaces within the brain that are lined with ependymal cells where cerebrospinal fluid (CSF) circulates. (Chapter 8.3)

Vestibule: A region of the inner ear that is responsible for balance. (Chapter 8.5)

Vestibulocochlear nerve (CN VIII): Composed of two parts: the vestibular nerve, which controls balance, and the cochlear nerve, which controls hearing. (Chapter 8.3)

Visceral sense: A general sense referring to body movement. (Chapter 8.5)

Vision: The special sense of sight that is based on light stimuli entering through the eyes. (Chapter 8.5)

Visual acuity: The sharpness of vision. (Chapter 8.5)

Vitreous humor: A viscous or jelly-like fluid found in the posterior cavity of the eye. (Chapter 8.5)

Wernicke's area: Responsible for speech comprehension. (Chapter 8.3)

White matter: Regions within the nervous system structures with many myelinated axons. (Chapter 8.3)

Zonule fibers: Suspensory ligaments that connect the ciliary body and lens of the eye. (**Chapter 8.5**)

PART IX

CHAPTER 9 ENDOCRINE SYSTEM

9.1 Introduction to the Endocrine System

Chapter Competency

Correlate the major organs of the endocrine system with their function in the body.

Learning Objectives

- Identify the endocrine organs and their associated hormones.
- Identify the general functions of the hormones.
- Illustrate the relationships among the components of the endocrine system.

Imagine you are working as a medical coding specialist reviewing a patient's health record. The provider documents diabetes mellitus, abnormal thyroid hormone levels, fatigue, changes in metabolism, and laboratory results related to blood glucose and calcium regulation. To understand the terminology in the record and accurately connect diagnoses, procedures, and patient education, you must understand how endocrine organs and hormones regulate body functions.

The endocrine system is a communication system made up of glands, tissues, and organs that secrete hormones. **Hormones** are chemical messengers that travel through the bloodstream to **target cells**, where they trigger specific responses. Compared with the nervous system, endocrine responses are often slower but longer-lasting. Together, the endocrine and nervous systems help maintain homeostasis by coordinating processes such as growth, metabolism, temperature regulation, stress responses, fluid and electrolyte balance, reproduction, and blood glucose regulation.

In this chapter, you will explore the major functions and anatomy of the endocrine system. You will learn how endocrine glands differ from exocrine glands, how hormones

interact with target cells, and how feedback loops regulate hormone secretion. You will also study major endocrine organs, including the hypothalamus, pituitary gland, thyroid gland, parathyroid glands, adrenal glands, pancreas, pineal gland, ovaries, and testes. Finally, you will examine common endocrine system disorders, including conditions related to abnormal hormone secretion or hormone response.

By mastering these concepts, you will gain a deeper understanding of how hormones help coordinate body functions and maintain internal balance. This foundation will help you connect endocrine structure and function to metabolism, growth, stress, reproduction, fluid balance, patient assessment, health records, and disorders such as diabetes and thyroid disease.

See Table 9.1 for a comparison of the characteristics of the endocrine and nervous systems.

Table 9.1. Comparison of the Endocrine and Nervous Systems[1]

Characteristic	Endocrine System	Nervous System
Signaling Mechanism(s)	Chemical	Chemical and electrical
Chemical Messenger	Hormones	Neurotransmitters
Distance Traveled	Long or short	Always short
Response Time	Fast or slow	Always fast
Length of Effect	Long-lasting	Short-lived
Environment Targeted	Internal	Internal and external

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

9.2 Major Functions of the Endocrine System

The major functions of the endocrine system are long-distance intercellular communication, coordination, and control that are critical for homeostasis. Additionally, hormones of the endocrine system coordinate and control growth, metabolism, temperature regulation, the stress response, and reproduction, as well as many other functions that will be further described in the following section.[1]

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

9.3 Anatomy of the Endocrine System

Endocrine Glands

The endocrine system consists of cells, tissues, and organs that secrete hormones as a primary or secondary function. **Endocrine glands** are the primary structural and functional units of the endocrine system. They are considered ductless glands because they secrete their hormones directly into the surrounding interstitial fluid rather than through a duct to the surface of the cells or body. The interstitial fluid and the blood vessels then transport the hormones throughout the body to specific **target cells**.

The endocrine system includes many organs that secrete hormones to regulate homeostasis, such as the pituitary, thyroid, pancreas, parathyroid, adrenal glands, pineal gland, ovaries, and testes. See Figure 9.1[1] for an illustration of the endocrine system and its major endocrine glands. The hypothalamus, thymus, heart, kidneys, stomach, small intestine, liver, and skin are also organs that contain cells with endocrine functions. In addition, adipose tissue produces hormones, and bone tissue also has endocrine functions.[2]

1. OpenStax College. (2013). *1801 The endocrine system* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1801_The_Endocrine_System.jpg
2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

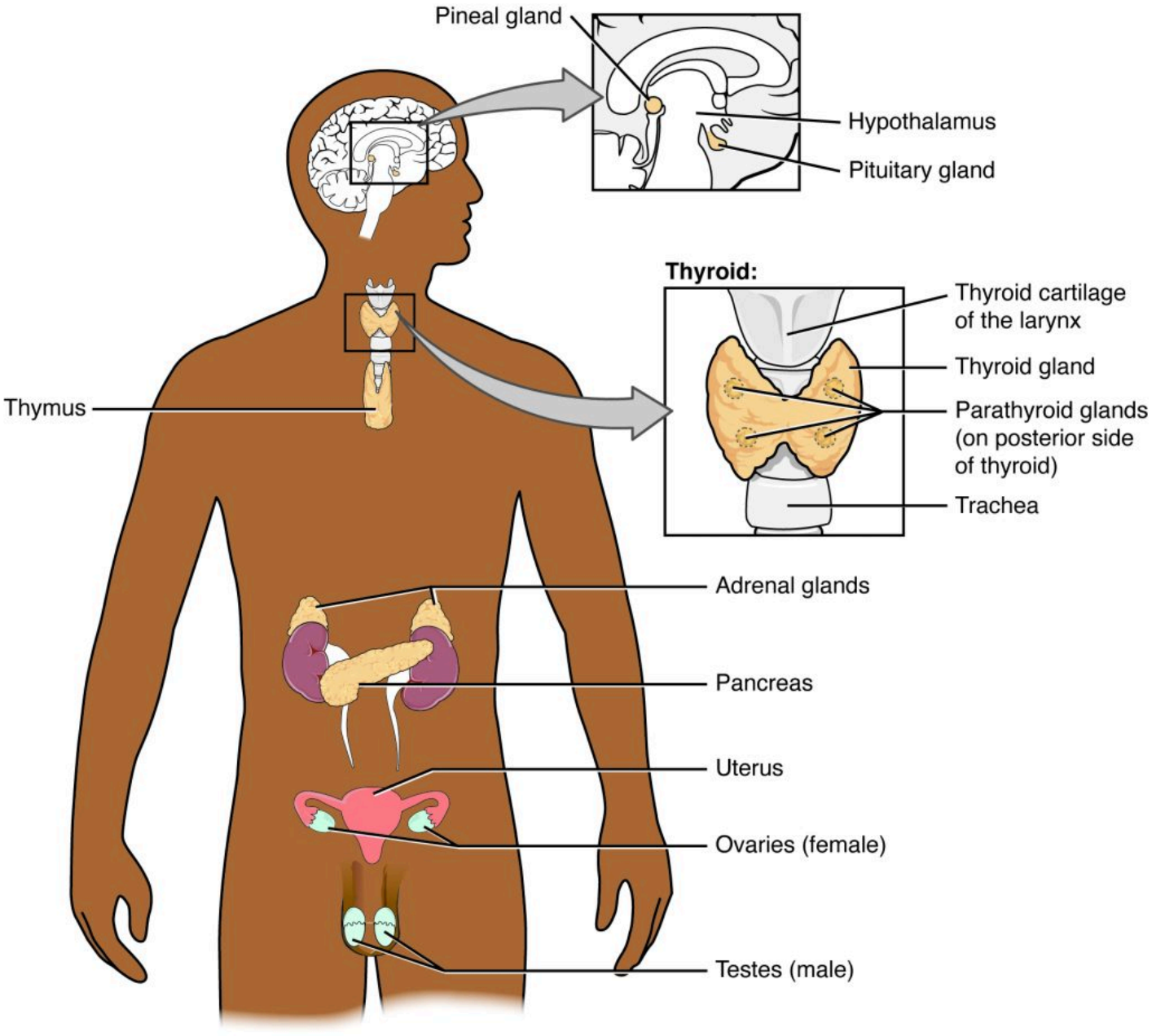


Figure 9.1 Endocrine System

As mentioned earlier, endocrine glands release their products (hormones) directly into the bloodstream, whereas **exocrine glands** release their secretions through ducts. Examples of exocrine glands include the sebaceous (oil) glands and sudoriferous (sweat) glands of the skin. Some organs serve as both endocrine and exocrine organs. For example, the pancreas secretes pancreatic juice into the small intestine as part of the

digestive process, but it also has an endocrine function of secreting insulin and glucagon into the blood to regulate blood glucose levels.[3]

Hormone Target Cells

Although a hormone travels throughout the body in the bloodstream, it only affects its specific target cells, which are cells with receptors for that particular hormone. A **receptor** is a protein located either inside the cell or within the cell's membrane that binds a hormone, initiating the target cell response. After the hormone binds to the receptor, a chain of events leads to the target cell's response. Different hormones contribute to many different physiological responses in the body, including human reproduction, growth and development of body tissues, metabolism, fluid and electrolyte balance, sleep, and many other body functions. We will review several hormones and their actions later in this chapter. The major hormones of the human body and their effects are identified in Table 9.3a.[4]

Table 9.3a. Endocrine Glands and Their Major Hormones[5]

3. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
4. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
5. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Endocrine Gland	Hormones	Effects
Pituitary (anterior)	Human growth hormone (hGH)	Promotes growth of body tissues
Pituitary (anterior)	Prolactin (PRL)	Promotes milk production
Pituitary (anterior)	Thyroid-stimulating hormone (TSH)	Stimulates thyroid hormone secretion by thyroid gland
Pituitary (anterior)	Adrenocorticotropic hormone (ACTH)	Stimulates hormone secretion by adrenal cortex
Pituitary (anterior)	Follicle-stimulating hormone (FSH)	Stimulates gamete production
Pituitary (anterior)	Luteinizing hormone (LH)	Stimulates sex hormone secretion by gonads and ovulation
Pituitary (posterior)	Antidiuretic hormone (ADH)	Stimulates water reabsorption by kidneys
Pituitary (posterior)	Oxytocin	Stimulates uterine contractions during childbirth and milk letdown
Thyroid	Thyroxine (T4) and triiodothyronine (T3)	Stimulates basal metabolic rate
Thyroid	Calcitonin	Decreases blood Ca2+ levels
Parathyroid	Parathyroid hormone (PTH)	Increases blood Ca2+ levels

Adrenal (cortex)	Aldosterone	Increases blood Na+ levels, water reabsorption, and K+ excretion by kidneys
Adrenal (cortex)	Cortisol, corticosterone, and cortisone	Increases blood glucose levels during the stress response, reduces inflammation, and, in high amounts, suppresses immunity
Adrenal (medulla)	Epinephrine, norepinephrine	Stimulates fight-or-flight response
Pineal	Melatonin	Regulates sleep cycles
Pancreas	Insulin	Decreases blood glucose levels
Pancreas	Glucagon	Increases blood glucose levels
Testes	Testosterone	Stimulates development of sex characteristics, including a deeper voice, increased muscle mass, development of body hair, and sperm production
Ovaries	Estrogens and progesterone	Stimulates development of sex characteristics, including the development of adipose and breast tissue, regulates menstrual cycles, and prepares the body for childbirth

Types of Hormones

The hormones of the human body can be categorized into two major groups based on their chemical structure as either water-soluble or fat-soluble. These chemical groups affect a hormone's distribution, the type of receptors it binds to, and other aspects of its function.

Hormones derived from amino acids include amines, peptides, and proteins, and are also known as **water-soluble hormones**. They cannot cross through the phospholipid cell membrane, as they are repelled by the fatty interior of the membrane. They bind to receptors on the outside of the cell membrane that will facilitate a cascade of events inside the cell to activate certain proteins.

Hormones derived from lipids are **fat-soluble** and include steroids. Because they are fat-soluble, they can cross through the cell membrane and bind to receptors inside the cell. Lipid-soluble hormones are not soluble in water (they are hydrophobic). Because blood is water-based, lipid-soluble hormones must travel to their target cell bound to a transport protein.[6]

Pathways of Hormone Action

The message a hormone sends is received by a **hormone receptor**, a protein located either inside the cell or within or on the cell membrane. The receptor will receive the message and initiate the target cell's response. Hormone receptors are selective and only bind to hormones with a specific shape or structure that matches the receptor. The same type of receptor may be located on cells in different body tissues and trigger somewhat different responses. Therefore, the response triggered by a hormone depends not only on the hormone but also on the target cell.

After the target cell receives the hormone signal, it can respond in a variety of ways. The response may include the stimulation of protein synthesis, activation or deactivation of enzymes, alteration in the permeability of the cell membrane, altered rates of mitosis and cell growth, or the stimulation of the secretion of products. Moreover, a single hormone may be capable of inducing different responses in a given cell.[7]

6. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

7. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young,

Factors Affecting Target Cell Response

As mentioned earlier, target cells must have receptors specific to a given hormone if that hormone is to trigger a response. However, several other factors influence the target cell response. For example, the presence of a significantly high level of a hormone circulating in the bloodstream can cause its target cells to decrease the number of receptors for that hormone. This process is called **downregulation**, and it allows cells to become less reactive to the excessive hormone levels.

When the level of a hormone is chronically reduced, target cells engage in **upregulation** to increase their number of receptors. This process allows cells to be more sensitive to the hormone that is present. Cells can also alter the sensitivity of the receptors themselves to various hormones.

Two or more hormones can interact to affect the response of cells in a variety of ways. The three most common types of interactions are as follows:

- The **permissive effect**, in which the presence of one hormone enables another hormone to act. For example, thyroid hormones have complex permissive relationships with certain reproductive hormones. A dietary deficiency of iodine, a component of thyroid hormones, can, therefore, affect reproductive system development and functioning.
- The **synergistic effect**, in which two hormones with similar effects produce an amplified or bigger response together. In some cases, two hormones are required for an adequate response. For example, two different reproductive hormones—FSH from the pituitary gland and estrogens from the ovaries—are required for the maturation of female ova (egg cells).
- The **antagonistic effect**, in which two hormones have opposing effects. A familiar example is the effect of two pancreatic hormones, insulin and glucagon. Insulin decreases blood glucose, whereas glucagon increases blood glucose.[8]

K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

8. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Regulation of Hormone Secretion

To prevent abnormal hormone levels and a potential disease state, hormone levels must be tightly controlled. The body maintains this control by balancing hormone production and breakdown with positive and negative feedback loops.

Positive Feedback Loops

Recall that **positive feedback loops** amplify or exaggerate the original stimulus. Positive feedback loops in hormonal regulation occur when the release of a hormone triggers the release of even more of that same hormone. An example of a positive feedback loop is the release of oxytocin during childbirth. The initial release of oxytocin begins to signal the uterine muscles to contract, which pushes the fetus toward the cervix, causing it to stretch. The stretching signals the pituitary gland to release more oxytocin, causing labor contractions to intensify. This continues until the birth of the child, when the stretching stops and oxytocin is decreased.[9]

Negative Feedback Loops

The more common method of hormone regulation is the negative feedback loop. Recall that in **negative feedback loops**, the original stimulus is reduced or stopped. Negative feedback loops in hormonal regulation slow down or stop (inhibit) further secretion of a hormone in response to adequate levels of a hormone or other substance, such as glucose or calcium. This allows blood levels of the hormone to be regulated within a narrow range. An example of a negative feedback loop is the release of glucocorticoid hormones from the adrenal glands, as directed by the hypothalamus and pituitary gland. As glucocorticoid concentrations in the blood rise, the hypothalamus and pituitary gland reduce their signaling to the adrenal glands to prevent additional

9. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

glucocorticoid secretion.[10] See Figure 9.2[11] for an illustration of this negative feedback loop.

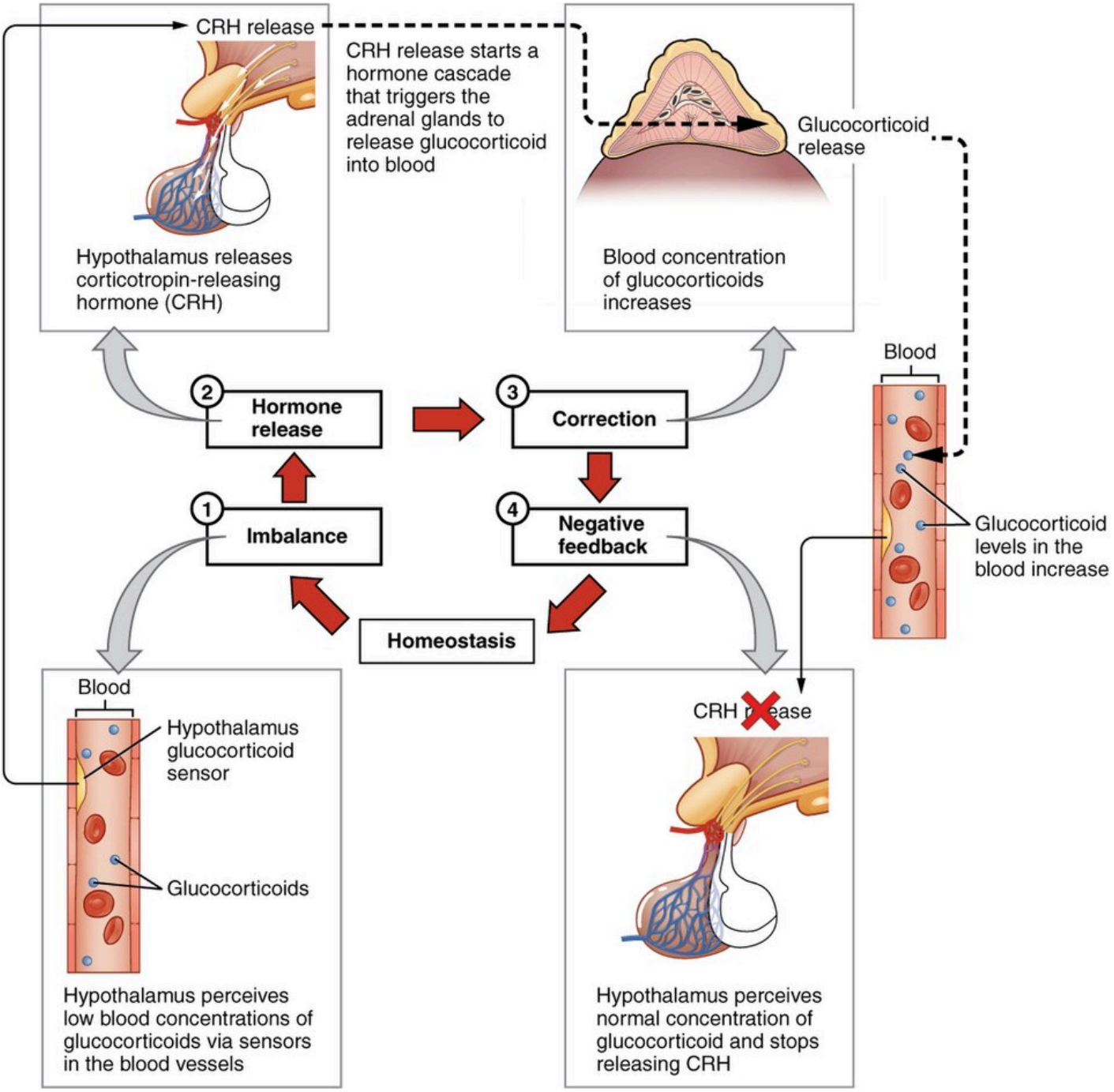


Figure 9.2 Negative Feedback Loop

10. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

11. OpenStax College. (2013). *1805_Negative_Feedback_Loop* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1805_Negative_Feedback_Loop.jpg

Hypothalamus–Pituitary Complex

The **hypothalamus–pituitary complex** can be thought of as the "command center" of the endocrine system. This complex secretes several hormones that directly produce responses in target tissues, as well as hormones that regulate the secretion (production and release) of hormones from other glands. In addition, the hypothalamus–pituitary complex coordinates the messages of the endocrine and nervous systems. In many cases, a stimulus received by the nervous system must pass through the hypothalamus–pituitary complex to be translated into hormones that can initiate a response.[12] See Figure 9.3[13] for an illustration of the hypothalamus-pituitary complex.

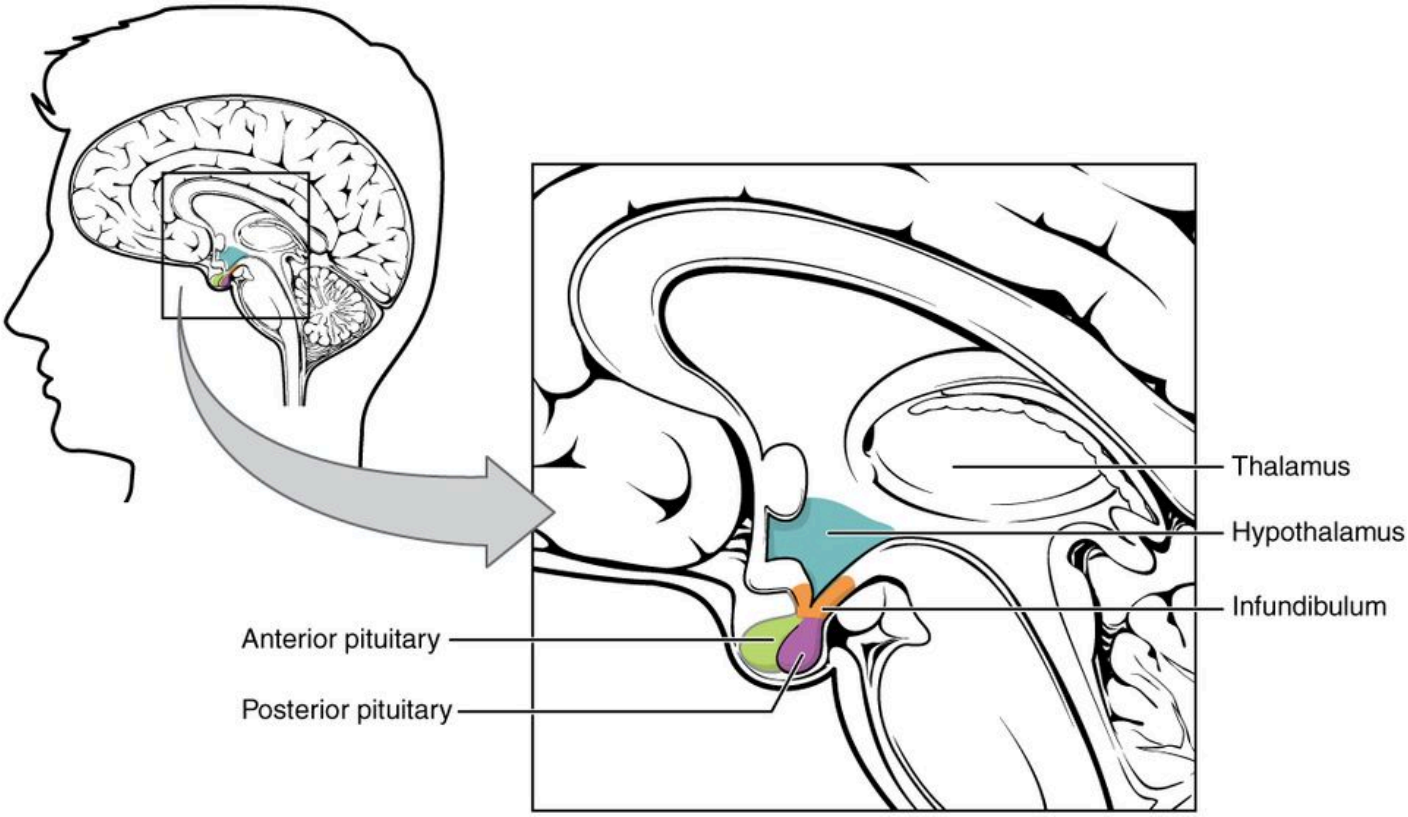


Figure 9.3 Hypothalamus–Pituitary Complex

12. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

13. OpenStax College. (2013). *1806_The_Hypothalamus-Pituitary_Complex* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1806_The_Hypothalamus-Pituitary_Complex.jpg

Hypothalamus

The hypothalamus is a structure of the diencephalon of the brain located anterior and inferior to the thalamus. It has both neural and endocrine functions, producing and secreting many hormones.[14]

Pituitary Gland

The hypothalamus is anatomically and functionally related to the **pituitary gland** (also known as the hypophysis), a pea-sized organ suspended from a stem called the **infundibulum** (or pituitary stalk). The pituitary gland is cradled within the sella turcica of the sphenoid bone of the skull. It consists of two lobes: the posterior pituitary (also known as the neurohypophysis) and the anterior pituitary (also known as the adenohypophysis), which both release hormones. The pituitary gland also contains the intermediate pituitary, a small group of cells between the lobes that secretes a hormone as well.[15]

Anterior Pituitary Gland

The anterior pituitary gland secretes several hormones. However, the secretion of hormones from the anterior pituitary is regulated by two classes of hormones that are secreted by the hypothalamus, called releasing hormones and inhibiting hormones:[16]

- **Releasing hormones**: The hypothalamus secretes releasing hormones to stimulate the secretion of hormones from the anterior pituitary gland.
- **Inhibiting hormones**: The hypothalamus secretes inhibiting hormones to slow or stop the secretion of hormones from the anterior pituitary gland.

14. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
15. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
16. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

See Figure 9.4[17] for an illustration of the anterior pituitary gland.

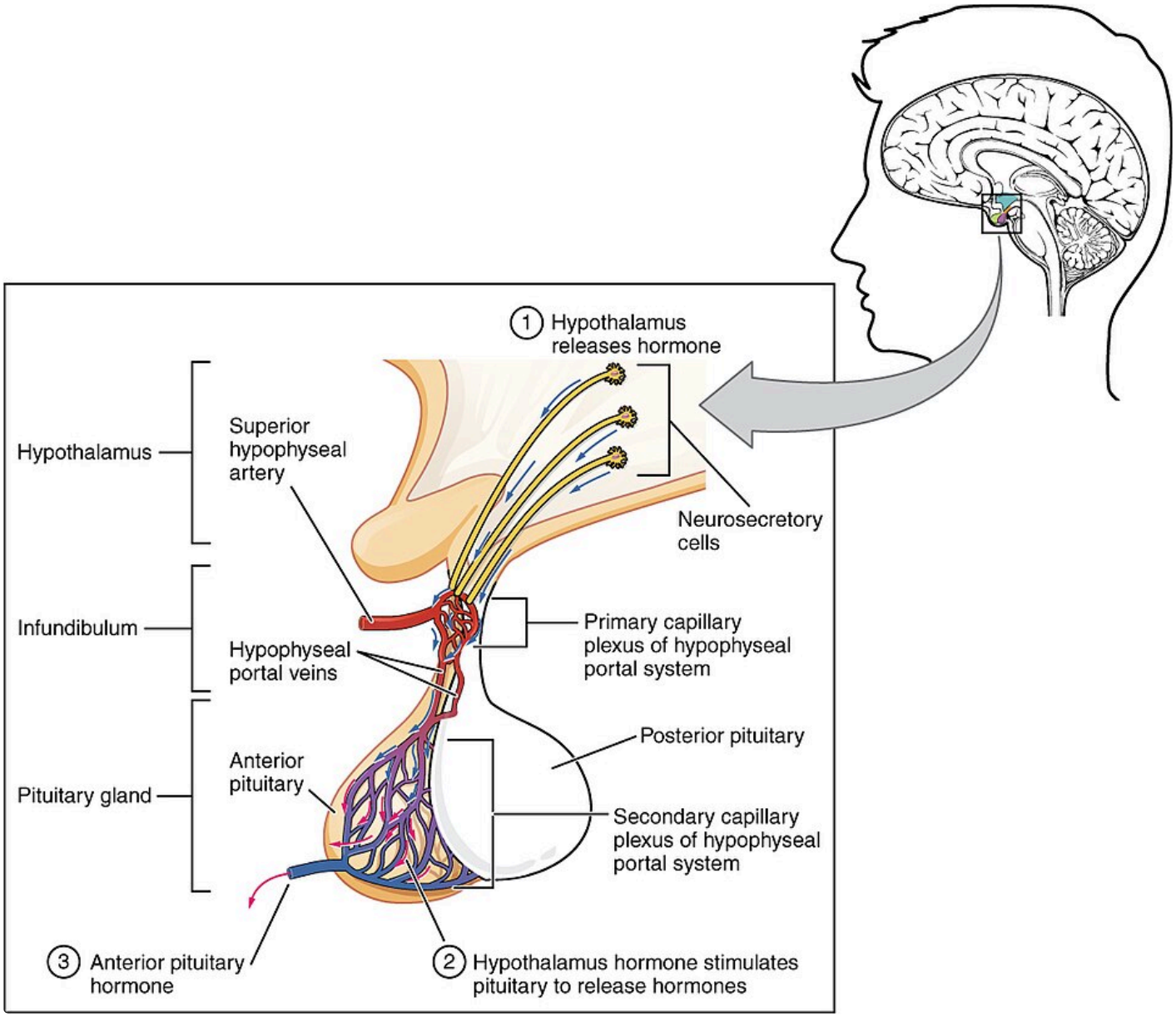


Figure 9.4 Anterior Pituitary

Anterior Pituitary Gland Hormones

The anterior pituitary produces several hormones, including the human growth hormone (hGH), thyroid-stimulating hormone (TSH), adrenocorticotropic hormone

17. OpenStax College. (2013). *1808_The_Anterior_Pituitary_Complex* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1808_The_Anterior_Pituitary_Complex.jpg

(ACTH), follicle-stimulating hormone (FSH), luteinizing hormone (LH), and prolactin (PRL). Of the hormones of the anterior pituitary, TSH, ACTH, FSH, and LH are collectively referred to as tropic hormones (*trope-* = "turning") because they turn on or off the function of other endocrine glands.[18]

Human Growth Hormone

The endocrine system regulates the growth of the human body, protein synthesis, and cellular replication. A major hormone involved in this process is the **human growth hormone (hGH)**, also called somatotropin—a protein hormone secreted by the anterior pituitary gland. It promotes protein synthesis and tissue building through direct and indirect mechanisms. See Figure 9.5[19] for an illustration of the release and inhibition of hGH and its effects. hGH levels are controlled by the release of GHRH (growth hormone-releasing hormone) and GHIH (growth hormone-inhibiting hormone), also known as somatostatin, from the hypothalamus.[20]

18. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

19. OpenStax College. (2013). *1809_Hormonal_Regulation_of_Growth* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1809_Hormonal_Regulation_of_Growth.jpg

20. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

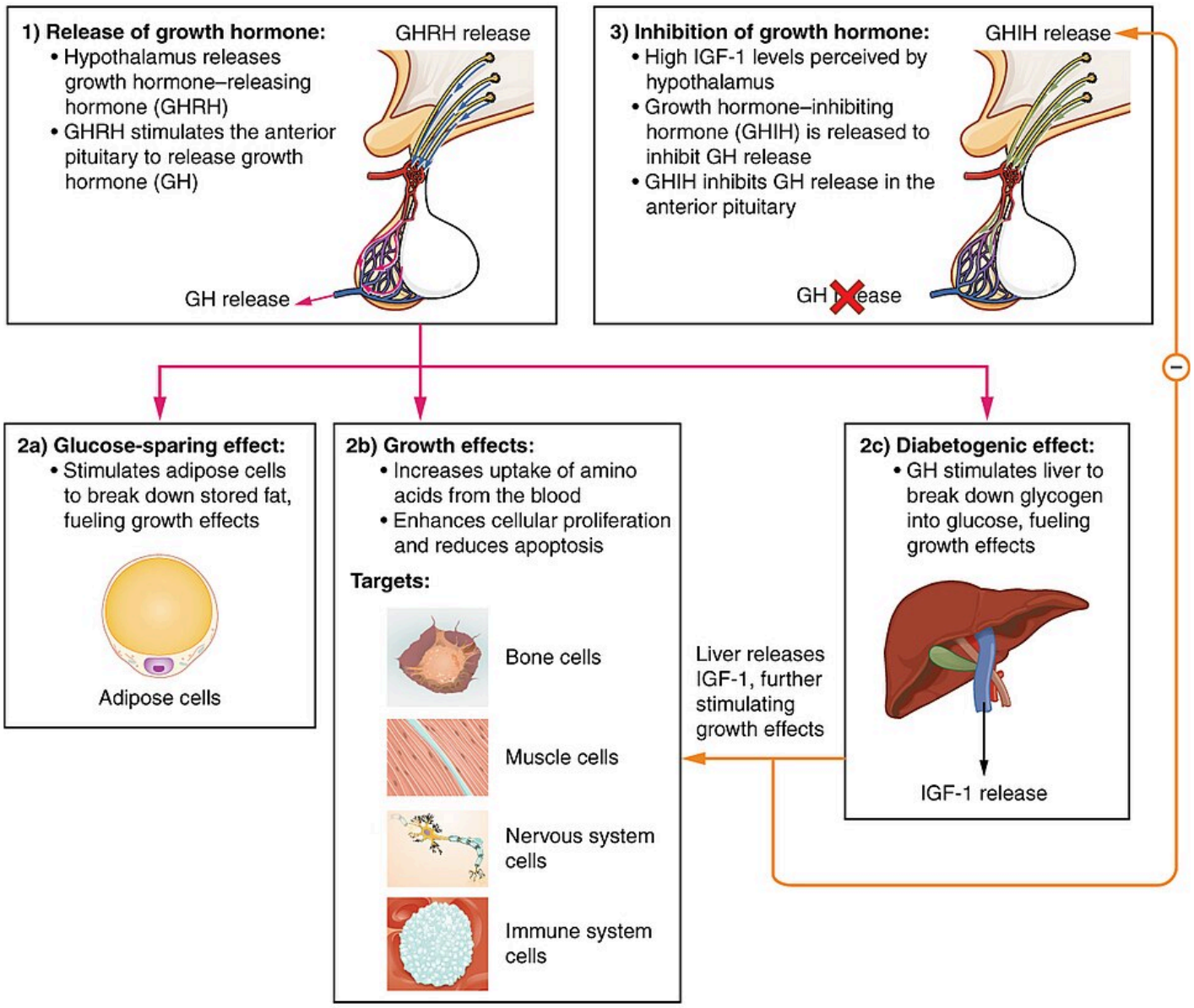


Figure 9.5 Hormonal Regulation of Growth

Human growth hormone directly increases the rate of protein synthesis in skeletal muscle and bones. hGH indirectly controls growth and protein synthesis by stimulating the liver and other tissues to produce a group of proteins called **insulin-like growth factors (IGFs)**. These proteins enhance cellular proliferation and inhibit apoptosis, or programmed cell death. IGFs stimulate cells to increase their uptake of amino acids from the blood for protein synthesis. Skeletal muscle and cartilage cells are particularly sensitive to stimulation from IGFs.

Excesses or deficiencies of any hormone can result in several disorders. For example, **gigantism** is a disorder in children that is caused by the secretion of abnormally large amounts of hGH, resulting in excessive growth. A similar condition in adults is

acromegaly, a disorder that results in the thickening of bones in the face, hands, and feet in response to excessive levels of hGH in individuals who have stopped growing. Abnormally low levels of hGH in children can cause growth impairment—a disorder called **pituitary dwarfism** (also known as growth hormone deficiency).

See Figure 9.6[21] for an image of an individual with gigantism compared to the size of his family members and Figure 9.7[22] for an image of two individuals with dwarfism.

21. Unknown Photographer. (1891). *Julius_Koch_Family_portrait* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Julius_Koch_Family_portrait.jpg

22. Gerhard Sisters. (1914). *People_with_dwarfism_from_the_Philippines_in_1914* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:People_with_dwarfism_from_the_Philippines_in_1914,_%22Philipino_midgets%22_LCCN2007680836_(cropped).jpg

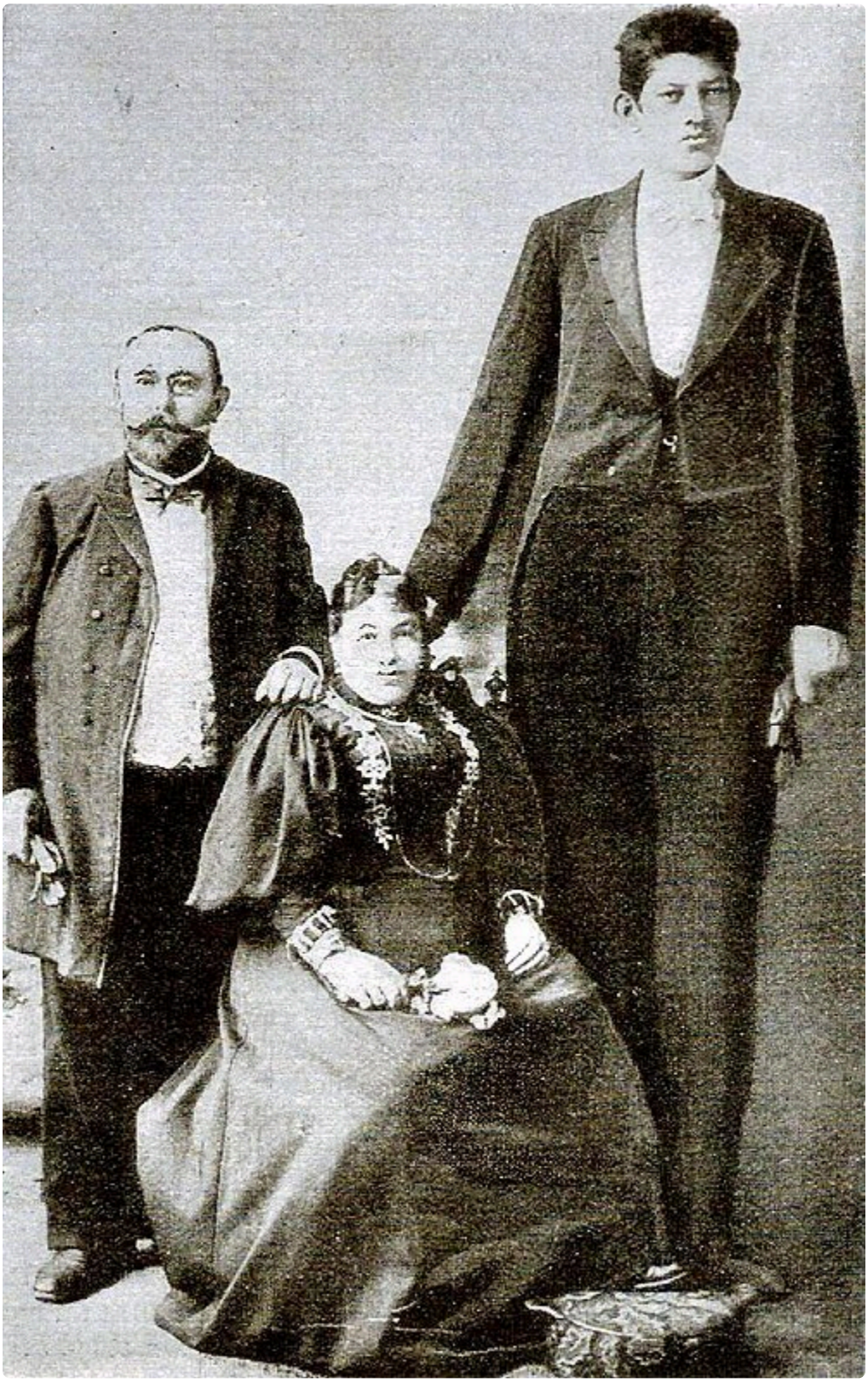


Figure 9.6 Gigantism



Figure 9.7 Dwarfism

Thyroid-Stimulating Hormone

The activity of the thyroid gland is regulated by **thyroid-stimulating hormone (TSH)**, also called thyrotropin. TSH is released from the anterior pituitary in response to thyrotropin-releasing hormone (TRH) from the hypothalamus and then triggers the secretion of thyroid hormones by the thyroid gland. In a classic negative feedback loop,

elevated levels of thyroid hormones in the bloodstream then trigger a drop in production of TRH and, subsequently, TSH.[23]

Adrenocorticotropic Hormone

The **adrenocorticotropic hormone (ACTH)**, also called corticotropin, stimulates the adrenal cortex (the outer layer of the adrenal glands) to secrete corticosteroid hormones such as cortisol. The release of ACTH is regulated by the corticotropin-releasing hormone (CRH) from the hypothalamus.[24]

Follicle-Stimulating Hormone and Luteinizing Hormone

The endocrine glands secrete a variety of hormones that control the development and regulation of the reproductive system. Much of the development of the reproductive system occurs during puberty, which is initiated by gonadotropin-releasing hormone (GnRH), a hormone secreted by the hypothalamus. GnRH stimulates the anterior pituitary to secrete **gonadotropins**—hormones that regulate the function of the gonads, which are the ovaries in females and the testes in males. Throughout life, gonadotropins regulate reproductive function and, in the case of females, the onset and end of reproductive ability.

The gonadotropins include two hormones: **follicle stimulating hormone (FSH)** and **luteinizing hormone (LH)**. FSH stimulates the production and maturation of sex cells, or gametes, which are ova and sperm. FSH also promotes follicular growth; follicles are sacs in which ova develop, and these follicles then release estrogens from the ovaries. LH triggers ovulation, as well as the production of estrogens and progesterone by the ovaries. In males, LH stimulates the production of testosterone by the testes.[25]

23. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

24. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

25. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Prolactin

As its name implies, **prolactin (PRL)** promotes lactation (milk production). During pregnancy, it contributes to the development of the mammary glands, and after birth, it stimulates the mammary glands to produce breast milk. However, the effects of prolactin depend heavily on the permissive effects of estrogens, progesterone, and other hormones.

In non-pregnant females, prolactin secretion is inhibited by prolactin-inhibiting hormone (PIH), which is actually the neurotransmitter dopamine released from neurons in the hypothalamus. Only during pregnancy do prolactin levels rise in response to prolactin-releasing hormone (PRH) from the hypothalamus.[26]

Intermediate Pituitary Hormone: Melanocyte-Stimulating Hormone

The cells in between the pituitary lobes secrete a hormone known as **melanocyte-stimulating hormone (MSH)**. Local production of MSH in the skin is responsible for melanin production in response to UV light exposure. The role of MSH made by the pituitary is more complicated. For instance, people with lighter skin generally have the same amount of MSH as people with darker skin. Nevertheless, this hormone is capable of darkening the skin by inducing melanin production in the skin's melanocytes. People also show increased MSH production during pregnancy; in combination with estrogens, it can lead to darker skin pigmentation, especially the skin of the areolas and labia minora.[27]

Posterior Pituitary Gland Hormones

The posterior pituitary gland does not produce hormones but rather stores and releases two hormones produced by the hypothalamus. These two hormones are oxytocin and ADH (antidiuretic hormone).[28]

26. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

27. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

28. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young,

Oxytocin

When fetal development is complete, the hormone **oxytocin** (*tocia-* = "childbirth") stimulates uterine contractions and dilation of the cervix. Additionally, oxytocin is necessary for the milk ejection reflex (commonly referred to as "let-down") in breastfeeding and is thought to contribute to parent–newborn bonding, known as attachment. Oxytocin is also thought to be involved in feelings of love and closeness, as well as in the sexual response for both men and women.

Antidiuretic Hormone (ADH)

The solute concentration of the blood, or **blood osmolality**, may change in response to the consumption of certain foods and fluids, as well as in response to disease, injury, medications, or other factors. Blood osmolality is constantly monitored by **osmoreceptors**—specialized cells within the hypothalamus that are particularly sensitive to the concentration of sodium ions and other solutes. The higher the osmolality, the more dehydrated a person can become.

In response to high blood osmolality, which can occur during dehydration or following a very salty meal, the osmoreceptors signal the posterior pituitary to release **antidiuretic hormone (ADH)**. The target cells of ADH are located in the kidneys. Its effect is to allow increased water reabsorption. The more water reabsorbed, the greater the amount of water that is returned to the blood and the less that is excreted in the urine. ADH is also known as vasopressin because, in very high concentrations, it causes constriction of blood vessels, which increases blood pressure.

Interestingly, drugs can affect the secretion of ADH. For example, alcohol consumption inhibits the release of ADH, resulting in increased urine production that can eventually lead to dehydration and a hangover. See Figure 9.8[29] for an illustration of the pituitary hormones and their target organs.

K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

29. OpenStax College. (2013). *1810_Major_Pituitary_Hormones* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1810_Major_Pituitary_Hormones.jpg

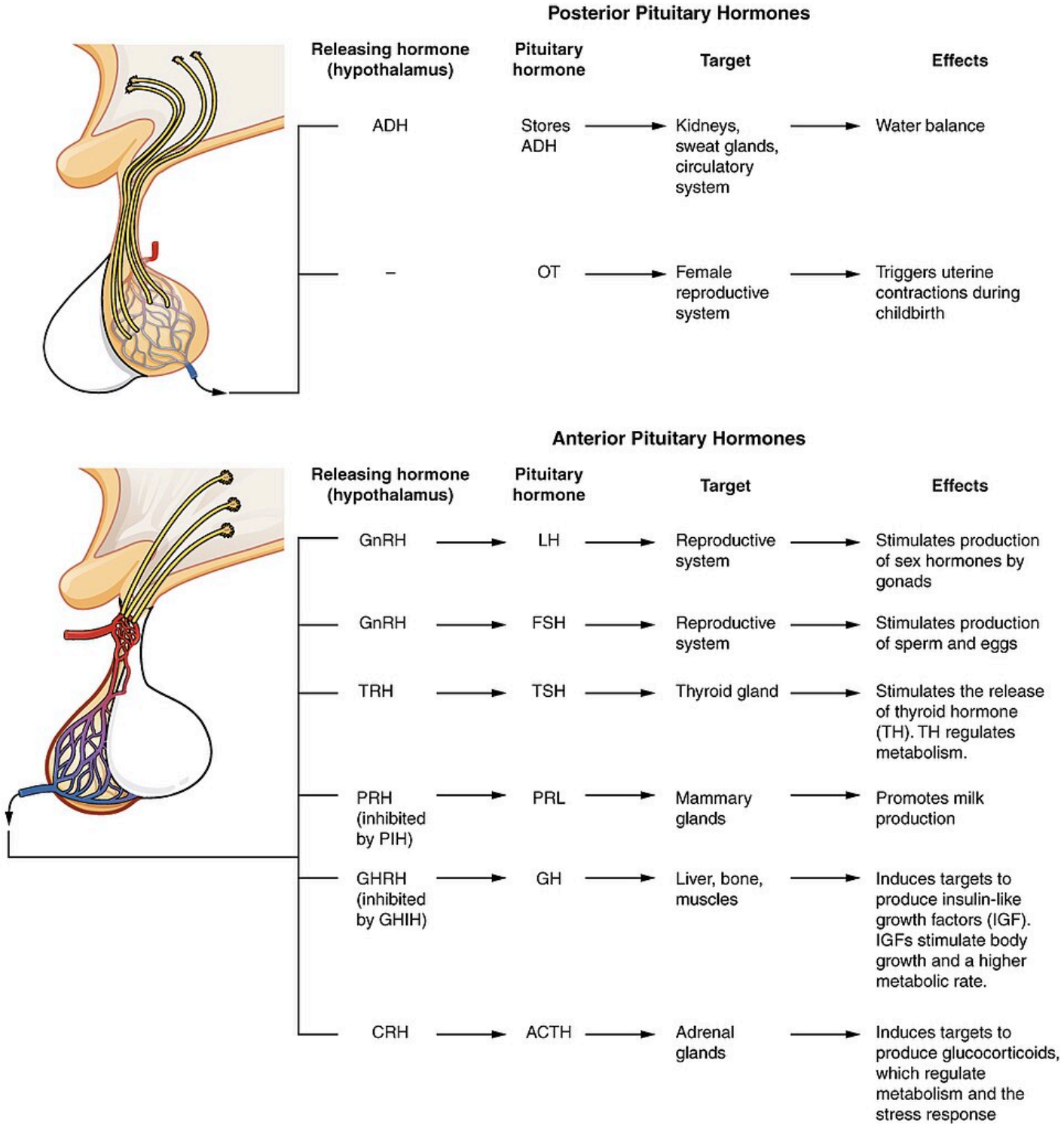


Figure 9.8 Major Pituitary Hormones and Their Target Organs

Other Endocrine Glands

Thyroid Gland

A butterfly-shaped organ, the **thyroid gland** is located anterior to the trachea, just inferior to the larynx in the neck.[30] See Figure 9.9[31] for an illustration of the thyroid gland and an image of thyroid follicle cells. The middle region, called the isthmus, connects the two wing-shaped left and right lobes. Each of the thyroid lobes is embedded with parathyroid glands, primarily on their posterior surfaces.

30. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

31. OpenStax College. (2013). *1811_The_Thyroid_Gland* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1811_The_Thyroid_Gland.jpg

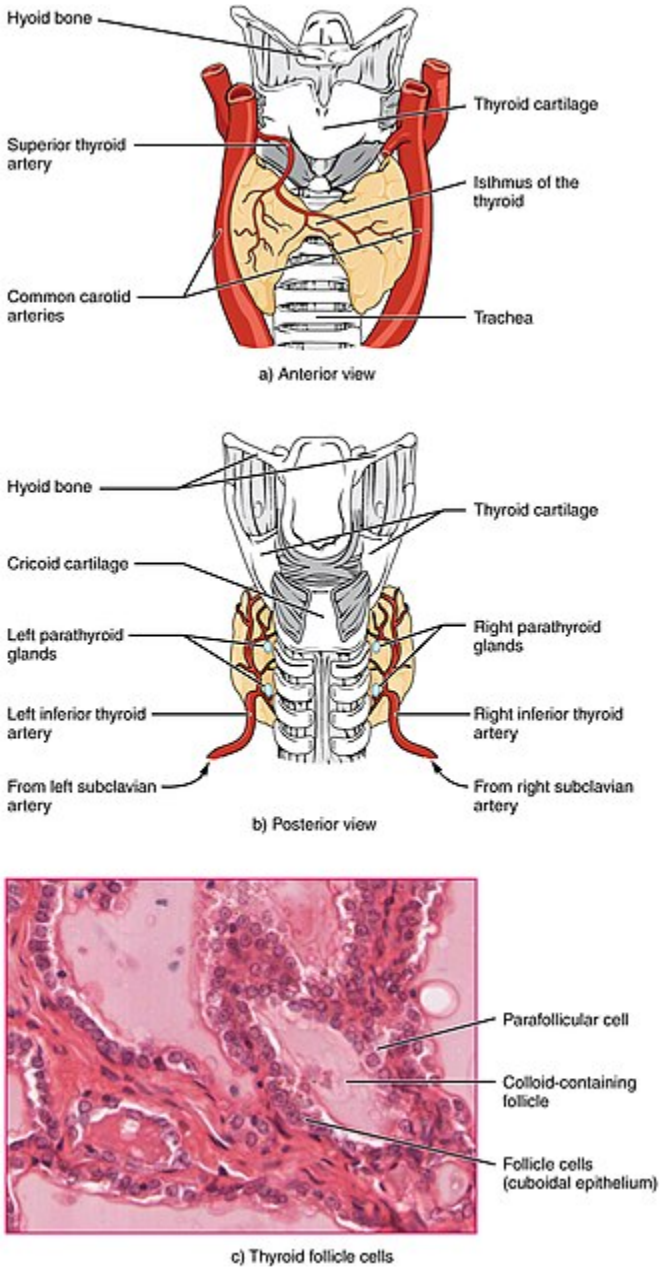


Figure 9.9 Thyroid Gland: (a) Anterior View, (b) Posterior View, and (c) Thyroid Follicle Cells

T3 and T4

TSH (thyroid stimulating hormone) from the anterior pituitary gland stimulates the thyroid gland to secrete **triiodothyronine** (T3), a thyroid hormone with three iodine atoms in its chemical structure and tetraiodothyronine, also known as **thyroxine** (T4), a thyroid hormone with four iodine atoms in its structure.

As shown in Figure 9.10[32], low blood levels of T3 and T4 stimulate the release of thyrotropin-releasing hormone (TRH) from the hypothalamus, which triggers secretion of TSH from the anterior pituitary. In turn, TSH stimulates the thyroid gland to secrete T3 and T4. Interestingly, the T4 produced by the thyroid gland is converted to T3 by some of the body's cells.[33] The levels of TRH, TSH, T3, and T4 are regulated by a negative feedback system in which increasing levels of T3 and T4 decrease the secretion of TSH.

32. OpenStax College. (2013). *1813_A_Classic_Negative_Feedback_Loop* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1813_A_Classic_Negative_Feedback_Loop.jpg

33. Cleveland Clinic. (2022). *Thyroid hormone.* https://my.clevelandclinic.org/health/articles/22391-thyroid-hormone

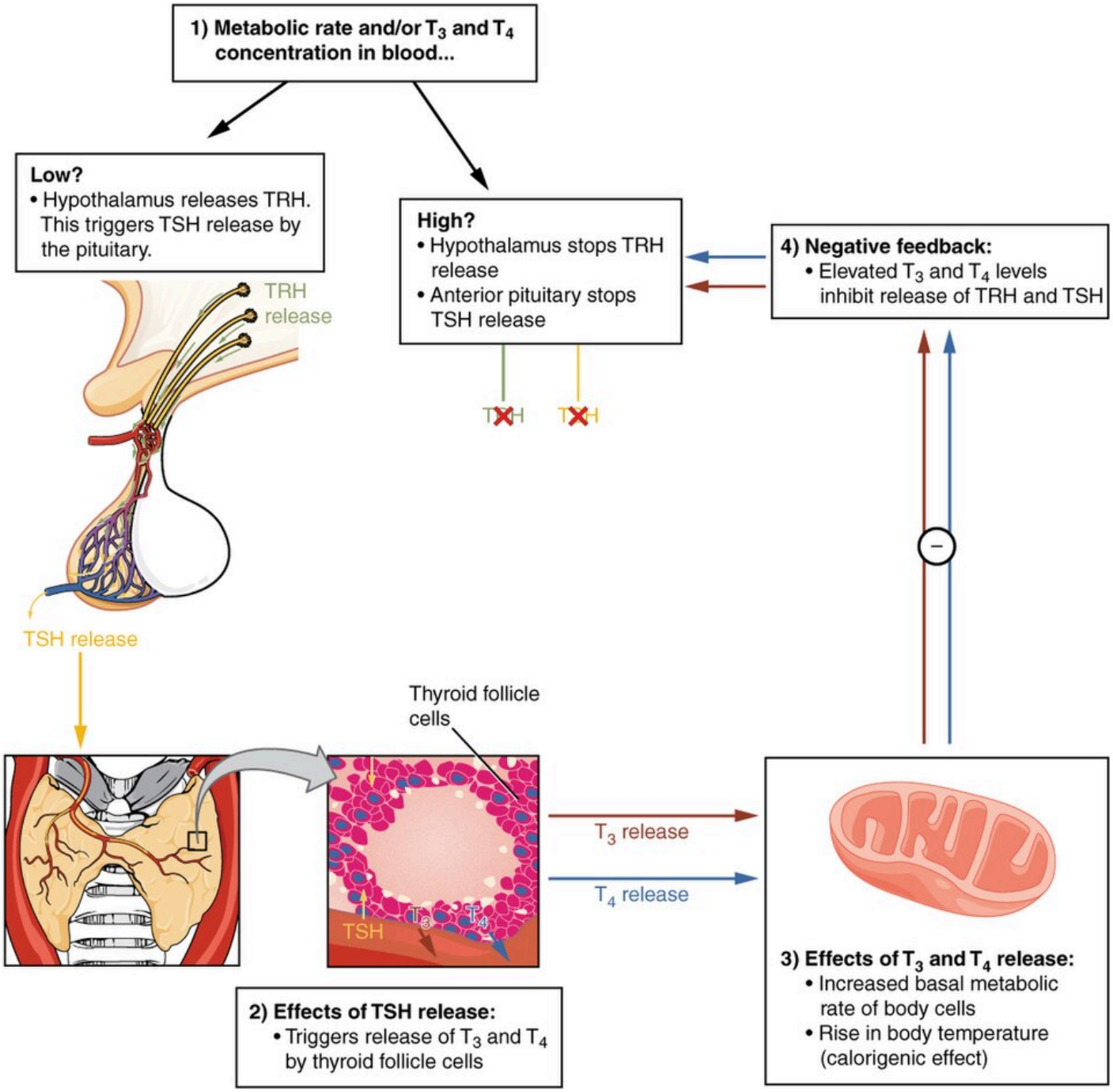


Figure 9.10 Negative Feedback Loop of Thyroid Hormone Levels

Functions of Thyroid Hormones

The thyroid hormones, T3 and T4, are often referred to as metabolic hormones because their levels influence the body's basal metabolic rate, the amount of energy used by the body at rest. Adequate levels of thyroid hormones are also required for protein synthesis and for fetal and childhood tissue development and growth. They are

especially critical for the normal development of the nervous system both in utero and in early childhood, and they continue to support neurological function in adults.

These thyroid hormones also have a complex interrelationship with reproductive hormones, and deficiencies can influence libido, fertility, and other aspects of reproductive function. Finally, thyroid hormones increase the body's sensitivity to epinephrine and norepinephrine from the adrenal medulla by upregulation of receptors in the blood vessels. When levels of T3 and T4 hormones are excessive, this effect accelerates the heart rate, strengthens the heartbeat, and increases blood pressure. Because thyroid hormones regulate metabolism, heat production, protein synthesis, and many other body functions, thyroid disorders can have severe and widespread consequences.

Calcitonin

The thyroid gland also secretes a hormone called **calcitonin** that is produced by the parafollicular cells (also called C cells) of the thyroid gland. Calcitonin is released in response to a rise in blood calcium levels. It is thought to decrease blood calcium levels by inhibiting the activity of osteoclasts, bone cells that release calcium into the circulation by breaking down bone and increasing osteoblastic (bone-building) activity. It also decreases calcium absorption in the intestines and increases calcium loss in the urine.

The hormones released by the thyroid gland and their effects are summarized in Table 9.3b.

Table 9.3b. Thyroid Hormones[34]

34. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Hormones	Effect
Thyroxine (T4), triiodothyronine (T3)	Stimulates basal metabolic rate
Calcitonin	Decreases blood Ca^{2+} levels

Parathyroid Glands

The **parathyroid glands** are tiny, round structures usually found embedded in the posterior surface of the thyroid gland. See Figure 9.11[35] for an illustration of the parathyroid glands and an image of parathyroid tissue. A thick connective tissue capsule separates the glands from the thyroid tissue. Most people have four parathyroid glands, but occasionally there are more in the tissues of the neck or chest. The primary functional cells of the parathyroid glands are the chief cells, which produce and secrete **parathyroid hormone (PTH)**, the major hormone responsible for increasing blood calcium levels.[36]

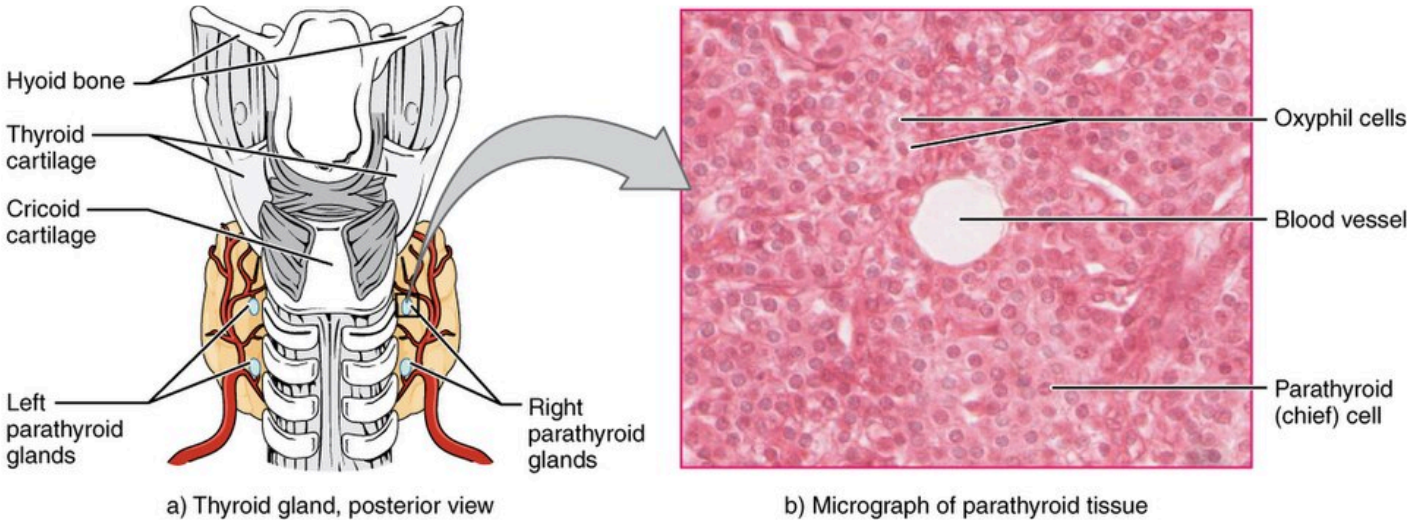


Figure 9.11 Parathyroid Glands: (a) Multiple Parathyroid Glands on the Thyroid Gland and (b) Parathyroid Tissue

The parathyroid glands produce and secrete PTH in response to low blood calcium levels. PTH secretion causes the release of calcium from the bones by stimulating osteoclasts, which secrete enzymes that break down bone and release calcium into the interstitial fluid. PTH also inhibits osteoblasts, the cells involved in bone building, thereby saving blood calcium. PTH also causes increased reabsorption of calcium (and magnesium) in the kidney from the urine filtrate. In addition, PTH initiates the production of the steroid hormone **calcitriol** (also known as 1,25-dihydroxyvitamin D),

35. OpenStax College. (2013). *1814_The_Parathyroid_Glands* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1814_The_Parathyroid_Glands.jpg

36. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

which is the active form of vitamin D3, in the kidneys. Calcitriol then stimulates increased absorption of dietary calcium by the intestines. A negative feedback loop regulates the levels of PTH, with rising blood calcium levels inhibiting further release of PTH. See Figure 9.12[37] for an illustration of this feedback loop.

37. OpenStax College. (2013). *1817_The role of parathyroid hormone in maintaining blood calcium homeostasis* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1817_The_Role_of_Parathyroid_Hormone_in_Maintaining_Blood_Calcium_Homeostasis.jpg

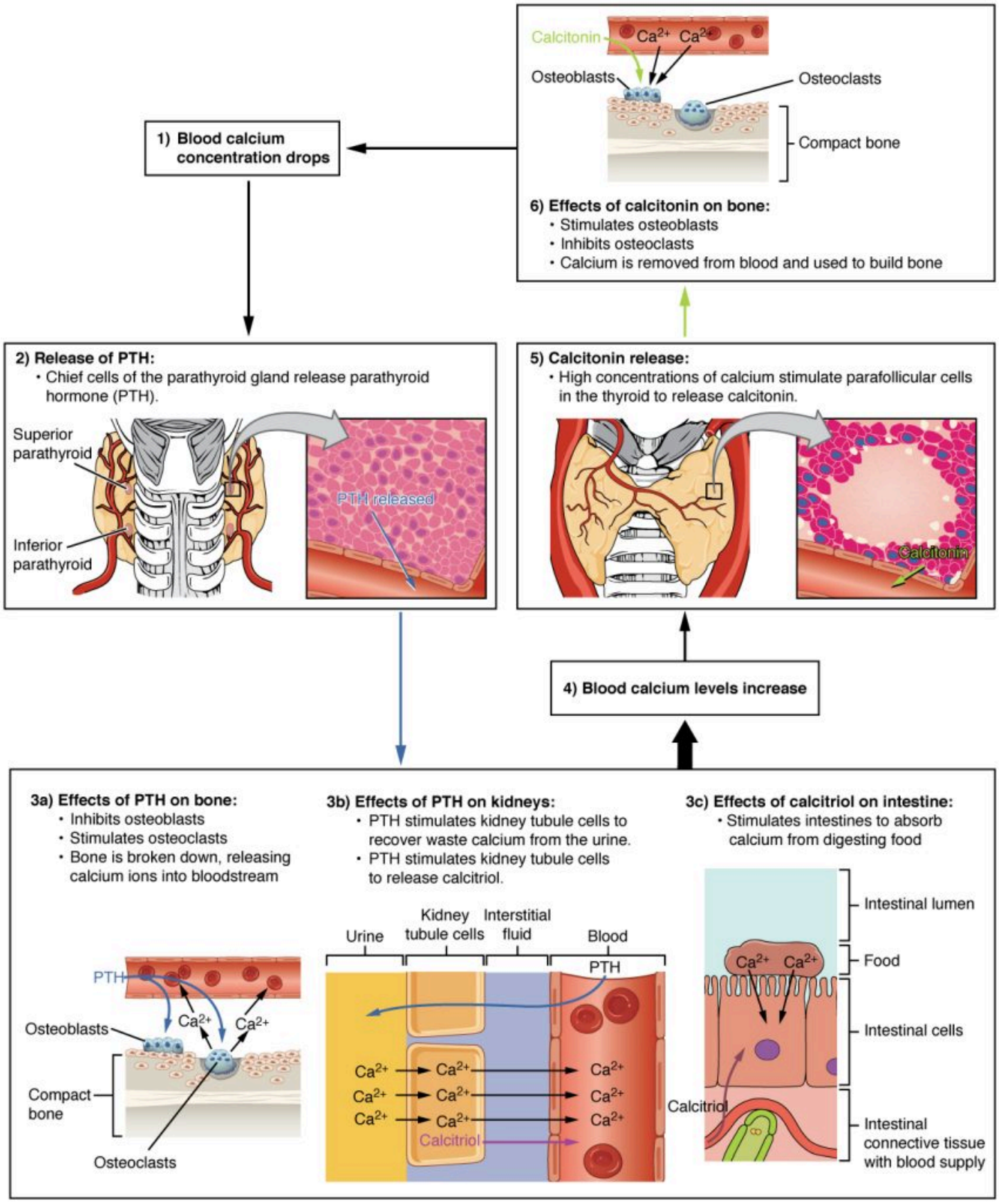


Figure 9.12 Parathyroid Hormone in Maintaining Blood Calcium Homeostasis

Adrenal Glands

The **adrenal glands** are wedges of tissue attached to the top of both kidneys by a fibrous capsule. The adrenal gland consists of an outer cortex of glandular tissue and an inner medulla of nervous tissue. The adrenal glands have a rich blood supply and experience one of the highest rates of blood flow in the body. Blood flows to each adrenal gland at the adrenal cortex and then drains into the adrenal medulla.[38] See Figure 9.13[39] for an illustration of the adrenal gland.

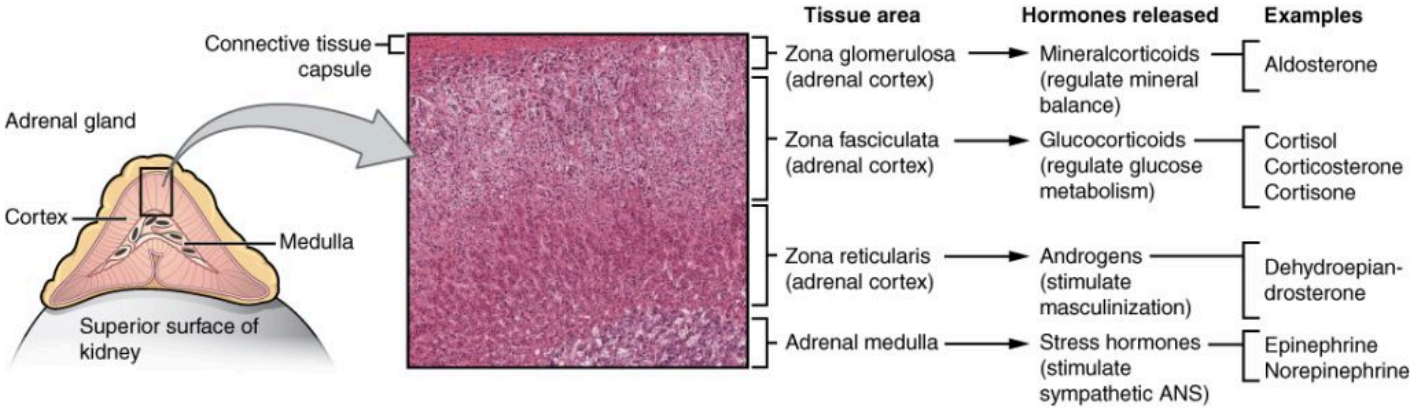


Figure 9.13 Adrenal Glands

The **adrenal cortex** is a component of the hypothalamic-pituitary-adrenal (HPA) axis. The HPA axis involves the secretion of corticotropin-releasing hormone (CRH) from the hypothalamus, which stimulates the secretion of adrenocorticotropic hormone (ACTH) from the pituitary. ACTH then stimulates the adrenal cortex to secrete steroid hormones, such as cortisol, which are important for the regulation of the long-term stress response, blood pressure and blood volume, nutrient uptake and storage, fluid and electrolyte balance, and inflammation.

The **adrenal medulla** is neuroendocrine tissue that is an extension of the autonomic nervous system. Impulses from the hypothalamus stimulate the adrenal medulla to secrete the hormones epinephrine and norepinephrine during the fight-or-flight response.

38. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

39. OpenStax College. (2013). *1818_The_Adrenal_Glands* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1818_The_Adrenal_Glands.jpg

One of the major functions of the adrenal gland is to respond to stress. Stress can be physical, psychological, or both. Physical stressors include illness, injury, malnutrition, or environmental exposures such as being outside in hot, cold, or wet conditions. Psychological stressors include events such as the perception of a physical threat, a fight with a loved one, or a bad day at work or school.

Adrenal hormones also have several non-stress-related functions, including the increase of blood sodium and glucose levels, which will be described in detail later in this chapter.

Adrenal Cortex Hormones

The adrenal cortex produces a group of hormones collectively referred to as **mineralocorticoids** because of their effect on body minerals, especially sodium and potassium. These hormones are essential for fluid and electrolyte balance. **Aldosterone** is the major mineralocorticoid. It is important in the regulation of sodium and potassium ions in the blood, urine, sweat, and saliva. For example, it is released in response to elevated blood potassium (K^+), low blood sodium (Na^+), low blood pressure, or low blood volume. In response, aldosterone increases the excretion of K^+ and the retention of Na^+, which, in turn, increases blood volume and blood pressure.

The adrenal cortex also produces hormones called **glucocorticoids** because of their role in glucose metabolism. The most important of these is **cortisol**, some of which the liver converts to cortisone. Their overall effect is to inhibit tissue building while stimulating the breakdown of stored nutrients to maintain adequate fuel supplies. In conditions of long-term stress, for example, cortisol promotes the breakdown of glycogen to glucose, the breakdown of stored triglycerides into fatty acids and glycerol, and the breakdown of muscle proteins into amino acids. These raw materials can then be used to make additional glucose and ketones for use as body fuels.

You may be familiar with prescription and over-the-counter medications containing glucocorticoids, such as cortisone injections into inflamed joints, prednisone tablets, and steroid-based inhalers used to manage severe asthma, and hydrocortisone creams applied to relieve itchy rashes. These drugs reflect another role of cortisol—the downregulation of the immune system, which reduces the inflammatory response and, in high amounts, can suppress immunity.

The adrenal cortex also produces small amounts of steroid sex hormones called androgens. During puberty and most of adulthood, androgens are produced in the gonads (ovaries and testes). The androgens produced in the adrenal cortex supplement the gonadal androgens. They are produced in response to ACTH from the anterior

pituitary and are converted in the tissues to testosterone or estrogens. In adult females, they may contribute to the sex drive, but their function in adult males is not well-understood. In postmenopausal females, as the functions of the ovaries decline, the main source of estrogens becomes the androgens produced by the adrenal cortex.

Adrenal Medulla Hormones

The adrenal medulla releases hormones in response to acute, short-term stress mediated by the sympathetic nervous system.

The adrenal medulla produces the hormones **epinephrine** (also called adrenaline) and **norepinephrine** (or noradrenaline). Epinephrine is produced in greater quantities—approximately a 4 to 1 ratio with norepinephrine—and is the more powerful hormone.

Both epinephrine and norepinephrine signal the liver and skeletal muscle cells to convert glycogen into glucose, resulting in increased blood glucose levels. These hormones increase the heart rate and blood pressure to prepare the body to fight the perceived threat or flee from it. In addition, they dilate the airways, raising blood oxygen levels. It also prompts vasodilation, further increasing the oxygenation of important organs such as the lungs, brain, heart, and skeletal muscle. At the same time, it triggers vasoconstriction in blood vessels serving less essential organs such as the gastrointestinal tract, kidneys, and skin, and downregulates some components of the immune system. Other effects include a dry mouth, loss of appetite, pupil dilation, and loss of peripheral vision. The major hormones of the adrenal glands and their effects are summarized in Table 9.3c.

Table 9.3c. Hormones of the Adrenal Glands[40]

40. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Adrenal Gland	Hormones	Effect
Adrenal Cortex	Aldosterone	Increases blood Na+ levels, water reabsorption, and K+ excretion by kidneys
Adrenal Cortex	Cortisol, corticosterone, and cortisone	Increases blood glucose levels during the stress response, reduces inflammation, and, in high amounts, suppresses immunity
Adrenal Medulla	Epinephrine and norepinephrine	Stimulates fight-or-flight response

Pineal Gland

The **pineal gland** is located inferior and somewhat posterior to the thalamus in the brain. It is a tiny endocrine gland whose functions are not entirely clear. The pineal gland is known to secrete the hormone **melatonin**, which is derived from serotonin.

The secretion of melatonin varies according to the level of light received from the environment. When light stimulates the retinas of the eyes, blood levels of melatonin fall, promoting wakefulness. In contrast, as light levels decline, such as during the evening, melatonin production increases, boosting blood levels and causing drowsiness.

The secretion of melatonin may influence the body's circadian rhythms, the dark-light fluctuations that affect not only sleepiness and wakefulness, but also appetite and body temperature. Interestingly, children have higher melatonin levels than adults, which may prevent the release of gonadotropins from the anterior pituitary, thereby inhibiting the onset of puberty. Finally, the antioxidant role of melatonin is the subject of current research.

Jet lag occurs when a person travels across several time zones and feels sleepy during the day or wakeful at night. Traveling across multiple time zones significantly disturbs the light-dark cycle regulated by melatonin. It can take up to several days for melatonin synthesis to adjust to the light-dark patterns in the new environment, resulting in jet lag. Some air travelers take melatonin supplements to induce sleep.[41]

See Figure 9.14[42] for an illustration of the pineal gland.

41. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

42. Unknown Author. (n.d.). *Illu_pituitary_pineal_glands* [Diagram]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Illu_pituitary_pineal_glands.jpg

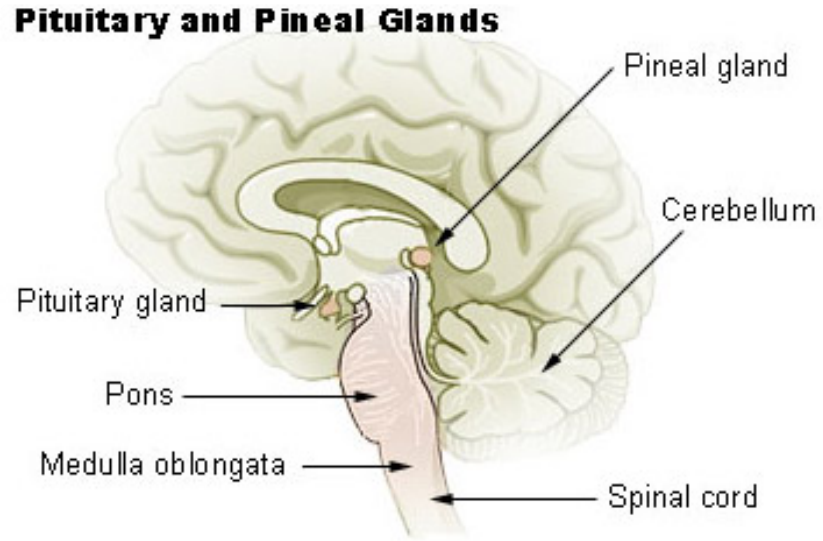


Figure 9.14 Pineal Gland

Ovaries and Testes

The ovaries in the female and the testes in the male are referred to as the gonads. Refer back to Figure 9.1 for an illustration of the ovaries and testes in the endocrine system. The gonads are responsible for producing secondary sex characteristics, as well as the reproductive cells – the sperm in males and the ova (eggs) in females.

The primary hormone produced by the testes is **testosterone**, a steroid hormone important in the development of the reproductive system, the maturing of sperm cells, and the development of secondary sex characteristics such as a deepened voice, body hair, and increased muscle mass. Interestingly, testosterone is also produced in the ovaries, but at a much-reduced level.

The primary hormones produced by the ovaries are **estrogens**, which include estradiol, estriol, and estrone. Estrogens play an important role in a larger number of physiological processes, including the development of the reproductive system, regulation of the menstrual cycle, the development of secondary sex characteristics such as increased adipose tissue and the development of breast tissue, and the maintenance of pregnancy.

Another significant ovarian hormone is **progesterone**, which contributes to the regulation of the menstrual cycle and is important in preparing the body for pregnancy,

as well as maintaining pregnancy.[43] Table 9.3d summarizes hormones produced by the testes and ovaries and their effects.

Table 9.3d. Reproductive Hormones and Their Effects[44]

43. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

44. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Gonad	Hormones	Effect
Testes	Testosterone	Stimulates the development of secondary sex characteristics and sperm production
Ovaries	Estrogens and progesterone	Stimulates the development of secondary sex characteristics, prepares the body for childbirth, and regulates the menstrual cycle

Everyday Connection: Anabolic Steroids

The endocrine system can be exploited for illegal or unethical purposes. A prominent example of this is the use of steroid drugs by professional athletes. Commonly used for performance enhancement, anabolic steroids are synthetic versions of the sex hormone testosterone. By boosting natural levels of this hormone, athletes experience increased muscle mass. Synthetic versions of human growth hormone are also used to build muscle mass.

The use of performance-enhancing drugs is banned by all major collegiate and professional sports organizations in the United States because they impart an unfair advantage to athletes who take them. In addition, the drugs can cause significant and dangerous side effects. For example, anabolic steroid use can increase cholesterol levels, raise blood pressure, and damage the liver. Altered testosterone levels (both too low or too high) have been implicated in causing structural damage to the heart and increasing the risk for cardiac arrhythmias, heart attacks, congestive heart failure, and sudden death. Paradoxically, steroids can have effects such as shriveled testicles and enlarged breast tissue. In females, their use can cause effects such as an enlarged clitoris and growth of facial hair. In all people, their use can promote increased aggression (commonly known as “roid-rage”), depression, sleep disturbances, severe acne, and infertility.

Pancreas

The **pancreas** is a long, slender organ, most of which is located posterior to the bottom half of the stomach. See Figure 9.15[45] for an illustration of the pancreas. Although it is primarily an exocrine gland, secreting a variety of digestive enzymes, the pancreas also has an endocrine function. Its **pancreatic islets**—clusters of cells formerly known

45. OpenStax College. (2013). *1820_The_Pancreas* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1820_The_Pancreas.jpg

as the islets of Langerhans—secrete the hormones glucagon, insulin, somatostatin, and pancreatic polypeptide (PP).[46]

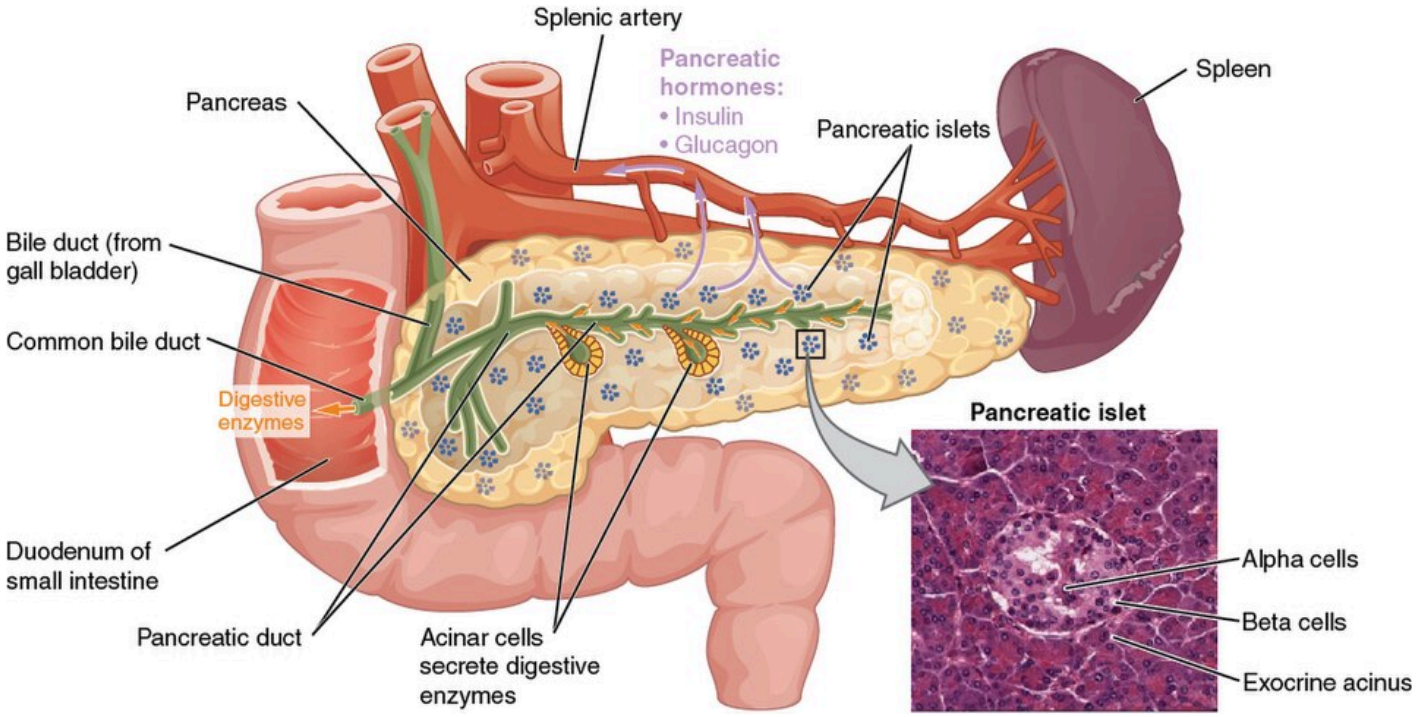


Figure 9.15 Pancreas

Cells and Secretions of the Pancreatic Islets

The pancreatic islets contain four types of cells:

- **Alpha cells** secrete the hormone glucagon, which increases blood glucose. Low blood glucose levels stimulate its release.
- **Beta cells** secrete the hormone **insulin**, which decreases blood glucose levels. Elevated blood glucose levels stimulate the release of insulin.
- **Delta cells** secrete the peptide hormone somatostatin. Somatostatin is also released by the hypothalamus (as GHIH), the stomach, and the intestines. Somatostatin inhibits the release of both glucagon and insulin.
- **PP cells** secrete pancreatic polypeptide hormone. It is thought to play a role in appetite, as well as in the regulation of pancreatic exocrine and endocrine

46. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

secretions. Pancreatic polypeptide, released following a meal, may reduce further food consumption; however, it is also released in response to fasting.

Regulation of Blood Glucose Levels by Insulin and Glucagon

Glucose is the preferred fuel for all body cells. The body derives glucose from the breakdown of the carbohydrate-containing foods and drinks we consume. Glucose not immediately used by cells for fuel can be stored by the liver and muscles as **glycogen** or converted to triglycerides and stored in the adipose tissue. Hormones regulate both the storage and the utilization of glucose. Receptors located in the pancreas sense blood glucose levels, and subsequently, the pancreatic cells secrete glucagon or insulin to maintain normal levels.

Glucagon

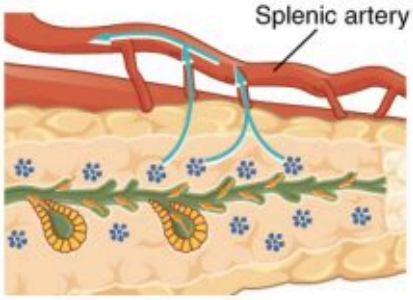
Receptors in the pancreas can sense the decline in blood glucose levels, such as during periods of fasting or during prolonged labor or exercise. In response, the alpha cells of the pancreas secrete the hormone **glucagon**, which has several effects:

- It stimulates the liver to convert its stores of glycogen back into glucose. This response is known as **glycogenolysis**. The glucose is then released into circulation for use by body cells.
- It stimulates the liver to take up amino acids from the blood and convert them into glucose. This response is known as **gluconeogenesis**.
- It stimulates lipolysis, the breakdown of stored triglycerides into free fatty acids and glycerol. Some of the free glycerol released into the bloodstream travels to the liver, which converts it into glucose. This is also a form of gluconeogenesis.

Together, these actions increase blood glucose levels. The activity of glucagon is regulated through a negative feedback mechanism, with rising blood glucose levels inhibiting further glucagon production and secretion. See Figure 9.16[47] for an illustration of the control of glucose levels.

47. OpenStax College. (2013). *1822_The_Homostatic_Regulation_of_Blood_Glucose_Level* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1822_The_Homostatic_Regulation_of_Blood_Glucose_Levels.jpg

Insulin release:
• Beta cells of pancreas release insulin



Insulin effects:

• Triggers body cells to take up glucose from the blood and utilize it in cellular respiration



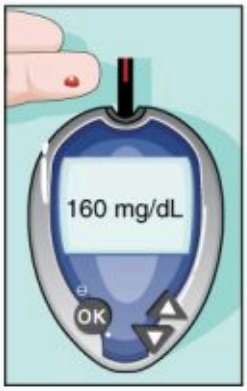
• Inhibits glycogenolysis
– glucose is removed from the blood and stored as glycogen in the liver



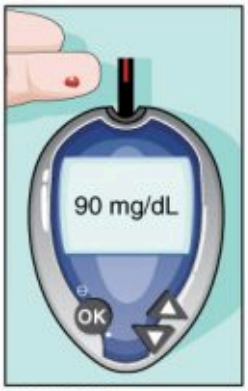

Rough ER

• Inhibits gluconeogenesis
– amino acids and free glycerol are NOT converted to glucose in the ER


Smooth ER



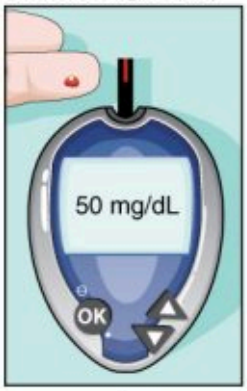
Hyperglycemia
(elevated blood glucose)



Blood glucose concentration decreases

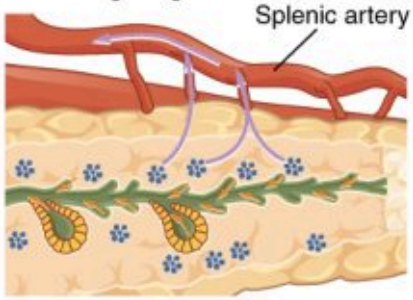
START: Homeostasis
(70–110 mg/dL)

Hypoglycemia
(low blood glucose)



Blood glucose concentration increases

Glucagon release:
• Alpha cells of pancreas release glucagon



Glucagon effects:

• Inhibits body cells from taking up glucose from the blood and utilizing it in cellular respiration



• Stimulates glycogenolysis
– glycogen in the liver is broken down into glucose and released into the blood




Rough ER

• Stimulates gluconeogenesis
– amino acids and free glycerol are converted to glucose in the ER and released into the blood


Smooth ER

Figure 9.16 Regulation of Blood Glucose Levels

Insulin

The primary function of **insulin** is to facilitate the uptake of glucose into body cells, which subsequently lowers blood glucose levels Red blood cells, as well as cells of the brain, liver, kidneys, and the lining of the small intestine, do not have insulin receptors on their cell membranes and do not require insulin for glucose uptake. Although all other body cells do require insulin if they are to take glucose from the bloodstream, skeletal muscle cells and adipose cells are the primary targets of insulin.

Insulin also reduces blood glucose levels by stimulating **glycolysis**, the breakdown of glucose for the generation of ATP. Moreover, it stimulates the liver to convert excess glucose into glycogen for storage, and it inhibits enzymes involved in glycogenolysis and gluconeogenesis. Finally, insulin promotes triglyceride and protein synthesis. The secretion of insulin is regulated through a negative feedback mechanism. As blood glucose levels decrease, further insulin release is inhibited.[48] The pancreatic hormones and their effects are summarized in Table 9.3e.

Table 9.3e. Hormones of the Pancreas

48. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Associated Hormones	Effect
Insulin (beta cells)	Decreases blood glucose levels
Glucagon (alpha cells)	Increases blood glucose levels
Somatostatin (delta cells)	Inhibits insulin and glucagon release
Pancreatic polypeptide (PP cells)	Plays a role in appetite

Video

Watch the video “Endocrine System Explained (Hormones and Glands)” below to learn more about hormones and the endocrine system.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.



9.4 Disorders of the Endocrine System

Addison's Disease (Primary Adrenal Insufficiency)

Addison's disease (also called **primary adrenal insufficiency**) is a disorder that occurs when the adrenal glands do not produce enough cortisol hormone. In many cases, they also do not produce enough aldosterone hormone. This disorder is commonly caused by an autoimmune disease. In fact, people with Addison's disease are more likely to also have another type of autoimmune disease. Symptoms of Addison's disease can start slowly and often include extreme tiredness, salt cravings, and weight loss. Without treatment, adrenal insufficiency can be life-threatening. Treatment involves hormone treatment to replace those that are missing.[1]

Cushing's Disease

Cushing's disease is caused by elevated levels of the cortisol hormone produced by the adrenal glands, which results in a wide variety of symptoms. Cushing's disease affects 10 to 15 per one million people worldwide, and females are at higher risk than males. This condition usually occurs in adults between the ages of 20 and 50, but children may also be affected. The first symptom of Cushing's disease is typically weight gain around the trunk and in the face. Affected individuals may get stretch marks (striae) on their thighs and abdomen, and they may bruise easily. They may also develop a hump on their upper back caused by abnormal deposits of fat. Additional symptoms include muscle weakness, severe tiredness, and progressively thin and brittle bones that are prone to fracture. People with Cushing's disease have a weakened immune system and are at an increased risk of infections. They are also at increased risk of developing high blood pressure and diabetes. Cushing's disease can cause mood disorders such as anxiety, irritability, and depression, and can also affect a person's concentration and memory. Women with Cushing's disease may experience irregular menstruation and

1. Mayo Clinic. (n.d.). *Addison's disease*. https://www.mayoclinic.org/diseases-conditions/addisons-disease/symptoms-causes/syc-20350293?p=1

have excessive hair growth (hirsutism) on their face, abdomen, and legs. Men with Cushing's disease may have erectile dysfunction. Children with Cushing's disease typically experience slow growth. The primary treatment for Cushing's disease involves surgical removal of a tumor in the pituitary gland, which is often the cause of excess cortisol production. Other options include radiation therapy, medications to inhibit cortisol production, or bilateral adrenalectomy (removal of both adrenal glands).[2]

Diabetes Insipidus

Diabetes insipidus is a condition marked by increased thirst and urination. It is not to be confused with the more common type of diabetes, diabetes mellitus.

Central diabetes insipidus is the most common type and is caused by destruction of part of the pituitary gland that produces ADH (vasopressin), which regulates water balance and urine output from the kidneys. In infants and children, this is often an inherited condition. Other causes include tumors, infections, and head injury.

Nephrogenic diabetes insipidus occurs when the pituitary produces enough ADH, but the kidneys fail to recognize it because of an inherited or acquired kidney disease.

Maintaining proper water balance by drinking enough fluids is critical for individuals with diabetes insipidus, as they tend to lose a lot of water with frequent urination, which can lead to life-threatening dehydration. However, drinking too much water is also dangerous, as it may lead to a rare condition called water intoxication.

Symptoms of diabetes insipidus include increased thirst, frequent urination, increased urine volume, pale or colorless watery urine, nocturia, and fatigue due to frequent nighttime urination and interrupted sleep.

Medications that deliver synthetic ADH are the therapy for central diabetes insipidus. For nephrogenic diabetes insipidus, diuretics are used.[3]

2. MedlinePlus [Internet]. (n.d.). *Cushing's disease*. https://medlineplus.gov/genetics/condition/cushing-disease/

3. Johns Hopkins Medicine. (n.d.). *Diabetes insipidus*. https://www.hopkinsmedicine.org/health/conditions-and-diseases/diabetes/diabetes-insipidus

Diabetes Mellitus

Diabetes mellitus is a disorder of the endocrine system where the body has trouble making insulin or using it properly, which affects how cells take in and use glucose (sugar) from the blood. Over 18 million adults and over 200,000 children in the United States have diabetes mellitus, and as many as 7 million adults are estimated to have the condition but have not yet been diagnosed. In addition, approximately 79 million people in the US have prediabetes, a condition in which blood glucose levels are abnormally high, but not yet high enough to be classified as diabetes.

There are two main forms of diabetes mellitus, called type 1 and type 2 diabetes. **Type 1 diabetes mellitus** causes less than 5% of all diabetes cases. It is an autoimmune disease that destroys the beta cells of the pancreas, so they no longer produce insulin. There is no cure for type 1 diabetes, but it is treated with daily synthetic insulin doses. Insulin is administered by injection or continuous infusion pump.

Type 2 diabetes mellitus accounts for approximately 95 percent of all diabetes cases. Around 80 to 90 percent of people with type 2 diabetes are overweight or obese and have contributing lifestyle factors such as poor diet and low physical activity that greatly increase a person's risk. In type 2 diabetes, cells become resistant to insulin. In response, the pancreas increases its insulin secretion, but over time, the beta cells become exhausted. Diabetes is diagnosed when lab tests reveal that blood glucose levels are higher than normal, a condition called **hyperglycemia**. In many cases, type 2 diabetes can be reversed by moderate weight loss, regular physical activity, and a healthy diet. Oral medications are typically prescribed to individuals with type 2 diabetes to stimulate the production of insulin and make body cells more sensitive to insulin. However, if blood glucose levels cannot be controlled with these treatments, the individual will eventually require insulin.

Early symptoms of diabetes mellitus are excessive urination, excessive thirst, and hunger. These symptoms are caused by elevated blood glucose levels that pull water into the blood and, ultimately, result in an abnormally large amount of sugary urine and excessive thirst. The individual may also experience persistent hunger and weight loss because the body's cells are unable to access the glucose in the bloodstream.

Over time, elevated levels of blood glucose injure tissues throughout the body, especially those in the blood vessels and nerves. Inflammation and injury of the lining of arteries can lead to atherosclerosis, resulting in an increased risk of heart attack and stroke. Damage to the microscopic blood vessels of the kidney impairs kidney function and can lead to kidney failure. Damage to blood vessels in the eyes can lead to blindness. Blood vessel damage also reduces circulation to the limbs, where nerve damage leads to

a loss of sensation, called **neuropathy**, particularly in the hands and feet. These changes increase the risk of injury, infection, and tissue death (necrosis), contributing to a high rate of toe, foot, and lower leg amputations in people with diabetes. Together, these complications make diabetes the seventh leading cause of death in the United States.

Uncontrolled diabetes can also lead to a specific type of metabolic acidosis called ketoacidosis. Without glucose, cells increasingly rely on fat stores for fuel. With no glucose, the liver is forced to use lipids, which results in the increased production of ketones that are acidic. The build-up of ketones in the blood causes ketoacidosis, which, if left untreated, can cause a life-threatening "diabetic coma."

Video

Watch the video "Type 2 Diabetes Mellitus Explained" below to learn more about insulin resistance, blood glucose regulation, and the effects of diabetes on the body.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Hyperparathyroidism

Abnormally high activity of the parathyroid glands can cause **hyperparathyroidism**, a disorder caused by an overproduction of parathyroid hormone (PTH) that results in excessive calcium reabsorption from bone. Hyperparathyroidism can significantly decrease bone density, leading to spontaneous fractures or deformities. As blood calcium levels rise, cell membrane permeability to sodium is decreased, and the responsiveness of the nervous system is reduced. At the same time, calcium deposits may collect in the body's tissues and organs, impairing their function.

Hyperparathyroidism is often surgically treated by removing the abnormal parathyroid gland.

Hypoparathyroidism

Abnormally low blood calcium levels may be caused by PTH deficiency, called **hypoparathyroidism**. Hypoparathyroidism may develop after inadvertent removal of the parathyroid glands during surgery involving the thyroid gland. Low blood calcium increases membrane permeability to sodium, resulting in muscle twitching, cramping, spasms, or convulsions. Severe deficits can paralyze muscles, including those involved in breathing, and can be fatal. Treatment includes calcium replacement therapy.

Hyperthyroidism

Hyperthyroidism is an abnormal, elevated level of thyroid hormone in the blood. It is characterized by an increased metabolic rate, excess production of body heat, sweating, diarrhea, weight loss, and increased heart rate. Hyperthyroidism is often caused by a pituitary or thyroid tumor and is more common in females. Hyperthyroidism is also caused by **Graves' disease**, an autoimmune disease in which antibodies overstimulate the thyroid gland. In addition to the hyperthyroidism symptoms previously described, the eyes of an individual with Graves' disease may bulge (called **exophthalmos**), as antibodies produce inflammation in the soft tissues of the orbits. The person may also develop a goiter or enlarged thyroid gland.

Hyperthyroidism can be treated with a combination of approaches, including medication, radioiodine therapy, or surgery. Antithyroid medications are used to control thyroid hormone production, and radioiodine therapy can shrink the thyroid gland. Surgical removal of part of the thyroid may be necessary in certain cases, such as large goiters or when medications are ineffective.

Hypothyroidism

Hypothyroidism is a clinically abnormal, low level of thyroid hormone in the blood. It is characterized by low metabolic rate, weight gain, cold extremities, constipation, and reduced mental activity and is more common in females. Hypothyroidism is treated

by taking daily hormone replacement medication called levothyroxine. Hypothyroidism can be congenital, meaning it is present from birth, and caused by iodine deficiency, or a result of treatment for hyperthyroidism.

Congenital Hypothyroidism

Congenital hypothyroidism is a type of hypothyroidism that is present from birth. Congenital hypothyroidism occurs in about 1 out of every 3,000 to 4,000 newborns, and females are twice as likely to have the condition. Congenital hypothyroidism occurs when a newborn's thyroid gland doesn't develop properly or work as it should, resulting in thyroid hormone deficiency. Left untreated, congenital hypothyroidism can cause developmental delays. In fact, congenital hypothyroidism is one of the most common preventable risk factors for intellectual disability. For this reason, health care providers screen newborns shortly after birth to check their thyroid function with a simple blood test. Most babies with congenital hypothyroidism will need lifelong thyroid hormone replacement, but some babies have temporary hypothyroidism that resolves within a few weeks or months.[4]

Iodine Deficiency

Consumption of dietary iodine is required for the production of thyroid hormones T3 and T4. In many parts of the world, foods don't provide enough iodine because their iodine content depends on the soil, water, and fertilizers used in farming. Therefore, the primary source of dietary iodine in many countries is in the form of iodized salt. Fortification of salt with iodine to prevent hypothyroidism began in the United States in 1924, and international efforts to iodize salt in the world's poorest nations continue today. Iodine deficiency is the main cause of preventable intellectual disabilities worldwide. Neonatal hypothyroidism is characterized by cognitive deficits, short stature, and sometimes deafness and muteness in children born to mothers who were iodine-deficient during pregnancy.

Deficiency of dietary iodine can result in the inability to produce T3 and T4, leading to a variety of severe disorders. When T3 and T4 cannot be produced, TSH is secreted in

4. Cleveland Clinic. (2024). *Congenital hypothyroidism*. https://my.clevelandclinic.org/health/diseases/congenital-hypothyroidism

increasing amounts. As a result of this hyperstimulation, the thyroid gland increases its overall size, a condition called a **goiter**. See Figure 9.17[5] for an illustration of a goiter.



Figure 9.17 Goiter

5. Almazi. (2008). *Goitre* [Photograph]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Goitre.jpg

9.5 Career Connections Related to the Endocrine System

Endocrinology is a specialty in medicine that focuses on the endocrine system and hormone-related disorders. The endocrine system includes glands that release hormones to help regulate growth, metabolism, blood glucose levels, stress responses, reproduction, and many other body functions. While **endocrinologists** and **endocrine surgeons** require advanced medical training, many other professionals help patients manage endocrine-related conditions. Careers related to the endocrine system can include medical assistants, registered nurses, nutrition and dietetic technicians, dietary managers, and health and wellness professionals.

Medical Assistant

Medical assistants work in clinics and other health care settings where they support patient care and office procedures. In endocrinology or primary care settings, medical assistants may help room patients, collect health information, record symptoms, prepare patients for examinations, assist with basic procedures, and communicate follow-up instructions. They may also help patients with routine monitoring related to conditions such as diabetes mellitus or thyroid disorders.

Registered Nurse

Registered nurses provide patient care, education, and support in hospitals, clinics, long-term care facilities, and community settings. This career connects to the endocrine system because nurses may care for patients with diabetes mellitus, thyroid disease, adrenal disorders, or other hormone-related conditions. Nurses may teach patients about blood glucose monitoring, medications, insulin administration, nutrition, skin and foot care, and signs of complications.

Nutrition and Dietetic Technician

Nutrition and dietetic technicians help provide nutrition services under the supervision of registered dietitians or as part of a health care team. This career connects closely to the endocrine system because nutrition plays an important role in managing diabetes mellitus, metabolic disorders, and other conditions affected by hormones. Nutrition and dietetic technicians may help collect diet information, support meal planning, provide basic nutrition education, and assist with food service management.

Dietary Manager

Dietary managers help oversee food service operations in health care, long-term care, and community settings. They may help plan menus, manage food safety, supervise food service staff, and support nutrition care plans. This career connects to the endocrine system because people with diabetes mellitus and other endocrine conditions may need meals that support blood glucose control, balanced nutrition, and overall health.

Health and Wellness Professional

Health and wellness professionals help individuals improve lifestyle habits related to physical activity, nutrition, stress management, and overall well-being. This career connects to the endocrine system because lifestyle choices can affect hormone balance, blood glucose levels, metabolism, and long-term disease prevention. Health and wellness professionals may provide education, encouragement, and support for people working toward healthier routines.

Take a Closer Look

Explore careers related to the human body's endocrine system on these websites.

- Medical assistant from the American Association of Medical Assistants
- Registered nurse from the American Nurses Association

- Diabetes care and education specialist from the Association of Diabetes Care & Education Specialists
- Nutrition and dietetic technician from the Academy of Nutrition and Dietetics
- Dietary manager from the Association of Nutrition & Foodservice Professionals
- Health education specialists and community health workers from the U.S. Bureau of Labor Statistics

9.6 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.



9.7 Glossary

Acromegaly: A disorder that results in the thickening of bones in the face, hands, and feet in response to excessive levels of hGH in individuals who have stopped growing. (Chapter 9.3)

Addison's disease: A disorder in which the adrenal glands do not produce enough cortisol; also called primary adrenal insufficiency. (Chapter 9.4)

Adrenal cortex: The outer layer of the adrenal glands that produces steroid hormones and is part of the hypothalamic-pituitary-adrenal (HPA) axis. (Chapter 9.3)

Adrenal glands: Wedges of tissue attached to the top of each kidney that produce various hormones. (Chapter 9.3)

Adrenal medulla: Neuroendocrine tissue that is an extension of the autonomic nervous system. (Chapter 9.3)

Adrenocorticotropic hormone (ACTH): A hormone from the anterior pituitary that stimulates the adrenal cortex to release corticosteroid hormones like cortisol; also called corticotropin. (Chapter 9.3)

Aldosterone: The main mineralocorticoid hormone that helps balance sodium and potassium levels and controls blood pressure and volume. (Chapter 9.3)

Alpha cells: Secrete the hormone glucagon, which increases blood glucose. Low blood glucose levels stimulate its release. (Chapter 9.3)

Antagonistic effect: When two hormones have opposing effects. (Chapter 9.3)

Antidiuretic hormone (ADH): A hormone released by the posterior pituitary that helps the body retain water when blood osmolality is high, such as during dehydration. (Chapter 9.3)

Beta cells: Secrete the hormone insulin, which decreases blood glucose levels. Elevated blood glucose levels stimulate the release of insulin. (Chapter 9.3)

Blood osmolality: The concentration of dissolved substances (solutes) in the blood, which can change due to diet, illness, medications, or other factors. (Chapter 9.3)

Calcitonin: A hormone from the thyroid's parafollicular (C) cells that lowers blood calcium levels when they rise too high. (Chapter 9.3)

Calcitriol: The active form of vitamin D3 produced in the kidneys under the influence

of parathyroid hormone (PTH); it helps the intestines absorb more calcium from food. (Chapter 9.3)

Cortisol: The main glucocorticoid hormone that helps the body respond to stress by breaking down stored nutrients for energy and slowing tissue building. (Chapter 9.3)

Cushing's disease: A disorder caused by elevated levels of cortisol from the adrenal glands, leading to a wide range of symptoms. (Chapter 9.4)

Delta cells: Secrete the peptide hormone somatostatin. Somatostatin is also released by the hypothalamus (as GHIH), the stomach, and the intestines. It inhibits the release of both glucagon and insulin. (Chapter 9.3)

Diabetes insipidus: A condition characterized by excessive thirst and urination, which is different from the more common diabetes mellitus. (Chapter 9.4)

Diabetes mellitus: A disorder of the endocrine system where the body has trouble making insulin or using it properly, which affects how cells take in and use glucose (sugar) from the blood. (Chapter 9.4)

Downregulation: A process where target cells reduce the number of hormone receptors to decrease their response to high hormone levels. (Chapter 9.3)

Endocrine glands: Primary structural and functional units of the endocrine system. (Chapter 9.3)

Endocrine surgeons: Treat endocrine disease through the removal, or resection, of the affected endocrine gland. (Chapter 9.5)

Endocrinologists: Medical doctors who specialize in treating diseases associated with hormonal systems. (Chapter 9.5)

Endocrinology: A specialty in the field of medicine that focuses on the treatment of endocrine system disorders. (Chapter 9.5)

Epinephrine: A hormone from the adrenal medulla that is produced in large amounts and helps the body respond quickly to stress; also called adrenaline. (Chapter 9.3)

Estrogens: Hormones produced by the ovaries, including estradiol, estriol, and estrone, that regulate the reproductive system, menstrual cycle, female secondary sex traits, and pregnancy. (Chapter 9.3)

Exocrine glands: Release their secretions through ducts. (Chapter 9.3)

Exophthalmos: A condition in which the eyes bulge outward, often associated with hyperthyroidism, especially Graves' disease. (Chapter 9.4)

Fat-soluble: Hormones derived from lipids. (Chapter 9.3)

Follicle-stimulating hormone (FSH): A gonadotropin that promotes the production and development of sex cells (ova in females and sperm in males). (Chapter 9.3)

Gigantism: A disorder in children that is caused by the secretion of abnormally large amounts of hGH, resulting in excessive growth. (Chapter 9.3)

Glucagon: A hormone secreted by alpha cells of the pancreas in response to low blood glucose levels. It raises blood glucose by triggering the release of stored glucose from the liver. (Chapter 9.3)

Glucocorticoids: Hormones from the adrenal cortex that help regulate glucose (sugar) metabolism and the body's response to stress. (Chapter 9.3)

Glycogen: A stored form of glucose found in the liver and muscles, used for energy when blood glucose levels are low. (Chapter 9.3)

Glycogenolysis: The process of converting stored glycogen in the liver back into glucose, which is then released into the blood. (Chapter 9.3)

Gluconeogenesis: The process by which the liver converts amino acids from the blood into glucose. (Chapter 9.3)

Glycolysis: The process of breaking down glucose to produce ATP (energy), stimulated by insulin to help lower blood glucose levels. (Chapter 9.3)

Goiter: An abnormal enlargement of the thyroid gland, often caused by iodine deficiency or thyroid dysfunction. (Chapter 9.4)

Gonadotropins: Hormones from the anterior pituitary that control the ovaries in females and testes in males, regulating reproductive functions. (Chapter 9.3)

Graves' disease: An autoimmune disease in which antibodies overstimulate the thyroid gland. (Chapter 9.4)

Hormone receptor: A protein located either inside the cell or within or on the cell membrane that receives a hormone's message. (Chapter 9.3)

Hormones: A chemical messenger that travels in the blood to target cells and causes a response in the body. (Chapter 9.1)

Human growth hormone (hGH): A protein hormone from the anterior pituitary that supports growth by promoting protein synthesis and tissue building; Also called somatotropin. (Chapter 9.3)

Hyperglycemia: A condition in which blood glucose levels are higher than normal; it is used to diagnose diabetes. (**Chapter 9.4**)

Hyperparathyroidism: A disorder caused by an overproduction of PTH that results in excessive calcium reabsorption from bone. (**Chapter 9.4**)

Hyperthyroidism: An abnormal, elevated level of thyroid hormone in the blood. (**Chapter 9.4**)

Hypoparathyroidism: Abnormally low blood calcium levels may be caused by parathyroid hormone deficiency. (**Chapter 9.4**)

Hypothalamus–pituitary complex: The "command center" of the endocrine system. (**Chapter 9.3**)

Hypothyroidism: A clinically abnormal, low level of thyroid hormone in the blood. (**Chapter 9.4**)

Infundibulum (pituitary stalk): A thin connection between the hypothalamus and the pituitary gland that allows hormones and signals to pass between them. (**Chapter 9.3**)

Inhibiting hormones: Slows or stops the secretion of hormones from the anterior pituitary gland. (**Chapter 9.3**)

Insulin: A hormone secreted by beta cells of the pancreas that decreases blood glucose levels. Elevated blood glucose levels stimulate its release. (**Chapter 9.3**)

Insulin-like growth factors (IGFs): Hormones released by the liver and other tissues in response to growth hormone; they help promote cell growth and tissue repair. (**Chapter 9.3**)

Luteinizing hormone (LH): A gonadotropin that triggers ovulation in females and stimulates testosterone production in males. (**Chapter 9.3**)

Melanocyte-stimulating Hormone (MSH): A hormone produced by cells between the pituitary lobes that helps the skin make melanin in response to UV light. (**Chapter 9.3**)

Melatonin: A hormone produced by the pineal gland that helps regulate the sleep-wake cycle. (**Chapter 9.3**)

Mineralocorticoids: Hormones produced by the adrenal cortex that regulate minerals like sodium and potassium in the body. (**Chapter 9.3**)

Negative feedback loops: The original stimulus is reduced or stopped. (**Chapter 9.3**)

Neuropathy: Loss of sensation caused by nerve damage, often occurring in the hands and feet due to reduced blood flow from blood vessel damage. (**Chapter 9.4**)

Norepinephrine: A hormone from the adrenal medulla that works with epinephrine to prepare the body for stress, but is produced in smaller amounts; also called noradrenaline. (**Chapter 9.3**)

Osmoreceptors: Specialized cells in the hypothalamus that detect changes in blood osmolality by sensing solute levels like sodium. (**Chapter 9.3**)

Oxytocin: A hormone that stimulates uterine contractions and cervical dilation to help with childbirth. (**Chapter 9.3**)

Pancreas: A long, thin organ located mostly behind the lower part of the stomach that produces hormones and digestive enzymes. (**Chapter 9.3**)

Pancreatic islets: Clusters of cells in the pancreas that produce hormones like glucagon, insulin, somatostatin, and pancreatic polypeptide. (**Chapter 9.3**)

Parathyroid glands: Tiny, round structures usually found embedded in the posterior surface of the thyroid gland. (**Chapter 9.3**3)

Parathyroid hormone (PTH): The major hormone responsible for increasing blood calcium levels. (**Chapter 9.3**)

Permissive effect: The presence of one hormone enables another hormone to act. (**Chapter 9.3**)

Pineal gland: A small gland in the brain below and behind the thalamus that produces melatonin, a hormone involved in regulating sleep. (**Chapter 9.3**)

Pituitary dwarfism: A disorder where abnormally low levels of hGH in children can cause growth impairment. (**Chapter 9.3**)

Pituitary gland: A pea-sized organ suspended from a stem called the infundibulum (or pituitary stalk); also known as the hypophysis. (**Chapter 9.3**)

Positive feedback loops: Amplify or exaggerate the original stimulus. (**Chapter 9.3**)

PP cells: Secrete pancreatic polypeptide hormone. It is thought to play a role in appetite and the regulation of pancreatic exocrine and endocrine secretions. (**Chapter 9.3**)

Primary adrenal insufficiency: A disorder in which the adrenal glands do not produce enough cortisol; also called Addison's disease. (**Chapter 9.4**)

Progesterone: A hormone from the ovaries that helps regulate the menstrual cycle and supports pregnancy preparation and maintenance. (**Chapter 9.3**)

Prolactin (PRL): Promotes lactation (milk production). (**Chapter 9.3**)

Receptor: A protein located either inside the cell or within the cell's membrane that binds a hormone. (**Chapter 9.3**)

Releasing hormones: Stimulate the secretion of hormones from the anterior pituitary gland. (**Chapter 9.3**)

Synergistic effect: When two hormones with similar effects produce an amplified or bigger response together. (**Chapter 9.3**)

Target cells: A cell that has specific receptors for a hormone and responds when the hormone binds to it. (**Chapter 9.1**, **Chapter 9.3**)

Testosterone: The main hormone produced by the testes that supports sperm development and causes male secondary sex traits like a deeper voice and muscle growth. (**Chapter 9.3**)

Thyroid gland: A butterfly-shaped organ in the neck, located in front of the trachea and below the larynx. (**Chapter 9.3**)

Thyroid-stimulating hormone (TSH): A hormone from the anterior pituitary that signals the thyroid gland to release thyroid hormones; also called thyrotropin. (**Chapter 9.3**)

Thyroxine (T4): A thyroid hormone with four iodine atoms that regulates metabolism and is converted into the active form, T3. (**Chapter 9.3**)

Triiodothyronine (T3): A thyroid hormone with three iodine atoms that helps regulate metabolism. (**Chapter 9.3**)

Type 1 diabetes mellitus: An autoimmune disease that destroys the pancreas's beta cells, preventing insulin production. It accounts for less than 5% of all diabetes cases. (**Chapter 9.4**)

Type 2 diabetes mellitus: A condition accounting for about 95% of all diabetes cases, often linked to overweight or obesity and lifestyle factors like poor diet and low physical activity. (**Chapter 9.4**)

Upregulation: A process where target cells increase the number of hormone receptors to increase their sensitivity to hormones present. (**Chapter 9.3**)

Water-soluble hormones: Hormones derived from amino acids include amines, peptides, and proteins. (**Chapter 9.3**)

PART X

CHAPTER 10 BLOOD

10.1 Introduction to Blood

Chapter Competency

Analyze how components of the cardiovascular system function in the body.

Learning Objectives

- Describe the microscopic components of blood.
- Summarize the functions of blood and each of its components.
- Describe the basis for blood typing.

Imagine you are working as a phlebotomist collecting a blood sample from a patient for laboratory testing. The results may provide information about oxygen transport, infection, clotting ability, blood type, hydration, or signs of disease. To understand why blood tests are so important, you must first understand what blood is made of, how it functions, and how its components help maintain homeostasis.

Blood is a specialized connective tissue that circulates throughout the **cardiovascular system**. It is made of plasma and formed elements, including erythrocytes, leukocytes, and thrombocytes. These components allow blood to transport oxygen, carbon dioxide, nutrients, hormones, and wastes; regulate pH, fluid balance, and body temperature; and protect the body through immune responses and clot formation.

Hematology is the study of blood cells and the tissues that form them. In this chapter, you will explore the functions, characteristics, and components of blood. You will learn about plasma, red blood cells, white blood cells, and platelets, as well as the process of hemostasis that helps stop bleeding. You will also study hemopoiesis, the process by which blood cells are produced, and examine the basis for ABO and Rh blood typing. Finally, you will learn about common hematological disorders and how changes in blood components can affect health.

By mastering these concepts, you will gain a deeper understanding of how blood supports transportation, regulation, protection, and homeostasis. This foundation will

help you connect blood structure and function to patient assessment, laboratory testing, transfusions, clotting, immune function, oxygen delivery, and disorders of the cardiovascular system.

10.2 Functions of Blood

Blood is a connective tissue. Like all connective tissues, it is made up of cellular elements and an extracellular matrix. The cellular elements—referred to as the **formed elements**—include **erythrocytes**, also called **red blood cells (RBCs)**; **leukocytes**, also called **white blood cells (WBCs)**, and **thrombocytes**, also called **platelets**. The extracellular matrix, called **plasma**, makes blood unique among connective tissues because it is a fluid. This fluid, which is mostly water, suspends the formed elements and enables them to circulate throughout the body within the cardiovascular system.[1]

The primary function of blood is transportation. Other functions of blood also include the regulation of homeostasis and protection.

Transportation

Blood transports nutrients, oxygen, carbon dioxide, hormones, and wastes. Nutrients from the food you eat are absorbed in the digestive tract and travel through the bloodstream to the liver, where they are processed and released back into the bloodstream for delivery to body cells. Oxygen diffuses into the blood in the lungs and is carried to tissues and cells throughout the body. Carbon dioxide is picked up from cells and transported to the lungs, where it is exhaled. Hormones are released by endocrine glands and carried to target cells in the bloodstream. Blood also picks up cell wastes and by-products from cells and transports them to various organs for removal.[2]

Regulation of Homeostasis

Blood helps regulate homeostasis in many ways. Proteins and other molecules in the blood act as **buffers** that help to regulate the pH of body tissues. Blood also helps

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

to maintain the chemical balance of the body and regulate the water content of body cells. Additionally, blood helps regulate body temperature through a classic negative feedback loop. For example, if you exercise outside on a warm day, your rising body temperature triggers several homeostatic mechanisms, including increased transportation of blood from your core to the skin, which is typically cooler. As blood passes through the vessels of the skin, heat dissipates to the environment, resulting in the blood returning to your core being cooler. In contrast, on a cold day, blood is diverted away from the skin to prevent heat dissipation, which maintains a warmer core body temperature.[3]

Protection

Many types of white blood cells (WBCs) protect the body from external threats, such as disease-causing bacteria that enter the bloodstream. Other types of WBCs seek out and destroy internal threats, such as cells with mutated DNA that could multiply and become cancerous or cells that are infected with viruses.

Platelets help protect the body from excessive bleeding. If a blood vessel is damaged from an injury, platelets stimulate blood clot formation to prevent further blood loss.[4]

3. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

4. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

10.3 Characteristics of Blood

Blood makes up approximately 8% of an adult's total body weight. On average, adult females have about 4–5 liters of blood, and adult males have about 5–6 liters. However, total blood volume is influenced more by overall body size than by gender.

The pH of blood ranges from 7.35 to 7.45 in a healthy person. Blood is considered slightly more basic (alkaline) on a chemical scale than pure water, which has a pH of 7.0. Blood contains numerous buffers that help to maintain a normal pH.

Blood that is fully oxygenated is bright red, whereas blood that has released oxygen in the tissues is a dusky red. This change in coloring is because hemoglobin in the blood is a pigment that changes color depending on the amount of oxygen it is carrying.

Blood is viscous and somewhat sticky to the touch. **Viscosity** is a measure of a fluid's thickness or resistance to flow. Blood has a viscosity approximately five times greater than water due to the presence of plasma proteins and formed elements (RBCs, WBCs, and platelets). The viscosity of blood significantly impacts blood pressure and blood flow. For example, consider the difference in flow between water and honey. The more viscous honey has a greater resistance to flow than the less viscous water. The same principle applies to blood flow.

The normal temperature of blood is slightly higher than normal body temperature. Blood temperature is about 38°C (100.4°F), compared to body temperature of 37°C (or 98.6°F). The temperature of blood is slightly higher due to the heat produced as it flows through blood vessels and experiences friction and resistance, especially as vessels age and lose their elasticity.[1]

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

10.4 Components of Blood

As mentioned previously, the major components of the blood are plasma and formed elements. Formed elements are the cellular components of blood that include erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (platelets). See Figure 10.1[1] for an image of a red blood cell, platelet, and white blood cell.

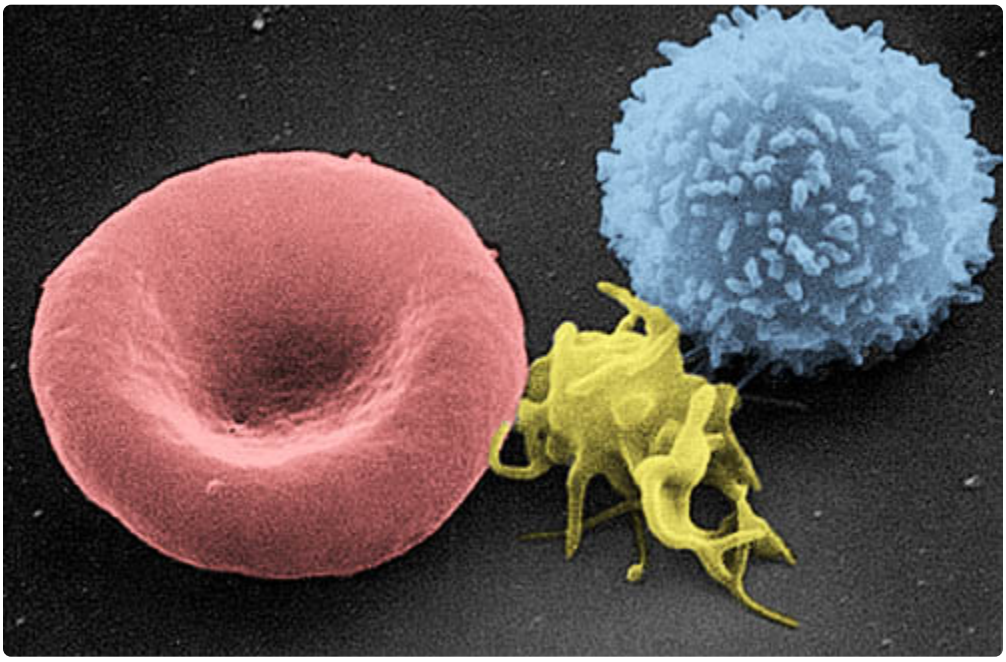


Figure 10.1 Red Blood Cell, Platelet, and White Blood Cell

See Table 10.4a for an overview of blood components.

Table 10.4a. Blood Components[2]

1. Electron Microscopy Facility. *Red_White_Blood_cells* [Photograph]. The National Cancer Institute at Frederick. Public Domain. https://commons.wikimedia.org/wiki/File:Red_White_Blood_cells.jpg
2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Component and % of Blood	Subcomponent and % of Component	Type and % (Where Appropriate)	Site of Production	Major Functions
Plasma 46–63%	Water 92%	Fluid	Absorbed by the intestinal tract or produced by metabolism	Transport medium
	Plasma proteins 7%	Albumin 54–60%	Liver	Maintain osmotic concentration; transport lipid molecules
		Globulins 35–36%	Alpha globulins – liver	Transport and maintain osmotic concentration
			Beta globulins – liver	Transport and maintain osmotic concentration
			Gamma globulins (immunoglobulins) – plasma cells	Immune responses
		Fibrinogen 4–7%	Liver	Blood clotting in hemostasis

	Regulatory proteins < 1%	Hormones and enzymes	Various sources	Regulate various body functions
	Other solutes 1%	Nutrients, gases, and wastes	Absorbed by the intestinal tract, exchanged in the respiratory system, or produced by cells	Numerous and varied
Formed elements 37–54%	Erythrocytes 99%	Erythrocytes	Red bone marrow	Transports gases, primarily oxygen and some carbon dioxide
	Leukocytes < 1%	Granular leukocytes: neutrophils, eosinophils, basophils	Red bone marrow	Nonspecific immunity

		Agranular leukocytes: lymphocytes, monocytes	Lymphocytes: bone marrow and lymphatic tissue	Lymphocytes: nonspecific and specific immunity
			Monocytes: red bone marrow	Monocytes: nonspecific immunity
	Platelets < 1%		Megakaryocytes: red bone marrow	Hemostasis

See Table 10.4b for a summary of the functions of the formed elements found in the blood.

Table 10.4b. Formed Elements in the Blood[3]

3. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Formed Element	Major Subtypes	Numbers Present Per Microliter (ul) and Mean (range)	Appearance in Standard Blood Smear	Summary of Functions	Comments
Erythrocytes (red blood cells)		5.3 million (4.4–6.0 million)	Flattened biconcave desk, no nucleus, and pale red color	Transport oxygen and some carbon dioxide between tissues and lungs	Life span of approximately 120 days
Leukocytes (white blood cells)		7,000 (5,000–10,000)	Obvious dark-staining nucleus	All function in body defenses	Exit capillaries and move into tissues; life span of usually a few hours or days
Leukocytes (white blood cells)	Granulocytes, including neutrophils, eosinophils, and basophils	4,360 (1,800–9,950)	Abundant granules in cytoplasm; nucleus normally lobed	Nonspecific (innate) resistance to disease	Classified according to membrane-bound granules in cytoplasm
	Neutrophils	4,150 (1,800–7,300)	Nuclear lobes increase with age; pale lilac granules	Phagocytic; particularly effective against bacteria. Release cytotoxic chemicals from granules	Most common leukocyte; life span of minutes to days

Eosinophils	165 (0–700)	Nucleus generally two-lobed; bright red-orange granules	Phagocyte cells; particularly effective with antigen-antibody complexes. Release antihistamines. Increase in allergies and parasitic infections	Life span of minutes to days
Basophils	44 (0–150)	Nucleus generally two-lobed but difficult to see due to presence of heavy, dense, dark purple granules	Promotes inflammation	Least common leukocyte; life span unknown
Agranulocytes, including lymphocytes and monocytes	2,640 (1,700–4,950)	Lacks abundant granules in cytoplasm; have a simple-shaped nucleus that may be indented	Body defenses	Group consists of two major cell types from different lineages

	Lymphocytes	2,185 (1,500–4,000)	Spherical cells with a single often large nucleus occupying much of the cell's volume; stains purple; seen in large (natural killer cells) and small (B and T cells) variants	Primarily specific (adaptive) immunity: T cells directly attach other cells (cellular immunity); B cells release antibodies (humoral immunity); natural killer cells are similar to T cells but non-specific	Initial cells originate in bone marrow, but secondary production occurs in lymphatic tissue; several distinct subtypes; memory cells form after exposure to a pathogen and rapidly increase responses to subsequent exposure; life span of many years
	Monocytes	455 (200–950)	Largest leukocyte with an indented or horseshoe-shaped nucleus	Very effective phagocytic cells engulfing pathogens or worn-out cells; also serve as antigen-presenting cells (APCs) for other components of the immune system	Produced in red bone marrow; referred to as macrophages after leaving circulation

Platelets	350,000 (150,000–500,000)	Cellular fragments surrounded by a plasma membrane and containing granules; purple stain	Hemostasis; release growth factors for repair and healing of tissue	Formed from megakaryocytes that remain in the red blood marrow and shed platelets into circulation

Each blood component is discussed in more detail in the following subsections.

Plasma

Plasma is a straw-colored fluid that transports a mixture of substances, most of which are proteins. Plasma is composed of about 92% water.

Plasma Proteins

About 7% of the volume of plasma—nearly all that is not water—is made of proteins. These include several **plasma proteins** (proteins that are unique to the plasma), plus a much smaller number of regulatory proteins, including enzymes and some hormones.

The three major groups of plasma proteins are as follows:

- **Albumin**: Albumin is the most abundant of the plasma proteins. Albumin normally accounts for approximately 54% of the total plasma protein content, with a normal blood sample level of 3.5–5.0 g/dL. Manufactured by the liver, albumin molecules serve as binding proteins that transport fatty acids and steroid hormones. Lipids are hydrophobic, so binding to albumin enables their transport in the watery plasma. Albumin also contributes to the osmotic pressure of blood, meaning its presence holds water inside the blood vessels and also draws water from the tissues into the bloodstream. Osmotic pressure helps to maintain blood volume and blood pressure.
- **Globulins**: Globulins are the second most common type of plasma proteins and make up approximately 38% of the total plasma protein volume, with a normal blood sample level of 1.0–1.5 g/dL. There are three main subgroups known as alpha, beta, and gamma globulins. The alpha and beta globulins transport iron, lipids, and the fat-soluble vitamins A, D, E, and K to the cells, and like albumin, they also contribute to osmotic pressure. The gamma globulins are proteins involved in immunity and are commonly known as **antibodies (Ab)** or **immunoglobulins (Ig)**. Although other plasma proteins are produced by the liver, immunoglobulins are produced by specialized leukocytes known as plasma cells.
- **Fibrinogen**: Fibrinogen is the third major plasma protein and accounts for about 7% of the total plasma protein volume, with a normal blood sample level of 0.2–0.45 g/dL. Fibrinogen is essential for blood clotting. Like albumin and the alpha and beta globulins, fibrinogen is produced by the liver.[4]

Other Plasma Solutes

In addition to proteins, plasma contains a wide variety of other substances that make up approximately 1% of the total volume of plasma. These substances include various electrolytes, such as sodium, potassium, and calcium ions; dissolved gases, such as oxygen, carbon dioxide, and nitrogen; various organic nutrients, such as vitamins, lipids, glucose, and amino acids; and metabolic wastes.

See Figure 10.2[5] for an illustration of the components of blood and plasma after a blood sample was centrifuged in a test tube.

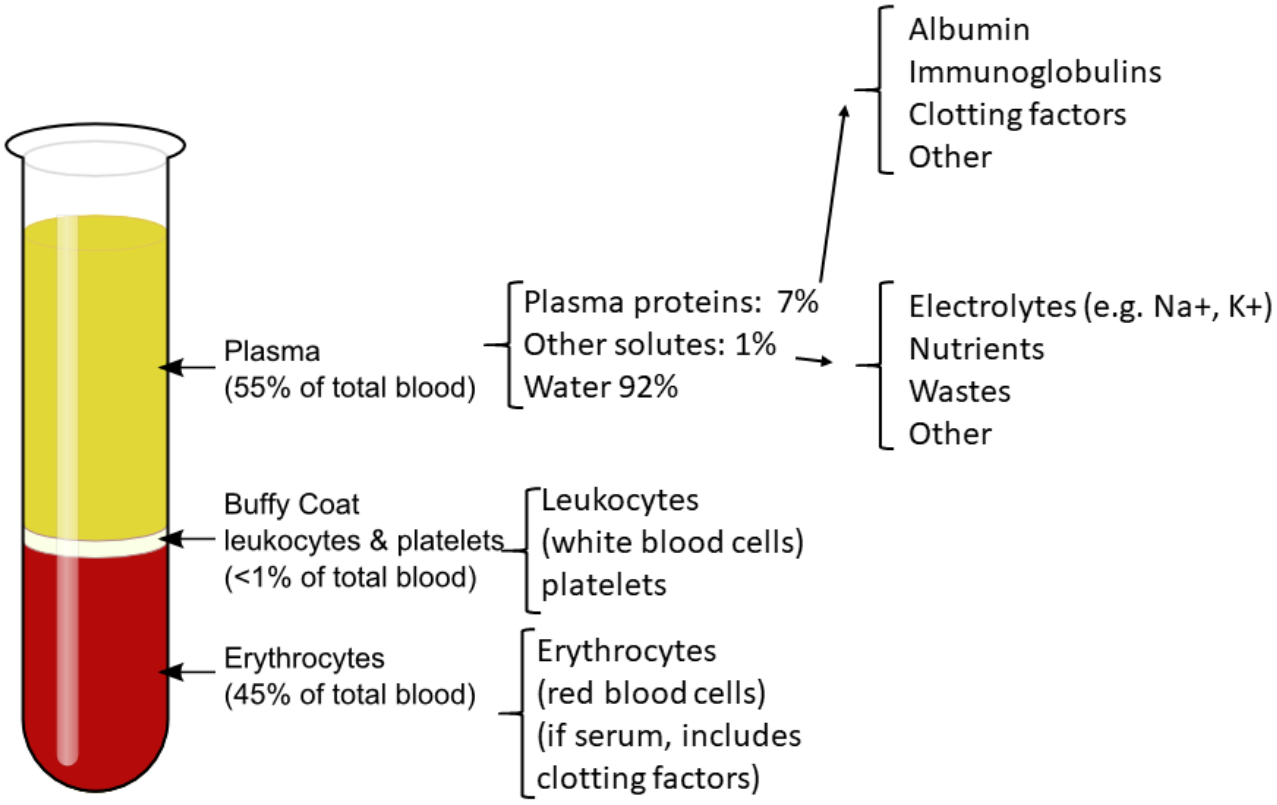


Figure 10.2 Components of Blood and Plasma

4. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

5. Alan Sved. (2019). *Components_of_blood* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Components_of_blood.png

Erythrocytes (Red Blood Cells)

The **erythrocyte**, commonly known as a red blood cell (RBC), is the most abundant formed element. A single drop of blood contains millions of erythrocytes and only thousands of leukocytes. Specifically, males have about 5.4 million erythrocytes per microliter (μL) of blood, and females have approximately 4.8 million per μL. In fact, erythrocytes are estimated to make up about 25% of the total cells in the body. As you can imagine, they are quite small cells, with a mean diameter of only about 7–8 micrometers (μm).[6]

Functions of Erythrocytes

The primary function of erythrocytes is to carry oxygen from the lungs to the body's tissues, but they also pick up some carbon dioxide from the tissues and transport it to the lungs for exhalation. Erythrocytes can release a chemical called nitric oxide to dilate blood vessels (vasodilation) to decrease blood pressure. Erythrocytes remain within blood vessels.[7]

Anatomy of Erythrocytes

As an erythrocyte matures, the nucleus and most of its other organelles are ejected. During the first day or two that it is in circulation, an immature erythrocyte, known as a **reticulocyte**, often contains remnants of organelles that are quickly shed as it matures. Reticulocytes make up about 1–2% of the erythrocyte count and provide a rough estimate of the rate of RBC production.

Erythrocytes are biconcave disks, meaning they are plump around the edge and very thin in the center. See Figure 10.3[8] for an image of erythrocytes. Because they lack most

6. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

7. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

8. OpenStax College. (2013). *1903_Shape_of_Red_Blood_Cells* [Image]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1903_Shape_of_Red_Blood_Cells.jpg

organelles, there is more interior space for hemoglobin molecules to transport gases. The biconcave shape also provides a greater surface area for gas exchange to occur.

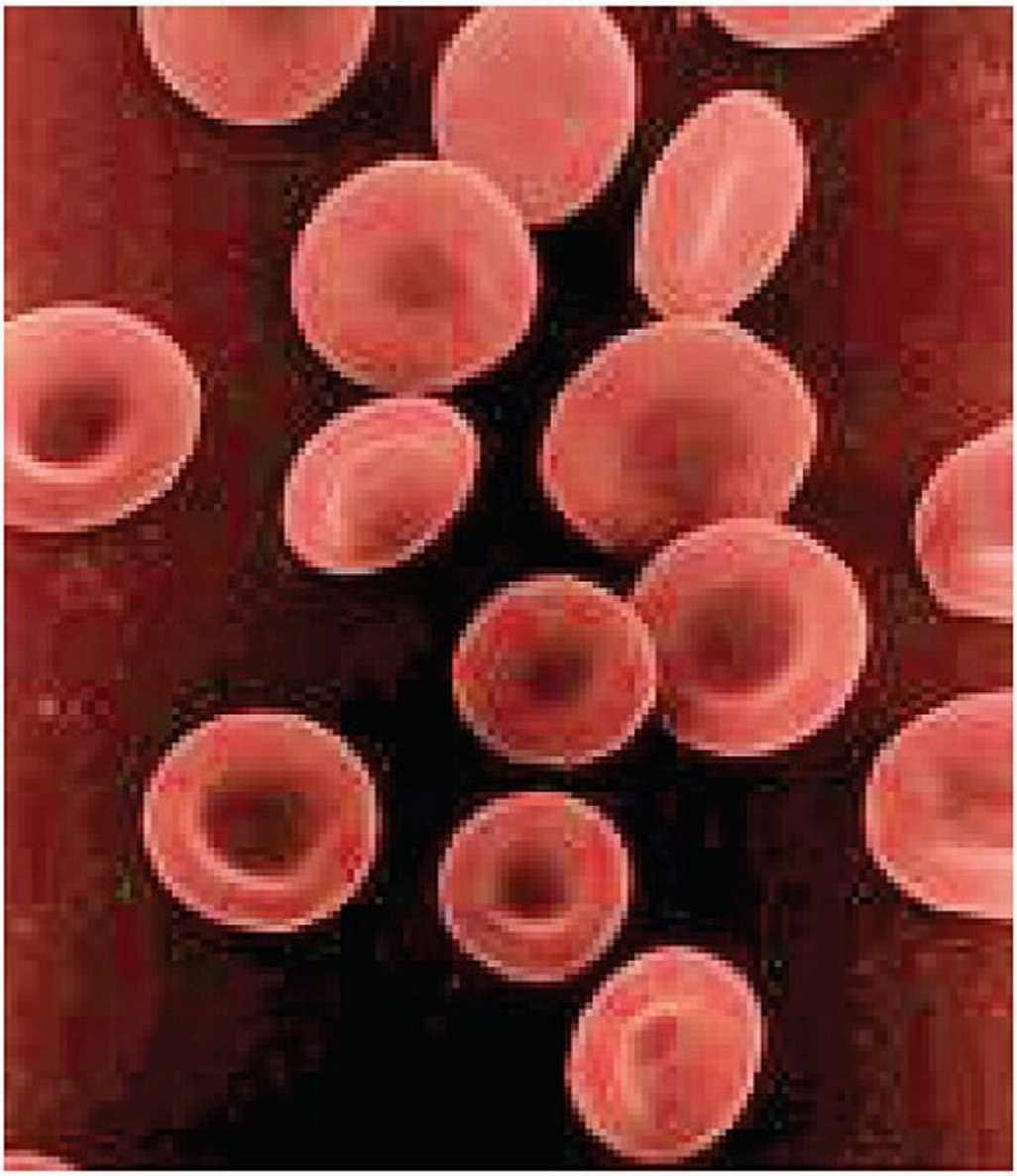


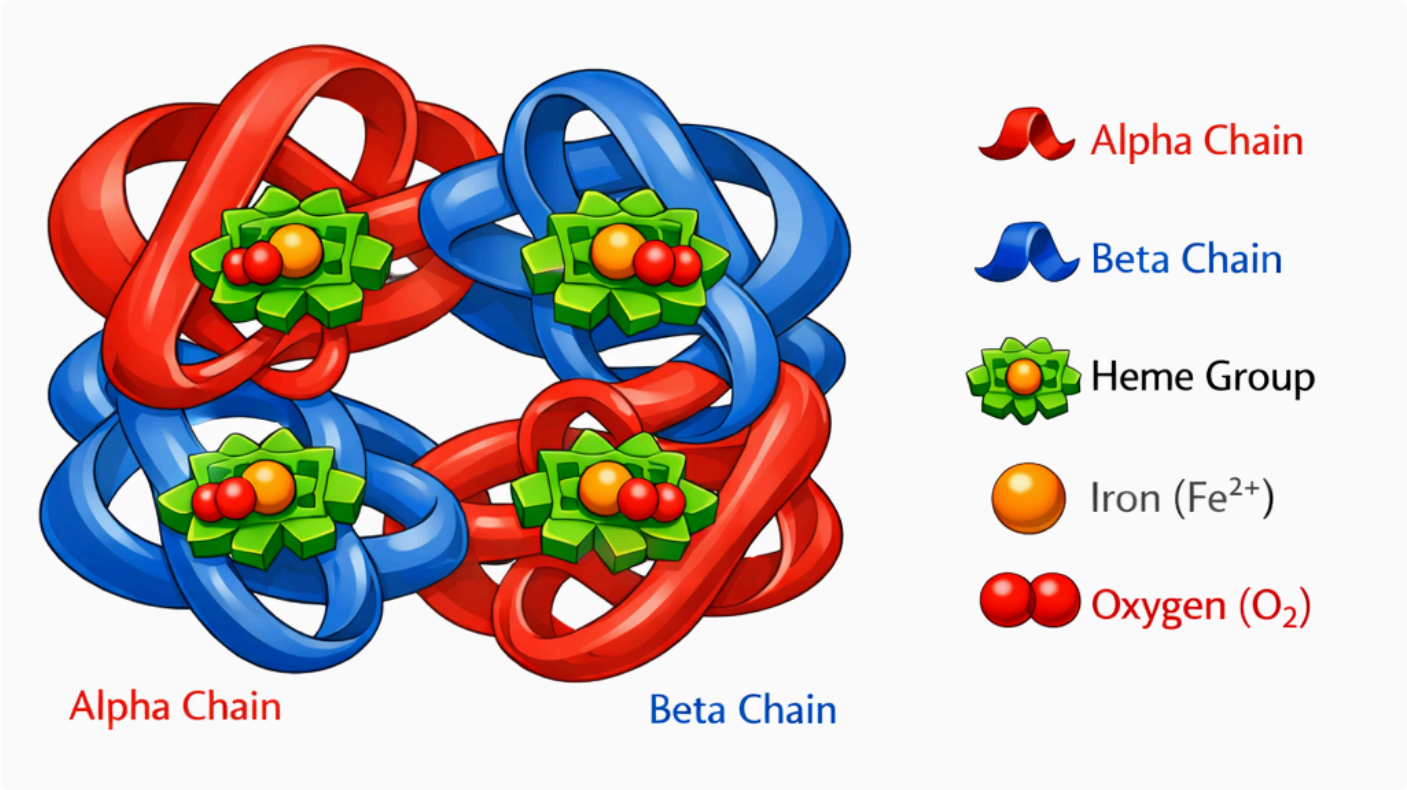
Figure 10.3 Erythrocytes

Capillary beds are extremely narrow, which slows the passage of the erythrocytes and provides an extended opportunity for gas exchange to occur. However, the space within capillaries can be so small that erythrocytes may have to fold in on themselves to make it through. Fortunately, their structural proteins are flexible, allowing them to bend and then spring back again when they enter a wider vessel.[9]

9. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young,

Hemoglobin

Hemoglobin is a large molecule made up of four protein chains. Each chain holds an iron atom capable of binding to an oxygen molecule. Each hemoglobin molecule can transport four oxygen molecules. An individual erythrocyte contains about 300 million hemoglobin molecules, and, therefore, can bind to and transport up to 1.2 billion oxygen molecules. See Figure 10.4[10] for an illustration of a hemoglobin molecule.



10.4 Hemoglobin Molecule

Hematocrit

A **hematocrit** is a blood test that measures the percentage of erythrocytes (RBCs) in a blood sample. A hematocrit is performed by spinning a blood sample in a centrifuge,

K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

10. WisTech Open. (2026). *Hemoglobin molecule by J. Brown & R. Keys* [Diagram]. Chippewa Valley Technical College. CC BY-SA 4.0.

a process that causes the heavier elements in the blood sample to separate from the lightweight liquid plasma. Because the RBCs are the heaviest components of blood, they settle at the bottom of the test tube. Located above the RBCs in the test tube is a pale, thin layer composed of the remaining formed elements, including the white blood cells (leukocytes) and the platelets (thrombocytes). This thin layer is referred to as the **buffy coat** because of its color and normally makes up less than 1% of a blood sample. Above the buffy coat is the blood plasma, a pale, straw-colored fluid. See Figure 10.5[11] for an illustration of the hematocrit blood test. Depressed and elevated hematocrit levels associated with anemia and polycythemia are shown for comparison to normal hematocrit levels.[12]

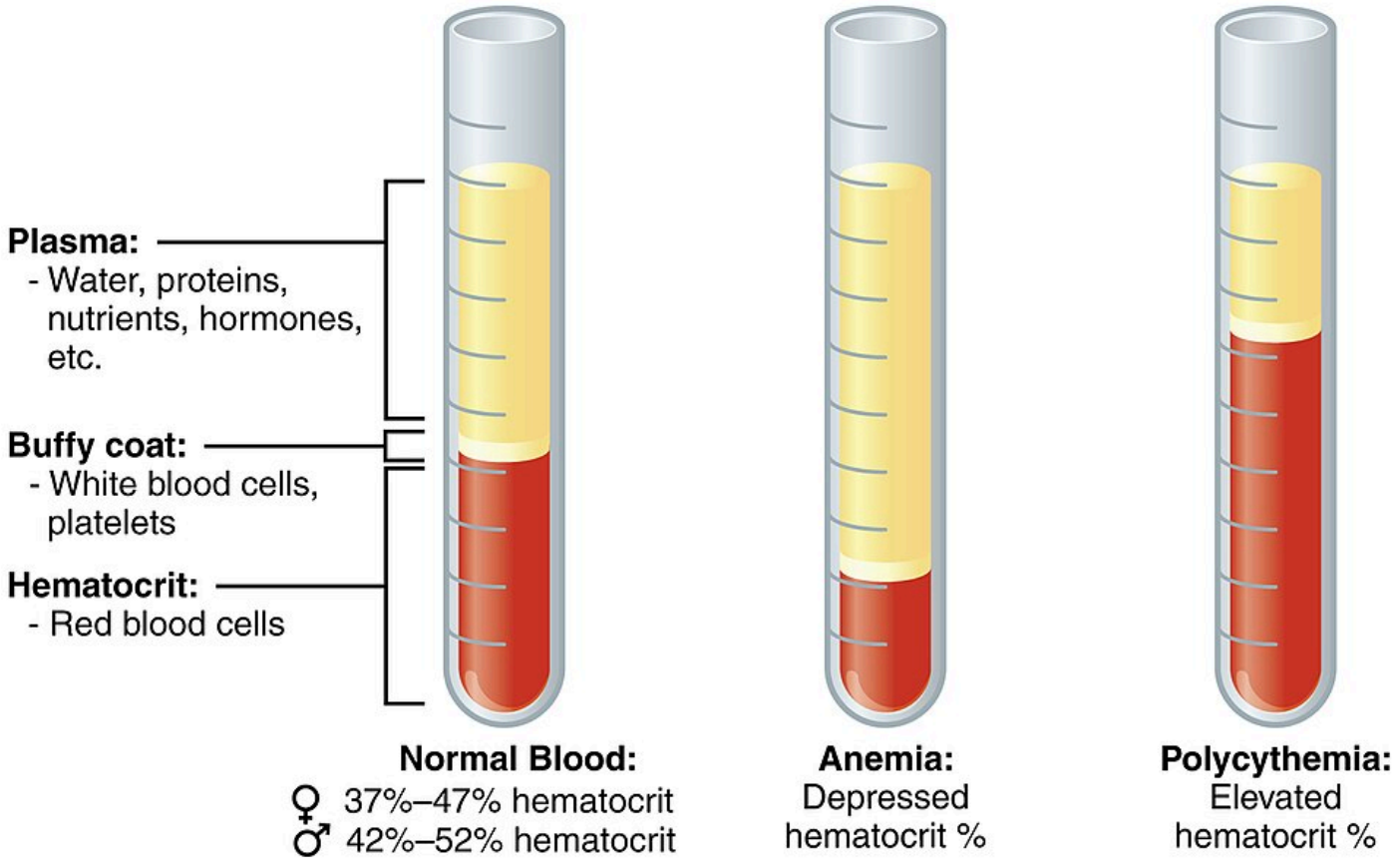


Figure 10.5 Hematocrit

11. OpenStax College. (2013). *1901_Composition_of_Blood* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1901_Composition_of_Blood.jpg

12. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Life Cycle of Erythrocytes

Erythropoiesis is the production of erythrocytes. It is stimulated by erythropoietin, a hormone made by the kidneys, and occurs in the red bone marrow at the staggering rate of more than 2 million cells produced per second. Erythrocytes live up to 120 days in the circulation, after which the worn-out cells are removed by a phagocytic cell called a **macrophage** in the bone marrow, liver, and spleen.[13]

Leukocytes

Leukocytes, commonly known as white blood cells (WBCs), are essential components of the immune system. Leukocytes protect the body against invading microorganisms, as well as destroy cells with mutated DNA. There are several different types of leukocytes, including neutrophils, basophils, lymphocytes, monocytes, and eosinophils. See Figure 10.5[14] for an illustration of different types of leukocytes.[15]

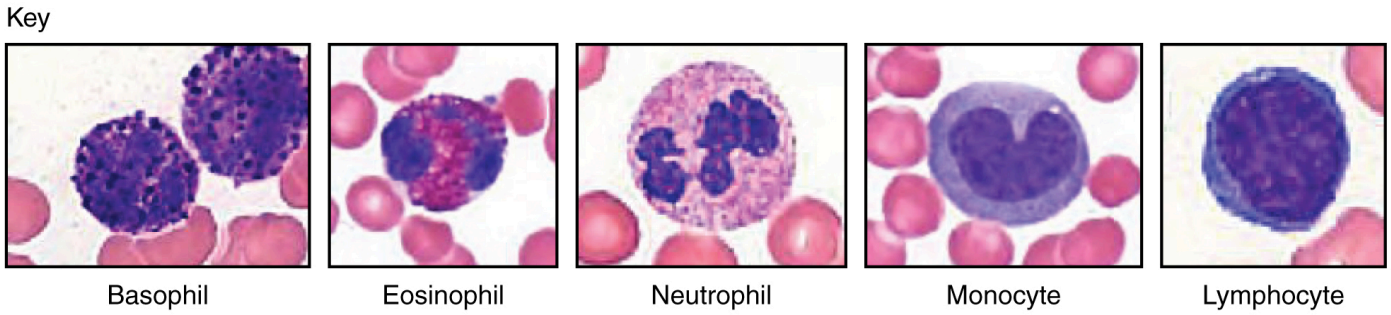


Figure 10.6 Types of Leukocytes

13. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

14. OpenStax College. (2013). *1916_Leukocyte_Key* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1916_Leukocyte_Key.jpg

15. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Characteristics of Leukocytes

Although leukocytes and erythrocytes both originate from hematopoietic stem cells in the red bone marrow, they are very different. Leukocytes are far less numerous but larger than erythrocytes, with about 5,000–10,000 per μL of blood. They are the only formed elements that are complete cells, meaning they possess a nucleus and organelles. Most leukocytes have a shorter life span than erythrocytes, some as short as a few hours or even a few minutes in cases of acute infection.

One of the most distinctive characteristics of leukocytes is their movement. While erythrocytes spend their days circulating within the blood vessels, leukocytes routinely leave the bloodstream to perform their defensive functions in the body's tissues. For leukocytes, the vascular network is simply a highway they use to travel to and then exit at their destination. When they arrive, they are often given distinct names, such as macrophage or microglia, depending on their function.

After leukocytes have exited the capillaries, some take fixed positions in lymphatic tissue and bone marrow or the spleen, thymus, or other organs. Others will move about through the tissue spaces like amoebas, wandering freely or moving toward the direction in which they are drawn by chemical signals.[16]

Classification of Leukocytes

Leukocytes can be divided into two groups based on whether their cytoplasm contains highly visible granules:

- **Granular leukocytes** contain abundant granules within their cytoplasm. They include neutrophils, eosinophils, and basophils.
- **Agranular leukocytes** have far fewer and less obvious granules. Agranular leukocytes include monocytes and lymphocytes.[17]

16. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

17. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Granular Leukocytes

Granulocytes are produced in the red bone marrow and have a short life span of hours to days. They typically have a lobed nucleus and are classified according to which type of stain best highlights their granules. See Figure 10.7[18] for an illustration of three types of granulocytes.[19]

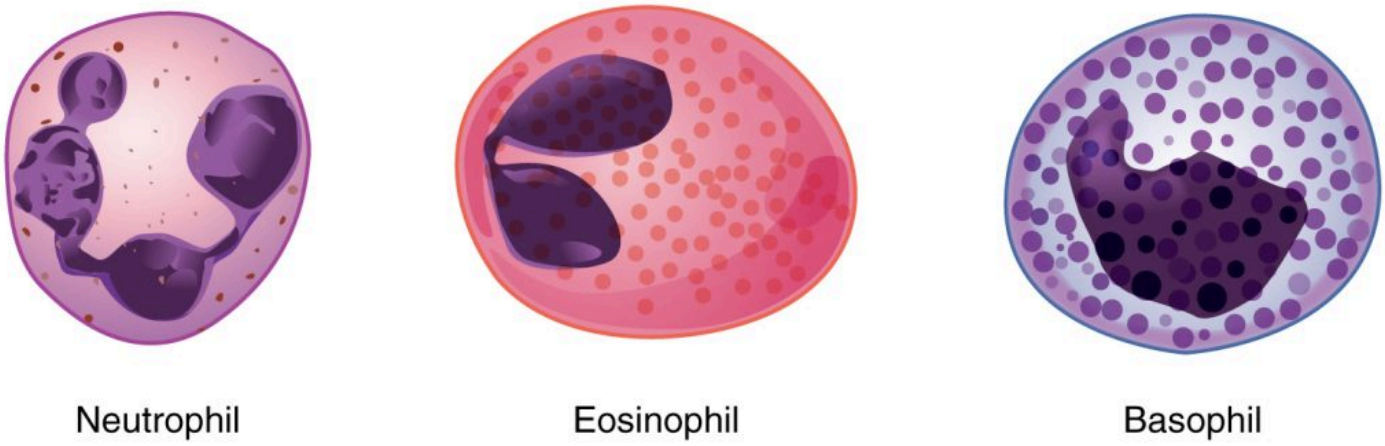


Figure 10.7 Granular Leukocytes

Neutrophils

The most common leukocytes are **neutrophils**, which comprise 50–70% of the total leukocyte count. They are 10–12 μm in diameter, much larger than erythrocytes. They are called neutrophils because their granules show up most clearly with a stain that is chemically neutral (neither acidic nor basic).

Granules are present and numerous but have a fine, light lilac appearance. Their nuclei have a distinct lobed appearance and may have two to five lobes, with the number increasing based on the age of the cell. Older neutrophils have increasing numbers of lobes and are often referred to as **polymorphonuclear (PMN)**, meaning a nucleus with many forms, or simply "polys." Young and immature neutrophils begin to develop lobes and are known as "bands."

18. OpenStax College. (2013). *1907_Granular_Leukocytes* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1907_Granular_Leukocytes.jpg

19. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Neutrophils are rapid responders to the site of infection and are efficient phagocytes with a preference for bacteria. Abnormally high counts of neutrophils indicate infection and/or inflammation, typically triggered by bacteria, but high counts are also found in patients with burns in order to fight off infection that can result from the destruction of the skin barrier. Low counts may be caused by high levels of stress and side effects of certain medications, and increase an individual's susceptibility to infection.[20]

Eosinophils

Eosinophils typically make up about 2–4% of total leukocytes and are roughly 10–12 μm in diameter. The granules of eosinophils stain best with an acidic stain known as eosin, and if stained properly, the granules will have a distinct red to orange color. Their nucleus typically has two to three lobes.

The granules of eosinophils include enzymes that may counteract the activities of histamine, an inflammatory chemical produced by basophils and mast cells. Some eosinophil granules contain molecules that are toxic to parasitic worms that can enter the body through the skin or by consumption of raw or undercooked fish or meat. Eosinophils are also capable of phagocytosis. High eosinophil counts are typically caused by allergies, parasitic worm infestations, and some autoimmune diseases. Low counts may be due to drug toxicity and stress.[21]

Basophils

Basophils are the least common leukocytes, typically making up less than 1% of the total leukocyte count. They are slightly smaller than neutrophils and eosinophils at 8–10 μm in diameter. The granules of basophils stain best with a basic (alkaline) stain. Basophils contain large granules that pick up a dark blue stain and are so numerous that they may make it difficult to see the two-lobed nucleus.

The granules of basophils release histamine that contributes to inflammation and heparin, which prevents blood clotting. High counts of basophils are associated with

20. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

21. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

allergies, parasitic infections, and hypothyroidism. Low counts are associated with pregnancy, stress, and hyperthyroidism.[22]

Agranular Leukocytes

Agranular leukocytes contain smaller, less-visible granules in their cytoplasm compared to granular leukocytes. The nucleus is simple in shape, sometimes with an indentation but without distinct lobes. There are two major types of agranulocytes: lymphocytes and monocytes.[23]

Lymphocytes

Lymphocytes are the second most common type of leukocyte, accounting for about 20–30% of all leukocytes, and are essential for the immune response. The size range of lymphocytes is quite extensive, ranging from 6–17 μm. Refer back to Figure 10.6 for an illustration of lymphocytes.

The three major types of lymphocytes include natural killer cells, B cells, and T cells. **Natural killer (NK) cells** are capable of recognizing cells that do not express "self" proteins on their plasma membrane or that contain foreign or abnormal markers. These "nonself" cells include cancer cells, cells infected with a virus, and other cells with atypical surface proteins. Thus, they provide generalized, nonspecific immunity. NK cells are larger than other lymphocytes.

B cells and T cells, also called **B lymphocytes** and **T lymphocytes**, play prominent roles in defending the body against specific pathogens (disease-causing microorganisms) and are involved in specific immunity. One form of B cells (plasma cells) produces the antibodies or immunoglobulins that bind to specific foreign or abnormal components of plasma membranes. This is referred to as humoral immunity. Many types of T cells have been identified. One type of T cell (CD8 cell) provides cell-mediated immunity by physically attacking foreign or diseased cells. Another type of T cell (CD4) can either assist with cell-mediated immunity or humoral immunity. Other T cells serve as regulatory cells.

22. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

23. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

A **memory cell** is a variety of both B and T cells that forms after exposure to a pathogen to "remember" that pathogen and mount rapid responses during subsequent exposures. Unlike other leukocytes, memory cells live for many years.

B cells mature in the bone marrow, whereas T cells mature in the thymus. This site of maturation gives rise to the names B and T cells.

Abnormally high lymphocyte counts are characteristic of viral infections, as well as some types of cancer. Abnormally low lymphocyte counts are characteristic of prolonged (chronic) illness or immunosuppression, including that caused by HIV infection and drug therapies that often involve steroids.[24]

Monocytes

Monocytes represent 2–8% of the total leukocyte count. They are typically easily recognized by their large size of 12–20 μm and indented or horseshoe-shaped nuclei. Refer back to Figure 10.6 for an illustration of monocytes.

Macrophages are monocytes that have left the circulation and phagocytize debris, foreign pathogens, worn-out erythrocytes, and many other dead, worn-out, or damaged cells. Some macrophages stay in fixed locations, whereas others wander through the tissue fluid.

Abnormally high counts of monocytes are associated with viral or fungal infections, tuberculosis, and some forms of leukemia and other chronic diseases. Abnormally low counts are typically caused by suppression of the bone marrow.[25]

Wisc-Online Interactive Activity

Complete the Wisc-Online interactive activity **"White Blood Cells"** to practice identifying different types of white blood cells using images and review questions.

24. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

25. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Platelets

Platelets are referred to as **thrombocytes**. A platelet is not a whole cell, but rather a fragment of the cytoplasm of a cell called a **megakaryocyte**. Each megakaryocyte releases 2,000–3,000 platelets during its life span. Following platelet release, megakaryocyte remnants, which are little more than a cell nucleus, are consumed by macrophages. See Figure 10.8[26] for an illustration of platelet formation.

26. OpenStax College. (2013). *1908_Platelet_Development* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1908_Platelet_Development.jpg

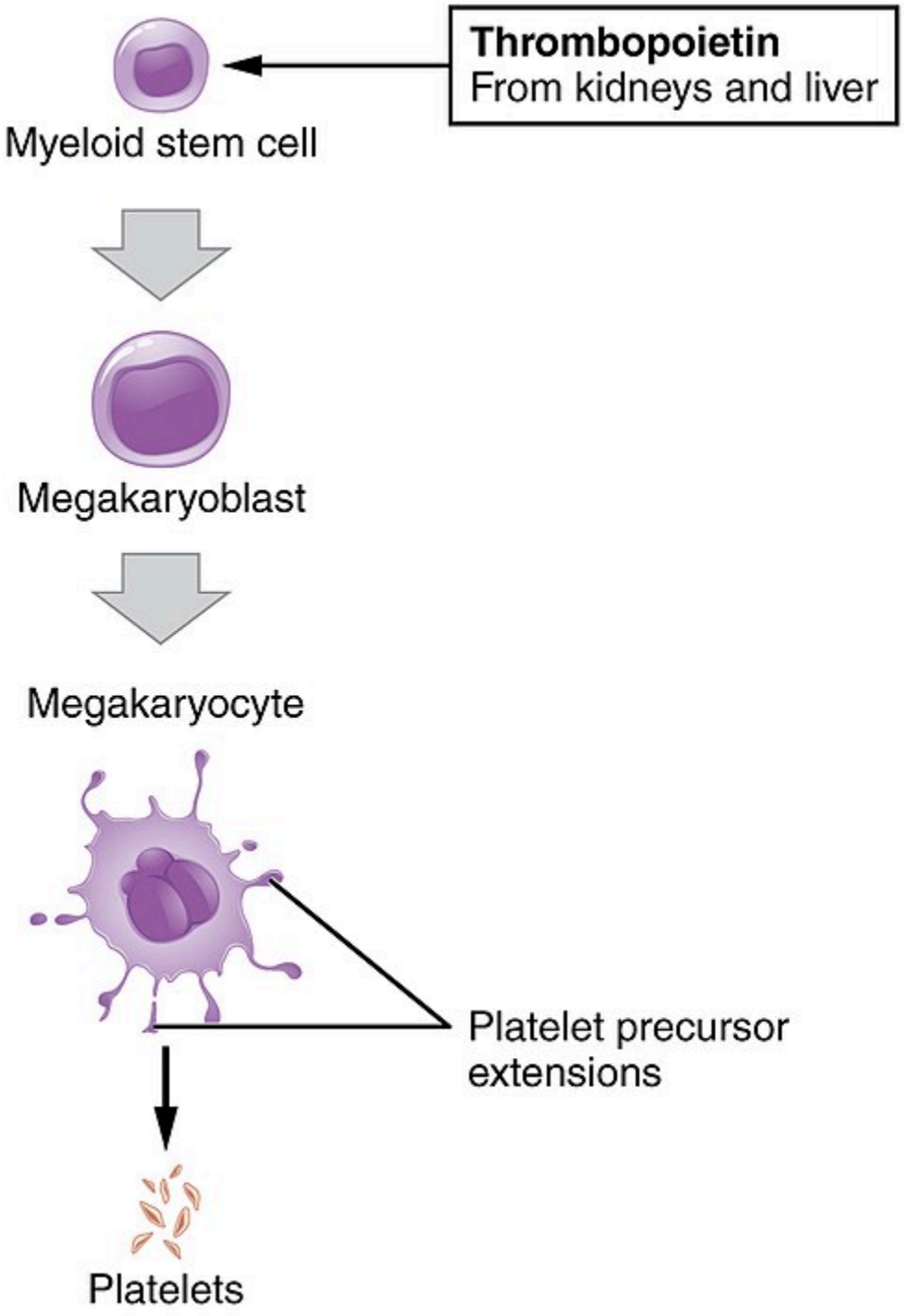


Figure 10.8 Platelets Derived From Megakaryocytes

Platelets are relatively small, 2–4 μm in diameter, but numerous, with typically 150,000–450,000 per μL of blood. After entering the circulation, approximately one-third migrate to the spleen for storage for later release in response to any rupture in a blood vessel. When released, they become activated to perform their primary function, which

is to limit blood loss. Platelets live only about ten days and then are phagocytized by macrophages.

Platelets are critical to **hemostasis**, the stoppage of blood loss following damage to a vessel. Hemostasis is further described in the following section. They also secrete a variety of growth factors essential for growth and repair of tissue, particularly connective tissue. Infusions of concentrated platelets are now being used in some therapies to stimulate healing.

Video

Watch the video "Blood Explained (Structure and Function Overview)" below to learn more about the components and functions of blood.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

10.5 Hemostasis

Although rupture of larger vessels usually requires medical intervention, hemostasis is very effective in dealing with small, simple wounds. There are three steps to the process: vascular spasm, the formation of a platelet plug, and coagulation (blood clotting). Failure of any of these steps will result in **hemorrhage** (excessive bleeding).[1]

Vascular Spasm

When a vessel is damaged, vascular spasm occurs to reduce blood loss. In a **vascular spasm**, the smooth muscle in the walls of the vessel constricts dramatically. The vascular spasm response is believed to be caused by several chemicals and by pain receptors in response to vessel injury. It typically lasts for up to 30 minutes, although it can last for hours.[2]

Formation of the Platelet Plug

In the second step, platelets, which normally float free in the plasma, are attracted to the damaged vessel by chemicals. Platelets become spiked and sticky, clump together, and bind to the damaged blood vessel wall. Platelets release chemicals that attract more platelets until a **platelet plug** is formed. This process is an example of positive feedback. A platelet plug can temporarily seal a small opening in a blood vessel until more durable repairs are made. The platelets also release chemicals that will stimulate coagulation, the next step.[3]

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
3. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Coagulation

The more durable repairs are collectively called **coagulation**, meaning the formation of a blood clot. This process is sometimes described as a cascade because a complex series of chronological chemical reactions happens, involving various proteins called clotting factors, where one step prompts the next. The result is a strong clot made up of a mesh of **fibrin**—an insoluble filamentous protein made from the plasma protein fibrinogen. Platelets and red blood cells are trapped within this fibrin mesh, much like fish would be caught in a net. See Figure 10.9[4] for a summary of the three steps of hemostasis. The stabilized clot is acted on by contractile proteins within the platelets. As these proteins contract, they pull on the fibrin threads, bringing the edges of the clot more tightly together, similar to what we do when tightening loose shoelaces. This process is called clot retraction.[5]

4. OpenStax College. (2013). *1909_Blood_Clotting* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1909_Blood_Clotting.jpg

5. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

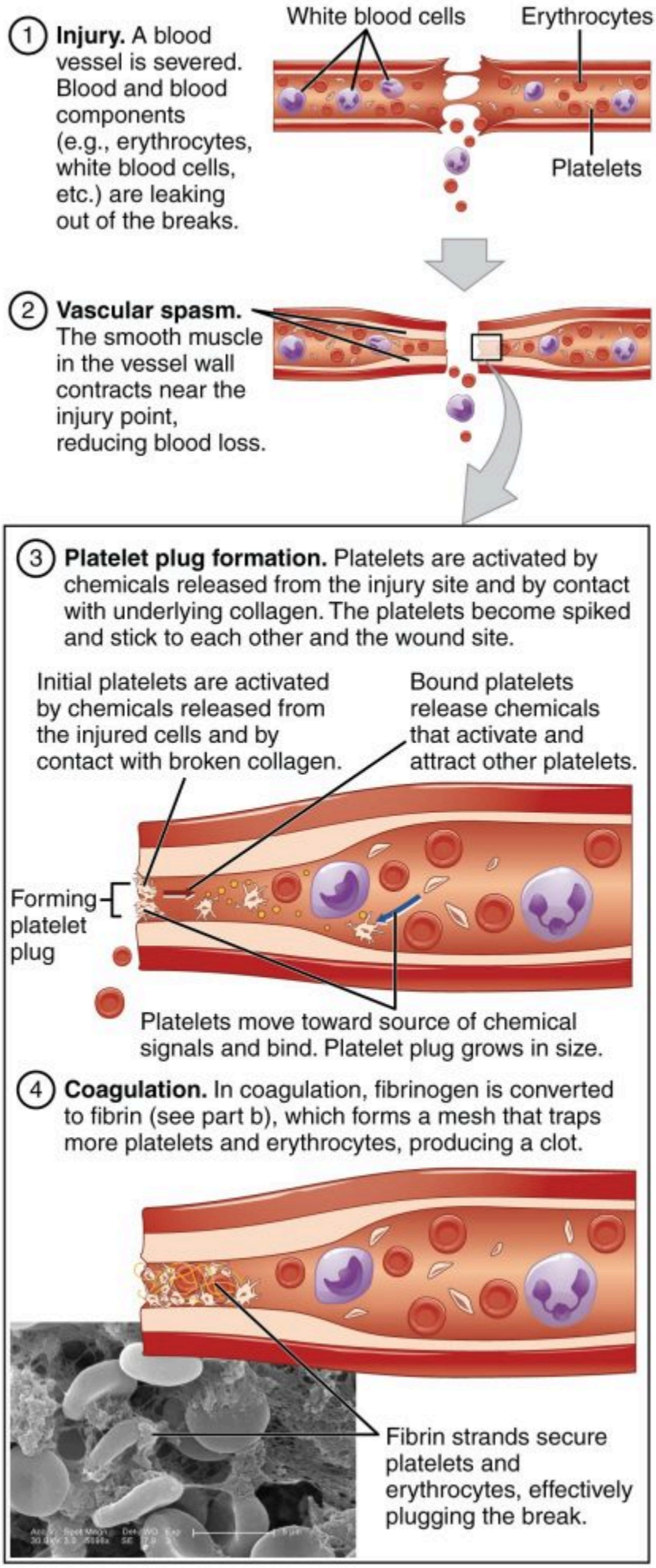

1 Injury. A blood vessel is severed. Blood and blood components (e.g., erythrocytes, white blood cells, etc.) are leaking out of the breaks.
White blood cells
Erythrocytes
Platelets
2 Vascular spasm. The smooth muscle in the vessel wall contracts near the injury point, reducing blood loss.
3 Platelet plug formation. Platelets are activated by chemicals released from the injury site and by contact with underlying collagen. The platelets become spiked and stick to each other and the wound site.
Initial platelets are activated by chemicals released from the injured cells and by contact with broken collagen.
Bound platelets release chemicals that activate and attract other platelets.
Forming platelet plug
Platelets move toward source of chemical signals and bind. Platelet plug grows in size.
4 Coagulation. In coagulation, fibrinogen is converted to fibrin (see part b), which forms a mesh that traps more platelets and erythrocytes, producing a clot.
Fibrin strands secure platelets and erythrocytes, effectively plugging the break.

Figure 10.9 Hemostasis

Fibrinolysis

To restore normal blood flow as the vessel heals, the clot must eventually be removed. **Fibrinolysis** is the gradual breakdown of the clot. During this process, the inactive protein plasminogen is converted into the active **plasmin**, which gradually breaks down the fibrin of the clot.[6]

Clinical Applications of Hemostasis

Antiplatelet Medications

Aspirin is very effective at inhibiting the aggregation (clumping) of platelets and is classified as an antiplatelet medication. Patients at risk for cardiovascular disease often take a low dose of aspirin every day to prevent the formation of clots. Aspirin is also routinely administered during a heart attack or stroke to reduce the formation of a clot.[7]

Anticoagulants

An **anticoagulant** is any substance that prevents coagulation. For example, **heparin** is a short-acting anticoagulant released by the basophils and found on the surfaces of cells lining the blood vessels. A pharmaceutical form of injectable heparin is typically administered to patients diagnosed with blood clots to prevent the growth of the clot or formation of additional clots. It is also commonly given to patients after surgery to prevent clots from forming, such as deep vein thrombosis.

6. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

7. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Warfarin is an oral anticoagulant that is also commonly used to prevent blood clots. For example, a patient with deep venous thrombosis (DVT) may be prescribed warfarin for several months after being discharged from the hospital to prevent the formation of additional life-threatening clots.[8]

Thrombolytics

A class of drugs called thrombolytic agents can help break down an abnormal clot during medical emergencies such as a cerebrovascular accident (CVA), commonly known as a stroke, or a myocardial infarction, commonly called a heart attack. **Tissue plasminogen activator (tPA)** is an enzyme that catalyzes the conversion of plasminogen to plasmin, the primary enzyme that breaks down clots. It is released naturally by endothelial cells but is also used as a medication. For example, if tPA is administered to a patient within three hours of developing symptoms of a thrombotic CVA, brain damage can often be avoided or lessened. However, some strokes are caused by a hemorrhage, in which a thrombolytic agent is not appropriate, so it is vital to determine the cause of the stroke before beginning treatment.[9]

8. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

9. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

10.6 Hemopoiesis

The life span of the formed elements is very short. Most erythrocytes, leukocytes, and platelets normally live only a few hours to a few weeks, so the body must form new blood cells and platelets quickly and continuously. The process by which this replacement occurs is called **hemopoiesis**, or hematopoiesis (from the Greek root *haima-* = "blood"; *-poiesis* = "production"). For example, when you donate a unit of blood during a blood drive (approximately 475 mL, or about 1 pint), your body typically replaces the donated plasma within 24 hours, but it takes about four to six weeks to replace the blood cells.

Most hemopoiesis occurs in the red bone marrow, a connective tissue within the spaces of spongy bone. In children, hemopoiesis can occur in the medullary cavity of long bones, but in adults, the process is largely restricted to the cranial and pelvic bones, the vertebrae, the sternum, and the proximal epiphyses of the femur and humerus.

All formed elements arise from stem cells of the red bone marrow. Hemopoiesis begins when the hematopoietic stem cell is exposed to chemical stimuli that prompt it to divide and differentiate. Development from stem cells to mature cells is initiated by hemopoietic growth factors that include the following:[1]

- **Erythropoietin (EPO)** is a hormone made by the kidneys in response to low oxygen levels. It prompts the production of erythrocytes. Some athletes use synthetic EPO as a performance-enhancing drug (called blood doping) to increase RBC counts and, subsequently, increase oxygen delivery to tissues throughout the body. EPO is a banned substance in most organized sports, but it is also used medically in the treatment of certain anemias, specifically those triggered by renal failure and certain types of cancer, and other disorders in which increased erythrocyte counts and oxygen levels are desirable.
- **Colony-stimulating factors (CSF)** are glycoproteins needed to stimulate leukopoiesis, the process of white blood cell formation and differentiation. CSFs are often given to patients undergoing chemotherapy and bone marrow transplants to prevent low white blood cell counts.
- **Thrombopoietin**, another hormone, is produced by the liver and kidneys. It triggers the development of megakaryocytes into platelets (thrombocytes).

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

10.7 Blood Types

ABO Blood Groups

The major human blood groups were discovered in 1900 by Karl Landsteiner, an Austrian biologist and physician. Blood groups are determined by the presence or absence of specific carbohydrate marker molecules on the plasma membranes of erythrocytes. With their discovery, it became possible to match patient-donor blood types and prevent transfusion reactions and deaths. Until that point, physicians did not understand why death sometimes followed blood transfusions.

Although the ABO blood group name consists of three letters, ABO blood typing designates the presence or absence of just two antigens called A and B. **Antigens** are substances that may trigger a defensive response from leukocytes of the immune system if the body does not recognize the antigen as belonging to "self."

ABO blood types are genetically determined. People whose erythrocytes have A antigens on their membrane surfaces are designated **blood type A**, and people whose erythrocytes have B antigens are designated **blood type B**. Some people have both A and B antigens on their erythrocytes, in which case they are designated **blood type AB**. Some people don't have A or B antigens on their red blood cells and are designated **blood type O**.

When a person's body is exposed to a foreign antigen, an antibody is produced by their immune system that labels that antigen as "foreign." ABO blood group antigens are found in foods and microbes throughout nature, so individuals' immune systems are exposed to A and B antigens at an early age, and antibodies are formed naturally. Because of this natural exposure, individuals with blood type A have naturally formed antibodies to the B antigen circulating in their blood plasma. These antibodies, referred to as anti-B antibodies, will cause agglutination and hemolysis if they are exposed to erythrocytes with B antigens. Similarly, an individual with type B blood has naturally formed anti-A antibodies that will cause agglutination and hemolysis if they are exposed to erythrocytes with A antigens. People with blood type O do not have A or B antigens on their erythrocytes, so they have anti-A and anti-B antibodies circulating in their blood plasma that will cause agglutination and hemolysis if they are exposed to erythrocytes with A or B antigens. However, individuals with blood type AB have both A and B

antigens and do not have naturally formed antibodies to either of these antigens, so they can receive a transfusion of blood type A, B, AB, or O.[1]

Take a Closer Look

Read additional information about blood types from trusted health organizations.

- Open the American Red Cross facts about blood and blood types webpage
- Open the NHS blood types webpage

Rh Factor

The Rh factor is classified according to the presence or absence of another erythrocyte antigen identified as Rh. Although dozens of Rh antigens have been identified, only one, designated D, is clinically important. Those who have the Rh D antigen present on their erythrocytes—about 85% of Americans—are described as Rh positive (Rh+), and those who lack it are Rh negative (Rh−).

The Rh factor is separate from the ABO group, so any individual, no matter their ABO blood type, may have or lack this Rh antigen. When identifying a patient's blood type, the Rh factor is designated by adding the word positive or negative to the ABO type. For example, A positive (A+) means ABO group A blood with the Rh antigen present, and AB negative (AB−) means ABO group AB blood without the Rh antigen. See Table 10.7 for a summary of the distribution of the ABO and Rh blood types within the United States.

Table 10.7. Summary of ABO and Rh Blood Types Within the United States[2]

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Blood Type	Asian	Black, non-Hispanic	Hispanic	North American Indian	White, non-Hispanic
A+	27.3	24.0	28.7	31.3	33.0
A−	0.5	1.9	2.4	3.8	6.8
B+	25.0	18.4	9.2	7.0	9.1
B−	0.4	1.3	0.7	0.9	1.8
AB+	7.0	4.0	2.3	2.2	3.4
AB−	0.1	0.3	0.2	0.3	0.7
O+	39.0	46.6	52.6	50.0	37.2
O−	0.7	3.6	3.9	4.7	8.0

Antibodies to the Rh antigen are produced only in Rh− individuals after they are exposed to the antigen. This process, called **sensitization**, occurs following a transfusion with Rh-incompatible blood or, more commonly, with the birth of an Rh+ baby to a mother who is Rh−. The baby's Rh+ cells rarely cross the placenta during pregnancy, but during or immediately after childbirth, the Rh− mother is often exposed to the baby's Rh+ cells. After exposure, the mother's immune system begins to generate anti-Rh antibodies. If the mother later becomes pregnant with another Rh+ baby, the Rh antibodies can cross the placenta into the fetal bloodstream and destroy the fetal RBCs. This condition, known as **hemolytic disease of the newborn (HDN)** or **erythroblastosis fetalis**, can cause wide-ranging effects in the baby if left untreated, ranging from anemia to death. See Figure 10.10[3] for an illustration of hemolytic disease of the newborn.

3. OpenStax College. (2013). *1910_Erythroblastosis_Fetalis* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1910_Erythroblastosis_Fetalis.jpg

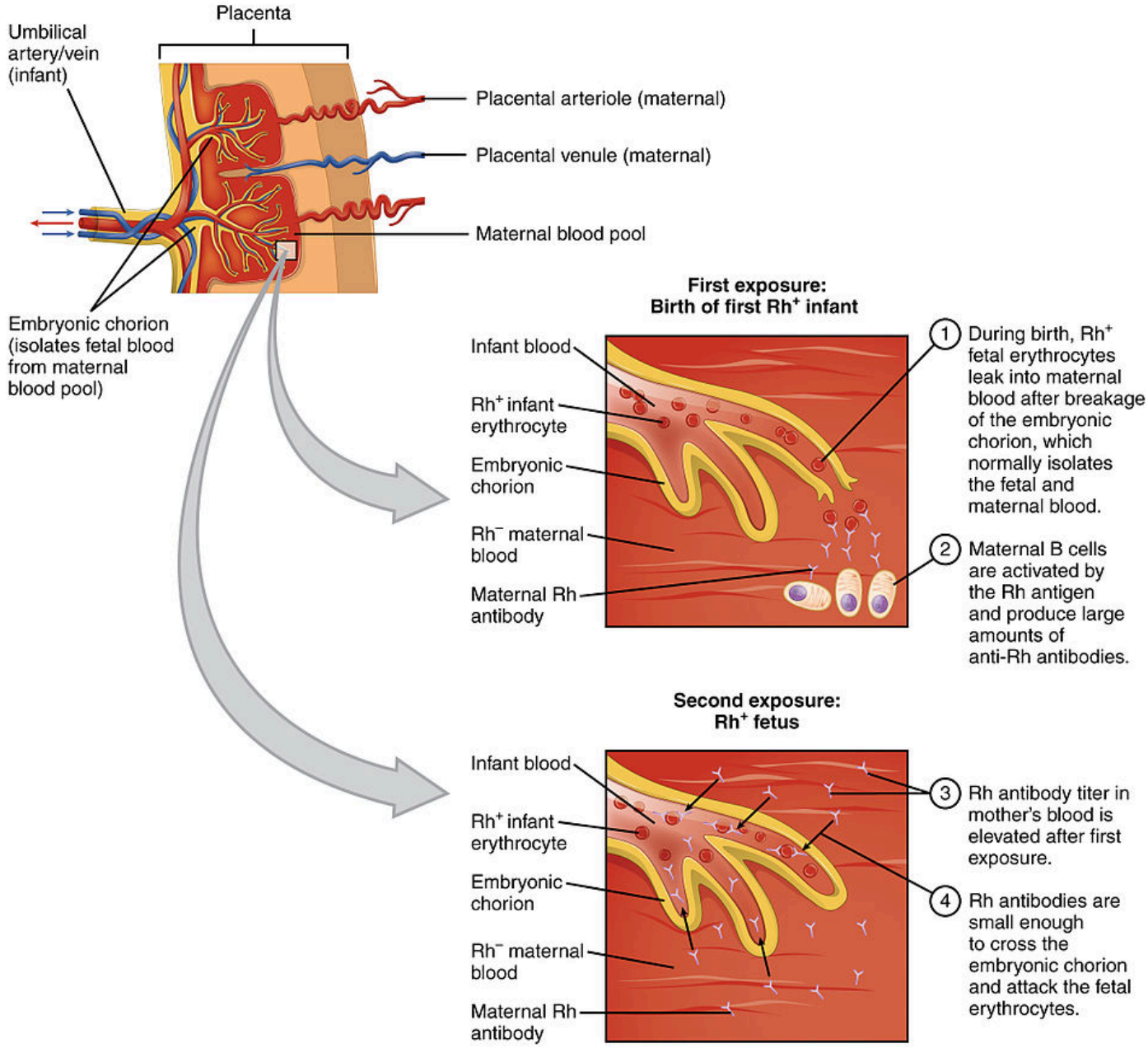


Figure 10.10 Hemolytic Disease of the Newborn

A drug known as **RhoGAM**, short for Rh immune globulin, can prevent the development of Rh antibodies in the Rh− mother, thereby avoiding this potentially serious disease for the fetus. RhoGAM antibodies destroy any fetal Rh+ erythrocytes that may cross the placental barrier. RhoGAM is typically administered to Rh− pregnant

women during weeks 26–28 of pregnancy and within 72 hours following birth of an Rh+ baby, and effectively decreases the incidence of HDN.[4]

ABO Transfusion Protocols

To avoid incompatibility reactions, matching blood types are typically transfused. For example, a patient with blood type B+ receives blood from a donor with blood type B+. In emergency situations where a patient could die from massive blood loss, blood from a **universal donor** (i.e., an individual with type O− blood) may be transfused because no antigens are present to trigger a reaction. Recall that type O erythrocytes do not display A or B antigens, and, therefore, have nothing to provoke an immune response.

However, if the donor with blood type O− had prior exposure to the Rh antigen, Rh antibodies may be present in the donated blood and trigger agglutination to some degree. Also, donated O- blood has antibodies present against A and B antigens, which may cause some problems for the recipient, but because the volume of blood transfused is much lower than the volume of the patient's own blood, the adverse effects of the relatively few infused plasma antibodies are typically limited.

A patient with blood type AB+ is known as the **universal recipient**. This patient can theoretically receive any type of blood because the patient's own blood—having both A and B antigens on the erythrocyte surface—does not produce anti-A or anti-B antibodies. In addition, an Rh+ patient can receive both Rh+ and Rh− blood. However, keep in mind that the donor's blood will contain circulating antibodies that can cause negative implications. See Figure 10.11[5] for a summary of ABO blood types and compatibilities.[6]

4. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

5. OpenStax College. (2013). *1913_ABO_Blood_Groups* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1913_ABO_Blood_Groups.jpg

6. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

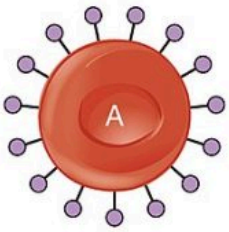
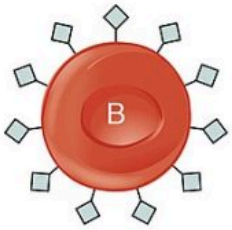
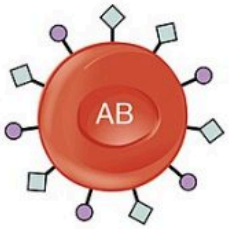
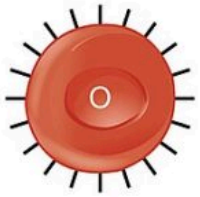
	Blood Type			
	A	B	AB	O
Red Blood Cell Type				
Antibodies in Plasma	 Anti-B	 Anti-A	None	 Anti-A and Anti-B
Antigens in Red blood Cell	 A antigen	 B antigen	 A and B antigens	None
Blood Types Compatible in an Emergency	A, O	B, O	A, B, AB, O (AB^+ is the universal recipient)	O (O is the universal donor)

Figure 10.11. ABO Blood Types

Wisc-Online Interactive Activity

Complete the Wisc-Online interactive activity **"Blood Groups"** to reinforce your understanding of blood group types and compatibility.

For more practice, play the **Blood Typing Game**[7]

Video

Watch the video "Blood Clotting and Blood Types Explained" below to learn more about blood clotting and blood type compatibility.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.



7. NobelPrize.org. (2022). *Blood typing game* [Game].

10.8 Blood Disorders

Anemia

The size, shape, and number of erythrocytes and the number of hemoglobin molecules can have a major impact on a person's oxygenation status and overall health. **Anemia** is a general condition involving a deficient number of red blood cells (RBCs) or hemoglobin. More than 3.5 million Americans suffer from over 400 types of anemia. The effects of the various anemias are widespread across body systems because deficient numbers of RBCs or hemoglobin result in lower levels of oxygen being delivered to body tissues. Because oxygen is required for tissue functioning, anemia produces shortness of breath, fatigue, lethargy, and an increased risk for infection. An oxygen deficit in the brain impairs the ability to think clearly and may prompt headaches and irritability.

Anemia can be categorized into three major types: those caused by blood loss, those caused by faulty or decreased RBC production, and those caused by excessive destruction of RBCs.

- Anemia caused by blood loss can be the result of excessive menstruation, excessive blood loss during childbirth, bleeding from wounds, ulcers, or hemorrhoids, inflammation of the stomach (gastritis), and cancer of the gastrointestinal tract. Excessive use of aspirin or other nonsteroidal anti-inflammatory drugs, such as ibuprofen, can trigger ulceration and gastritis.
- Anemias caused by faulty or decreased RBC production include iron-deficiency anemia, vitamin-deficiency anemia, and diseases of the bone marrow and stem cells. Chronic kidney disease is often associated with a decreased production of erythropoietin (EPO), resulting in decreased production of RBC.
- Anemia caused by the destruction of RBC includes sickle cell anemia and hemolytic anemia.

Examples of common types of anemias are discussed in the following subsections.[1]

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Iron-Deficiency Anemia

Iron-deficiency anemia is the most common type of anemia that results from an insufficient amount of iron to produce heme, the oxygen-binding component of hemoglobin. This condition can occur due to a deficiency of iron in the diet that is common in vegans, vegetarians, children, adolescents, and older adults. Iron-deficiency anemia can also be caused by an inability to absorb iron in the gastrointestinal tract or slow, chronic bleeding.

Vitamin-Deficiency Anemia

Vitamin-deficiency anemias often involve insufficient vitamin B12 and folate, also referred to as megaloblastic anemia. It is typically caused by diets deficient in these essential nutrients. Lack of meat or eating insufficient amounts of vegetables may lead to a lack of folate or vitamin B12. Vitamin-deficiency anemia can be caused by pregnancy, side effects of certain medications, excessive alcohol consumption, gastrointestinal bypass surgery, or gastrointestinal disease such as celiac disease. It is essential to provide sufficient folic acid during the early stages of pregnancy to reduce the risk of neural tube defects, such as spina bifida, in the newborn.

Sickle Cell Anemia

Sickle cell disease is a genetic disorder commonly found in individuals of African descent that causes the production of an abnormal type of hemoglobin, called hemoglobin S. In sickle cell anemia, abnormal hemoglobin causes red blood cells to become crescent-shaped, reducing their ability to carry oxygen, especially during episodes triggered by low oxygen levels or dehydration. These abnormally shaped cells can then become lodged in narrow capillaries and block blood flow to tissues and organs, causing a variety of complications. See Figure 10.12[2] for an illustration of sickled red blood cells.

2. OpenStax College. (2013). *1911_Sickle_Cells* [Photograph]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:1911_Sickle_Cells.jpg

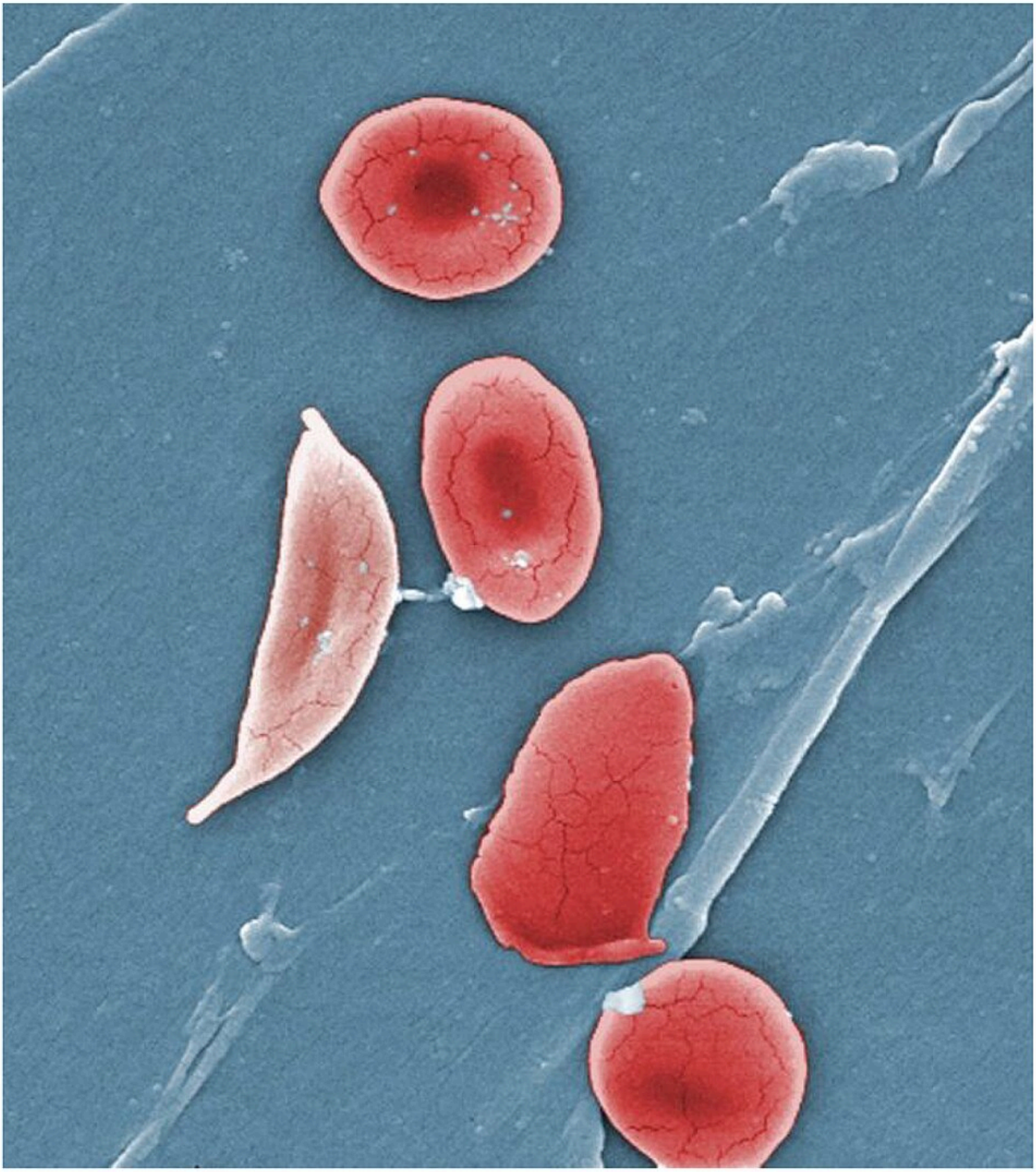


Figure 10.12 Sickled Erythrocytes in Sickle Cell Anemia

Aplastic Anemia

Aplastic anemia is a rare condition caused by stem cells in the bone marrow not producing enough RBCs, WBCs, and platelets. Aplastic anemia is often inherited or can be triggered by radiation, medication, chemotherapy, or infection.

Anemia of Chronic Disease

Anemia of chronic disease occurs as a result of other long-term conditions, particularly those that cause inflammation. Long-term inflammation can make it difficult for the body to make sufficient red blood cells, which leads to anemia. Some diseases that can cause anemia of chronic disease are cancer, chronic kidney disease, congestive heart failure, and autoimmune conditions such as rheumatoid arthritis or lupus. Treatment of anemia of chronic disease consists of managing the underlying condition that led to anemia in the first place. Other treatments may include blood transfusions, synthetic erythropoietin, or iron supplements.[3]

Leukocyte Disorders

Leukopenia is a condition in which not enough leukocytes are produced, increasing the risk of infection. Conversely, excessive leukocyte production, known as **leukocytosis**, often results in nonfunctional WBCs that also increase the risk for infection.

Leukemia is a blood cancer involving an abundance of leukocytes. In chronic leukemia, mature leukocytes accumulate and fail to die. In acute leukemia, there is an overproduction of young, immature leukocytes. In both conditions, the white blood cells do not function properly and increase the risk for infection. They also crowd out the production of erythrocytes and platelets, which causes anemia and bleeding problems, too.[4]

3. Cleveland Clinic. (2022). *Anemia of chronic disease*. https://my.clevelandclinic.org/health/diseases/14477-anemia-of-chronic-disease

4. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Hemophilia

Hemophilia is a genetic bleeding disorder in which blood doesn't clot properly, which can lead to hemorrhage from injuries, surgery, or spontaneous bleeding (bleeding that occurs for no known reason). Blood contains many proteins called clotting factors that help stop bleeding. In hemophilia, there is a deficiency of these clotting factors. The severity of hemophilia that a person has is determined by the amount of factor in the blood. The lower the amount of the factor, the more likely it is that bleeding will occur, which can lead to serious health problems.[5] Inherited hemophilia occurs in about 1 of every 5,000 male births. About 33,000 males in the United States are living with the disorder.[6]

Hemorrhage

Minor blood loss is managed by hemostasis and repair. **Hemorrhage** is a loss of blood that cannot be controlled by hemostatic mechanisms. Initially, the body responds to hemorrhage by initiating mechanisms aimed at increasing blood pressure and maintaining blood flow. Ultimately, however, blood volume will need to be restored, either through physiological processes or through medical intervention.[7]

Polycythemia

An elevated RBC count is called **polycythemia** and is detected in a patient's elevated hematocrit (percentage of red blood cells). It can occur transiently in a person who is dehydrated; when water intake is inadequate or water losses are excessive, the plasma volume decreases. As a result, the hematocrit rises.

5. Centers for Disease Control and Prevention. (2025). *About hemophilia*. https://www.cdc.gov/hemophilia/about/index.html
6. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
7. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

A mild form of polycythemia is chronic but normal in people living at high altitudes. Some elite athletes train at high elevations specifically to induce this phenomenon.

A type of bone marrow disease called **polycythemia vera** (from the Greek *vera* = "true") causes an excessive production of immature RBCs, WBCs, and platelets. Polycythemia vera can dangerously elevate the viscosity of blood, raising blood pressure and making it more difficult for the heart to pump blood throughout the body. Polycythemia occurs more often in males than in females and is more likely to be present in elderly patients over 60 years of age.[8]

Thrombosis and Embolism

A **thrombus** (plural = thrombi) is a blood clot. While the formation of a clot is normal following hemostasis triggered by a vessel injury, the development of an abnormal thrombus can seriously impede blood flow. An excessive production of platelets can lead to severe disease or death. **Thrombocytosis** is a condition in which too many platelets are produced and may trigger the formation of unwanted blood clots, causing a potentially life-threatening condition known as **thrombosis**. When a portion of a thrombus breaks free from the vessel wall and enters the circulation, it is referred to as an **embolus**. An embolus that is carried through the bloodstream can be large enough to block a vessel to a major organ. When this happens, it is called an **embolism**. An embolism may affect the heart, brain, or lungs.

When the inner lining of blood vessels is damaged, thrombi can form. Vessel damage can be caused by conditions such as **venous stasis**, when blood in the veins, particularly in the legs, remains still for long periods. For example, venous stasis during long airplane flights can cause deep vein thrombosis (DVT).

Thrombophilia, also called hypercoagulation, is a condition in which there is a tendency to form thrombi. This may be familial (genetic) or acquired. Acquired forms include the autoimmune disease lupus, immune reactions to heparin, polycythemia vera, thrombocytosis, sickle cell disease, pregnancy, and even obesity.[9]

8. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

9. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Thrombocytopenia

An insufficient number of platelets is called **thrombocytopenia** and can result in excessive bleeding if the blood does not clot properly.

Thrombocytopenia can be caused by either an increased destruction of platelets or a reduction in platelet production. Thrombocytopenia has been linked to autoimmune conditions, certain medications, infections, pregnancy, and cancer.

Treatment of thrombocytopenia depends on the specific cause of the disorder. Potential treatment options are managing underlying conditions, monitoring platelet counts, stopping medications that affect platelet production, and transfusing platelets in severe cases.[10]

10. Jinna, S., & Khandhar, P. B. (2023). *Thrombocytopenia.* StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK542208/

10.9 Career Connections Related to Blood

Blood plays an important role in transporting oxygen, nutrients, hormones, immune cells, and waste products throughout the body. Because blood can provide important information about a person's health, many professionals are involved in collecting, testing, and analyzing blood and other body fluid samples. Careers related to blood and laboratory testing can include medical laboratory scientists, medical laboratory technicians, and phlebotomists.

Medical Laboratory Scientist

Medical laboratory scientists, also called clinical laboratory technologists, perform complex laboratory tests on blood and other body fluids. The results of these tests help health care providers diagnose disease, monitor a patient's condition, and evaluate how well treatments are working. Medical laboratory scientists use knowledge of biology, chemistry, hematology, microbiology, laboratory equipment, quality control, and safety practices.

Medical Laboratory Technician

Medical laboratory technicians perform many types of laboratory tests that help providers diagnose and monitor disease. They may prepare samples, operate laboratory instruments, record results, and follow quality control procedures. Medical laboratory technicians often work with blood, urine, and other body fluid samples in hospitals, clinics, and medical laboratories.

Phlebotomist

Phlebotomists are health care professionals who collect blood samples for testing, donation, or research. They commonly perform venipuncture, which involves collecting

blood from a vein, and may also collect small capillary samples from a finger, heel, or other site. Phlebotomists use knowledge of anatomy, infection prevention, patient identification, specimen labeling, and safety procedures to help ensure accurate test results and patient safety.

Take a Closer Look

Explore careers related to blood and laboratory testing on these websites.

- Medical laboratory scientist from ASCP's What's My Next
- Medical laboratory technician from the American Society for Clinical Laboratory Science
- Clinical laboratory technologists and technicians from the U.S. Bureau of Labor Statistics
- Phlebotomy from the American Society for Clinical Pathology
- Phlebotomists from the U.S. Bureau of Labor Statistics

10.10 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

10.11 Glossary

Agranular leukocytes: White blood cells with few or no visible granules, including monocytes and lymphocytes. (**Chapter 10.4**)

Albumin: The most abundant plasma protein, made by the liver. It helps transport fatty acids and steroid hormones in the blood and maintains fluid balance. (**Chapter 10.4**)

Anemia: A general condition characterized by a deficient number of red blood cells (RBCs) or low hemoglobin levels. (**Chapter 10.8**)

Antibodies (Ab): Proteins that recognize and bind to specific antigens to help defend the body against pathogens; also called immunoglobulins. (**Chapter 10.4**)

Anticoagulant: Any substance that prevents coagulation. (**Chapter 10.5**)

Antigens: Substances that may trigger a defensive response from leukocytes of the immune system if the body does not recognize the antigen as belonging to "self." (**Chapter 10.7**)

Aspirin: A medication that effectively inhibits the clumping (aggregation) of platelets and is classified as an antiplatelet drug. (**Chapter 10.5**)

B lymphocytes (B cells): White blood cells that defend the body against specific pathogens. A form of B cells called plasma cells produces antibodies. (**Chapter 10.4**)

Basophils: The least common leukocytes, typically making up less than 1% of the total leukocyte count. (**Chapter 10.4**)

Blood type A: A blood type classification for individuals whose erythrocytes (red blood cells) have A antigens on their surface. (**Chapter 10.7**)

Blood type AB: A blood type classification for individuals whose erythrocytes (red blood cells) have both A and B antigens on their surfaces. (**Chapter 10.7**)

Blood type B: A blood type classification for individuals whose erythrocytes (red blood cells) have B antigens on their surface. (**Chapter 10.7**)

Blood type O: A blood type classification for individuals whose red blood cells lack both A and B antigens. (**Chapter 10.7**)

Buffers: Substances in the blood, such as proteins and other molecules, that help maintain a stable pH in body tissues by neutralizing excess acids or bases. (**Chapter 10.2**)

Buffy coat: A thin, light-colored layer in a blood sample that contains white blood cells and platelets, usually less than 1% of the total blood volume. (**Chapter 10.4**)

Cardiovascular system: The body system made up of the heart and blood vessels that circulates blood to deliver oxygen and nutrients and remove waste products. (**Chapter 10.1**)

Clinical laboratory technologists: Professionals with a bachelor's degree and certification who perform a wide variety of tests on body fluids, including blood. (**Chapter 10.9**)

Coagulation: The process of blood clotting. (**Chapter 10.5**)

Colony-stimulating factors (CSF): Glycoproteins that stimulate the production and differentiation of white blood cells. Often used in patients receiving chemotherapy or bone marrow transplants to prevent low white blood cell counts. (**Chapter 10.6**)

Embolism: A condition that occurs when an embolus travels through the bloodstream and blocks a blood vessel supplying a major organ. (**Chapter 10.8**)

Embolus: A portion of a thrombus that breaks free from the vessel wall and enters the circulation. (**Chapter 10.8**)

Eosinophils: White blood cells that make up about 2–4% of all leukocytes. (**Chapter 10.4**)

Erythroblastosis fetalis: A condition that occurs when an Rh− mother has developed antibodies against Rh+ red blood cells, which cross the placenta and destroy the red blood cells of her Rh+ fetus. (**Chapter 10.7**)

Erythrocytes: Cells that carry oxygen from the lungs to the tissues and remove carbon dioxide; also called red blood cells (RBCs). (**Chapter 10.2**, **Chapter 10.4**)

Erythropoiesis: The production of red blood cells (erythrocytes), stimulated by the hormone erythropoietin from the kidneys, occurring in red bone marrow at over 2 million cells per second. (**Chapter 10.4**)

Erythropoietin (EPO): A hormone made by the kidneys in response to low oxygen levels that prompts the production of erythrocytes. (**Chapter 10.6**)

Fibrin: An insoluble filamentous protein made from the plasma protein fibrinogen. (**Chapter 10.5**)

Fibrinogen: A plasma protein produced by the liver that is essential for blood clotting, making up about 7% of plasma proteins. (**Chapter 10.4**)

Fibrinolysis: The gradual breakdown of a blood clot. (**Chapter 10.5**)

Formed elements: The solid components of blood, which include erythrocytes (RBCs), leukocytes (WBCs), and thrombocytes (platelets). (**Chapter 10.2**)

Globulins: The second most common type of plasma protein, making up about 38% of the total plasma protein volume. (**Chapter 10.4**)

Granular leukocytes: White blood cells with many granules in their cytoplasm, including neutrophils, eosinophils, and basophils. (**Chapter 10.4**)

Hematocrit: A blood test that measures the percentage of erythrocytes (RBCs) in a blood sample. (**Chapter 10.4**)

Hematology: The study of blood cells (erythrocytes, leukocytes, and platelets) and the tissues that form them. (**Chapter 10.1**)

Hemoglobin: A large protein in red blood cells made of four chains, each holding an iron atom that binds oxygen for transport in the blood. (**Chapter 10.4**)

Hemolytic disease of the newborn (HDN): A condition that occurs when an Rh− mother has developed antibodies against Rh+ red blood cells, which cross the placenta and destroy the red blood cells of her Rh+ fetus. (**Chapter 10.7**)

Hemophilia: A genetic bleeding disorder in which blood does not clot properly, leading to hemorrhage from injuries, surgery, or spontaneous bleeding (bleeding with no known cause). (**Chapter 10.8**)

Hemopoiesis: The process by which blood cells are produced and replaced in the body. (**Chapter 10.6**)

Hemorrhage: Excessive or uncontrolled bleeding. (**Chapter 10.5**)

Hemostasis: The process that stops bleeding by forming a blood clot at the site of a damaged blood vessel. (**Chapter 10.4**)

Heparin: A medication that prevents blood clotting by inhibiting the formation of fibrin; used as an anticoagulant. (**Chapter 10.5**)

Hypoxemia: A condition where there are low levels of oxygen in the blood. (**Chapter 10.4**)

Immunoglobulins (Ig): Proteins made by B cells that help the immune system recognize and fight antigens like bacteria and viruses; also called antibodies. (**Chapter 10.4**)

Leukemia: A blood cancer characterized by an excessive number of leukocytes (white blood cells). (**Chapter 10.8**)

Leukocytes: Cells that defend the body against infection and disease; also called white blood cells (WBCs); (**Chapter 10.2**, **Chapter 10.4**)

Leukocytosis: Excessive production of leukocytes (white blood cells), often resulting in nonfunctional WBCs and an increased risk of infection. (**Chapter 10.8**)

Leukopenia: A condition where too few leukocytes (white blood cells) are produced, increasing the risk of infection. (**Chapter 10.8**)

Lymphocytes: The second most common type of leukocyte, accounting for about 20–30% of all leukocytes, and are essential for the immune response. (**Chapter 10.4**)

Macrophage: A phagocytic cell in the bone marrow, liver, and spleen that removes worn-out red blood cells from circulation. (**Chapter 10.4**)

Medical laboratory scientists (MLS): Professionals with a bachelor's degree and certification who perform a wide variety of tests on body fluids, including blood. (**Chapter 10.9**)

Medical laboratory technicians (MLT): Professionals who typically have an associate's degree and may perform duties similar to those of clinical laboratory technologists. (**Chapter 10.9**)

Megakaryocyte: A large bone marrow cell that produces thrombocytes (platelets) by breaking off small fragments of its cytoplasm. (**Chapter 10.4**)

Memory cell: A variety of both B and T cells that form after exposure to a pathogen to "remember" that pathogen and mount rapid responses during subsequent exposures. (**Chapter 10.4**)

Monocytes: Large agranular white blood cells that circulate in the blood and migrate into tissues, where they mature into macrophages to engulf and digest pathogens and debris. (**Chapter 10.4**)

Natural killer (NK) cells: White blood cells that recognize and destroy cells lacking "self" proteins or containing foreign or abnormal markers, providing a rapid response to infected or cancerous cells. (**Chapter 10.4**)

Neutrophils: The most common white blood cells, making up 50–70% of all leukocytes. (**Chapter 10.4**)

Phlebotomists: Health care professionals trained in the collection of blood samples. (**Chapter 10.9**)

Plasma: The liquid portion of blood that suspends the formed elements and transports nutrients, hormones, and waste. (**Chapter 10.2**)

Plasma proteins: Proteins that are unique to the plasma. (Chapter 10.4)

Plasmin: An active enzyme that gradually breaks down the fibrin mesh of a blood clot during the process of fibrinolysis. (Chapter 10.5)

Platelet plug: The process by which platelets release chemicals that attract more platelets to help seal a damaged blood vessel. (Chapter 10.5)

Platelets: Help form blood clots to stop bleeding; another name for thrombocytes; (Chapter 10.2)

Polycythemia: An elevated red blood cell (RBC) count, often detected by an increased hematocrit (the percentage of red blood cells in the blood). (Chapter 10.8)

Polycythemia vera: A type of bone marrow disease that causes excessive production of immature red blood cells (RBCs), white blood cells (WBCs), and platelets. (Chapter 10.8)

Polymorphonuclear (PMN) neutrophils: Older neutrophils with a nucleus that has many lobes or shapes; often called "polys." (Chapter 10.4)

Pulse oximeter: A device placed on the fingertip that measures oxygen saturation by using red and infrared light to detect how much oxygen is in the blood. (Chapter 10.4)

Red blood cells (RBCs): Responsible for transporting oxygen and carbon dioxide; another name for erythrocytes. (Chapter 10.2)

Reticulocyte: An immature red blood cell that still contains some organelle remnants. (Chapter 10.4)

RhoGAM: Short for Rh immune globulin, this medication prevents an Rh− mother from developing antibodies against Rh+ red blood cells, helping to avoid hemolytic disease of the newborn. (Chapter 10.7)

Sensitization: The process by which an Rh− individual produces antibodies against the Rh antigen after exposure, such as through an Rh-incompatible transfusion or pregnancy with an Rh+ baby. (Chapter 10.7)

T lymphocytes (T cells): White blood cells that help coordinate immune responses and play a key role in specific immunity. (Chapter 10.4)

Thrombocytes: Cell fragments involved in blood clotting to prevent bleeding; also called platelets. (Chapter 10.2, Chapter 10.4)

Thrombocytopenia: An insufficient number of platelets in the blood, which can lead to excessive bleeding due to impaired clotting. (Chapter 10.8)

Thrombocytosis: A condition in which too many platelets are produced, potentially triggering unwanted blood clots that can be life-threatening. (**Chapter 10.8**)

Thrombophilia (hypercoagulation): A condition characterized by an increased tendency to form blood clots (thrombi). (**Chapter 10.8**)

Thrombopoietin: A hormone produced by the liver and kidneys that stimulates the development of megakaryocytes into platelets (thrombocytes). (**Chapter 10.6**)

Thrombosis: A potentially life-threatening condition caused by the formation of unwanted blood clots inside blood vessels. (**Chapter 10.8**)

Thrombus: A blood clot. (**Chapter 10.8**)

Tissue plasminogen activator (tPA): An enzyme that converts plasminogen into plasmin, which breaks down blood clots. It is used medically to treat strokes and heart attacks caused by clots. (**Chapter 10.5**)

Universal donor: An individual with type O− blood who can donate blood to anyone because their red blood cells lack A, B, and Rh antigens, reducing the risk of an immune reaction. (**Chapter 10.7**)

Universal recipient: A patient with blood type AB+ who can receive red blood cells from any blood type because their blood contains all A, B, and Rh antigens, so they do not produce antibodies against these antigens. (**Chapter 10.7**)

Vascular spasm: A sudden constriction of the smooth muscle in the walls of a blood vessel that reduces blood flow to limit bleeding. (**Chapter 10.5**)

Venous stasis: A condition in which blood in the veins, especially in the legs, remains still or flows very slowly for long periods, increasing the risk of vessel damage. (**Chapter 10.8**)

Viscosity: A measure of a fluid's thickness or resistance to flow. (**Chapter 10.3**)

Warfarin: An anticoagulant medication that prevents blood clot formation by interfering with vitamin K-dependent clotting factors. (**Chapter 10.5**)

White blood cells (WBCs): Immune cells that help fight infections; another name for leukocytes. (**Chapter 10.2**)

PART XI

CHAPTER 11 CARDIOVASCULAR SYSTEM

11.1 Introduction to the Cardiovascular System

Chapter Competency

Analyze how components of the cardiovascular system function in the body.

Learning Objectives

- Address major gross and microscopic structural components of the cardiovascular system.
- Describe the flow of fluid through the systemic and pulmonary circulations.
- Illustrate the functional relationships among the cardiovascular components.

Imagine you are working as an electrocardiogram (EKG) technician preparing to record a patient's heart rhythm. As the test begins, you monitor the electrical activity that coordinates each heartbeat. The results may provide clues about heart rate, rhythm, conduction problems, or signs of decreased blood flow to the heart. To understand what the tracing represents, you must first understand how the heart is structured, how electrical signals move through it, and how blood circulates through the body.

Cardiology is the study of the heart. The cardiovascular system includes the heart, blood, and blood vessels, which work together to deliver oxygen and nutrients to tissues and remove carbon dioxide and other wastes. The heart acts as a pump, while blood vessels form pathways that carry blood through pulmonary circulation between the heart and lungs and systemic circulation between the heart and the rest of the body.

In this chapter, you will explore the structure and function of the cardiovascular system. You will learn about the anatomy of the heart, including its chambers, valves, layers, and major blood vessels. You will examine the heart's conduction system and cardiac cycle, including how electrical signals coordinate contraction and relaxation. You

will also study the structure and function of arteries, veins, and capillaries, as well as blood pressure, blood flow, and the pathways of systemic, pulmonary, coronary, cerebral, hepatic portal, and fetal circulation. Finally, you will learn about common cardiovascular disorders and how changes in heart or blood vessel function can affect health.

By mastering these concepts, you will gain a deeper understanding of how the cardiovascular system transports blood, maintains circulation, supports tissue oxygenation, and helps maintain homeostasis. This foundation will help you connect cardiovascular structure and function to EKG interpretation, blood pressure assessment, pulse assessment, patient care, circulation disorders, and heart disease.

11.2 Anatomy of the Heart

The heart is located in the center of the thoracic cavity, deep to the sternum and medially between the lungs in the space known as the **mediastinum**. Roughly two-thirds of the heart is found left of the midline. Figure 11.1[1] shows the position of the heart within the thoracic cavity.

1. OpenStax College. (2013). *2001_Heart_Position_in_ThoraxN* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2001_Heart_Position_in_ThoraxN.jpg

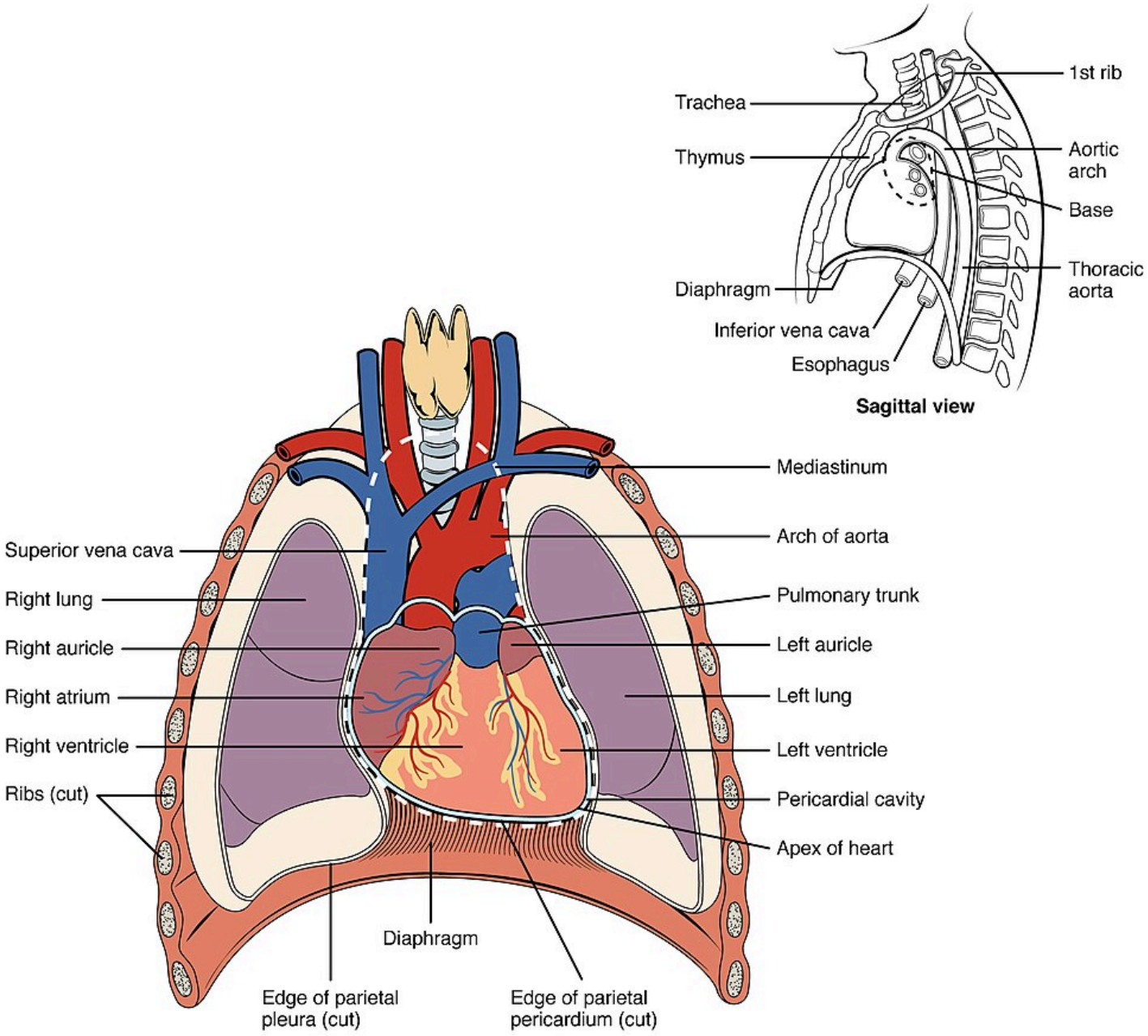


Figure 11.1 Position of the Heart Within the Thorax

The superior surface of the heart at the widest point is called the base. The inferior tip of the heart, the **apex**, lies just left of the sternum. The right side of the heart is tilted anteriorly, and the left side is tilted posteriorly. The position and orientation of the heart are important to remember when placing a stethoscope on a patient's chest and listening for heart sounds.

The heart is divided into four chambers. The two superior chambers are the right and left atria, and the two inferior chambers are the right and left ventricles.

A typical heart is approximately the size of your fist: 12 cm (5 in) in length, 8 cm (3.5 in) wide, and 6 cm (2.5 in) in thickness. The weight of a female heart is approximately 250–300 grams (9 to 11 ounces), and the weight of a male heart is approximately 300–350 grams (11 to 12 ounces).[2]

Pericardium

Within the mediastinum, the heart is located inside a tough double membrane sac known as the **pericardium**, or pericardial sac. The **pericardial cavity** is filled with a lubricating serous (watery) fluid that reduces friction between the heart and the pericardium during contraction.

The word *pericardium* literally translates to "around the heart." It consists of two distinct layers: the sturdy outer fibrous pericardium and the inner serous pericardium. The **fibrous pericardium** is made of tough, dense connective tissue that protects the heart and maintains its position in the chest cavity. The more delicate **serous pericardium** consists of two layers: the **parietal pericardium**, which is fused to the fibrous pericardium, and an inner visceral pericardium, or **epicardium**, which is fused to the heart and is part of the heart wall. See Figure 11.2[3] for an illustration of the pericardial membranes.[4]

2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

3. OpenStax College. (2013). *2004_Heart_Wall* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2004_Heart_Wall.jpg

4. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

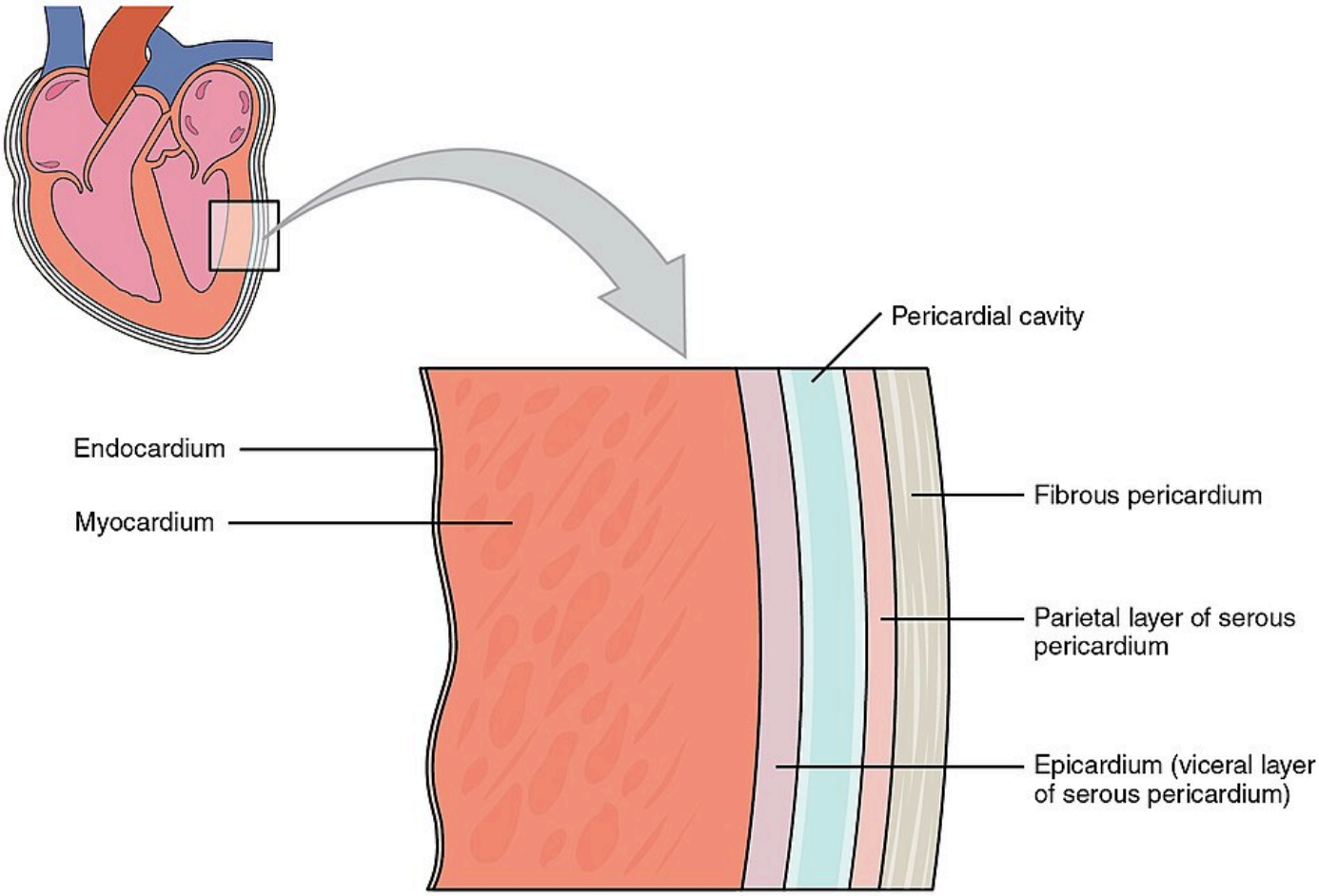


Figure 11.2 Pericardial Membranes and Layers of the Heart Wall

Layers of the Heart Wall

The wall of the heart is composed of three layers of unequal thickness. From superficial to deep, they are the epicardium, the myocardium, and the endocardium. Refer back to Figure 11.2 for an illustration of these three layers.[5]

5. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Epicardium

The **epicardium** is the outermost layer of the heart wall. It is also the innermost layer of the serous pericardium, called the **visceral pericardium**.

Myocardium

The middle and thickest layer of the heart is the **myocardium**, made up largely of cardiac muscle cells. It is the contraction of the myocardium that pumps blood through the heart and into the major arteries. The muscle pattern is elegant and complex, as the muscle cells swirl and spiral around the chambers of the heart. This complex swirling pattern allows the heart to pump blood more effectively than a simple linear pattern would. See Figure 11.3[6] for an illustration of the arrangement of the cardiac muscle.

6. OpenStax College. (2013). *2006_Heart_Musculature* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2006_Heart_Musculature.jpg

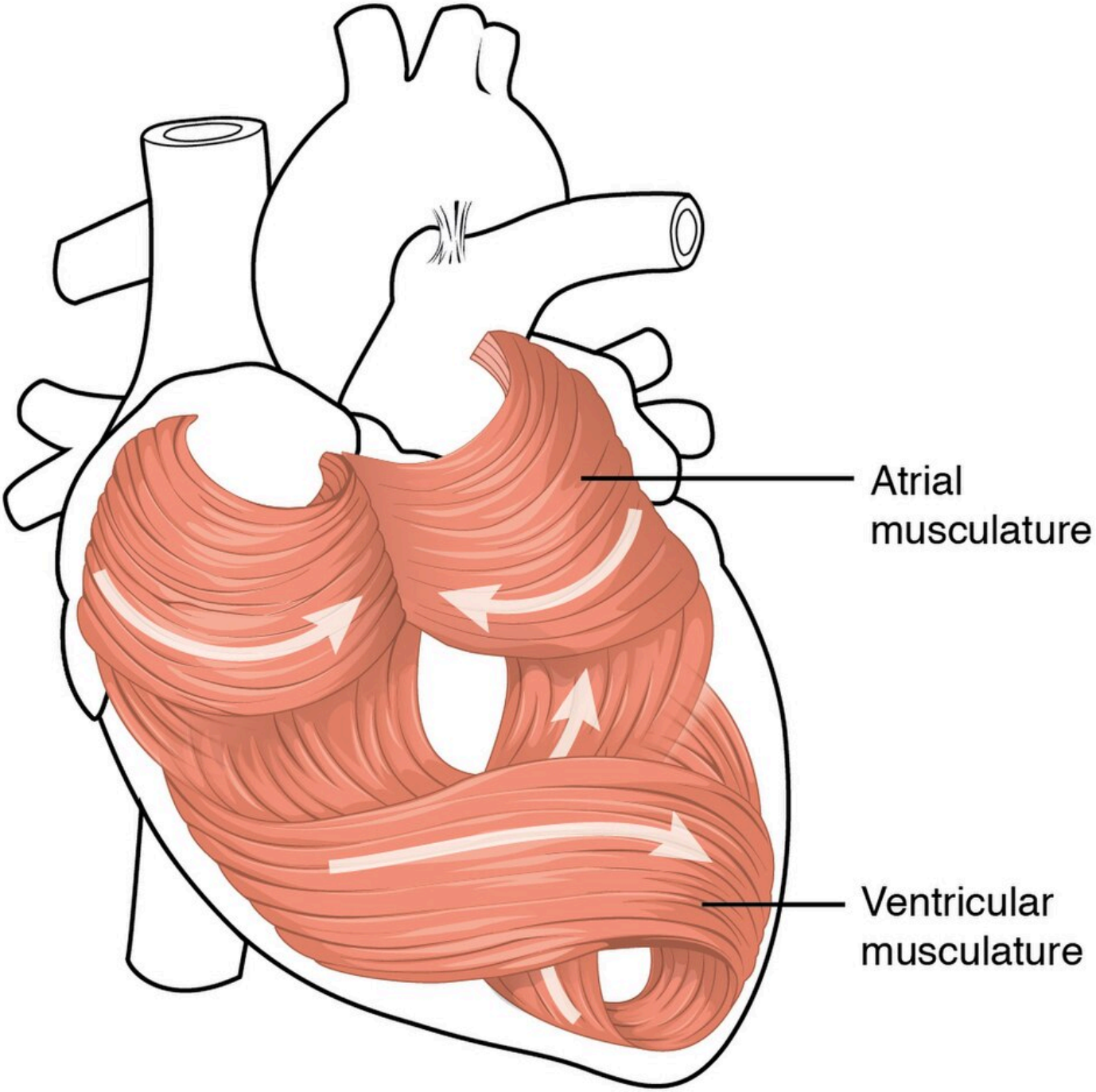


Figure 11.3 Heart Musculature

Endocardium

The **endocardium** is the innermost layer of the heart wall that is joined to the myocardium with a thin layer of connective tissue. The endocardium lines the chambers where the blood circulates and covers the heart valves. It is made of simple squamous

epithelium called **endothelium**, which is continuous with the endothelial lining of the blood vessels.

Surface Features of the Heart

Inside the pericardium, the surface features of the heart are visible. On both the right and left sides of the heart, there is an extension of the atria visible on the superior surface called an auricle. **Auricles** are flaplike, thin-walled structures that can slightly expand to increase the volume of the atria, the upper chambers of the heart. It is named *auricle*, which means "ear-like," because its shape resembles the external ear of a human. See Figure 11.4 for an illustration of the right and left auricles.

Also prominent is a series of fat-filled grooves, each of which is known as a **sulcus** (plural = sulci), along the superior surfaces of the heart. Major coronary blood vessels are located in these sulci. The deep **coronary sulcus** is located between the atria and ventricles. Located between the left and right ventricles are two additional sulci that are not as deep as the coronary sulcus. The **anterior interventricular sulcus** is visible on the anterior surface of the heart, whereas the **posterior interventricular sulcus** is visible on the posterior surface of the heart.[7] See Figure 11.4[8] for an illustration of the surface features of the heart.

7. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

8. Blausen Medical Communications, Inc. (2013). *Blausen_0451_Heart_Anterior* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Blausen_0451_Heart_Anterior.png

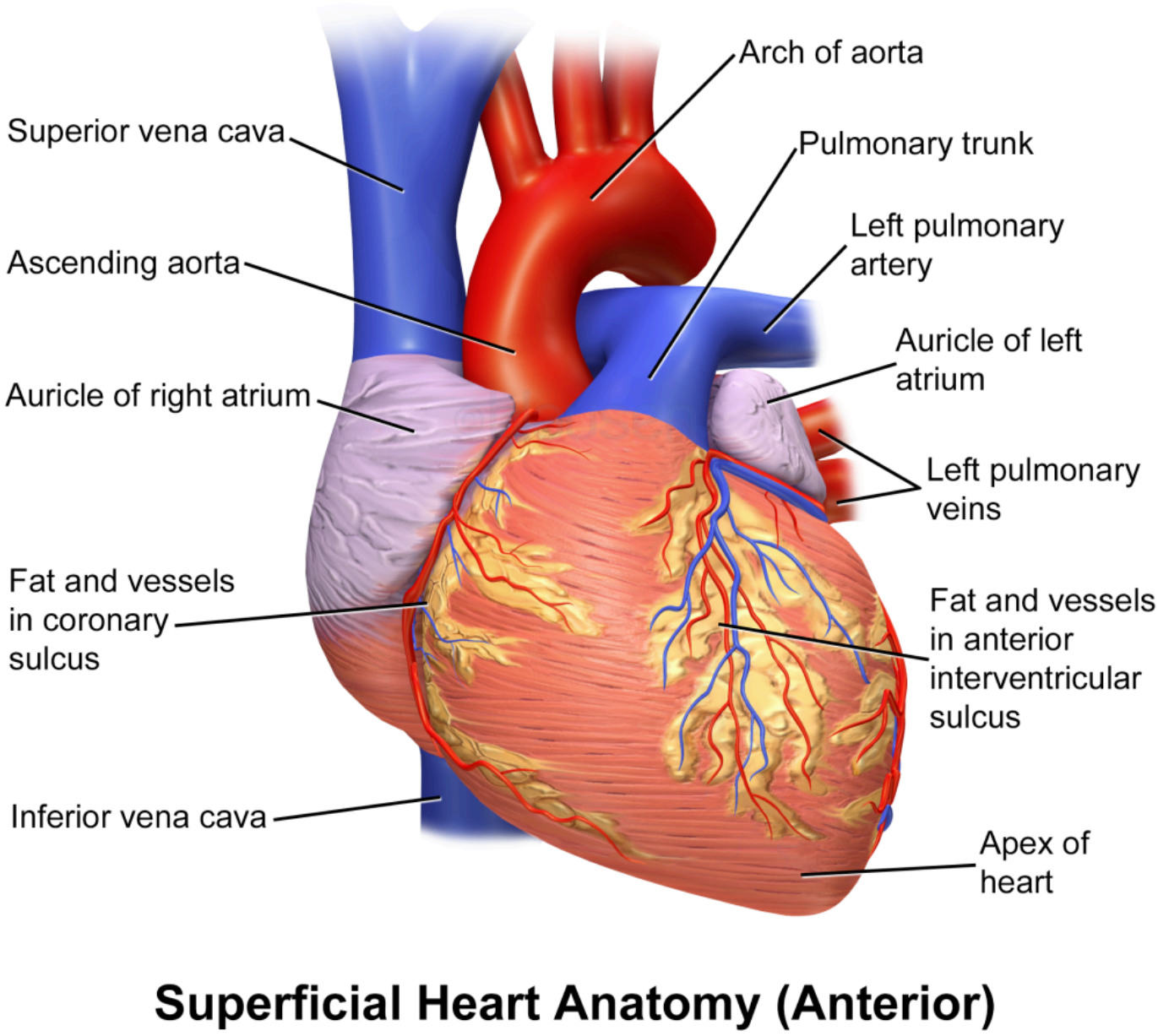


Figure 11.4 Surface Features of the Heart

Chambers of the Heart

The heart consists of four chambers: two upper chambers called **atria** (single = atrium) and two lower chambers called **ventricles** (single = ventricle). The right atrium and the left atrium act as receiving chambers for blood, which then empty the blood into the right and left ventricles. The ventricles serve as the primary pumping and ejecting

chambers of the heart, propelling blood to the lungs (pulmonary circulation) or to the rest of the body (systemic circulation).

The atria and ventricles are divided by septa. A **septum** (plural = septa) refers to a wall or partition that divides. The septa are physical extensions of the myocardium, lined with endocardium. The **interatrial septum** (or atrial septum) is located between the right and left atria.

The **interventricular septum (or ventricular septum)** is located between the right and left ventricles. The interventricular septum is substantially thicker than the interatrial septum because the ventricles generate much more pressure when they contract. The septum between the atria and ventricles is known as the **atrioventricular septum**.

See Figure 11.5[9] for an illustration of the internal structures of the heart. Note that the interatrial septum is not visible as it is covered by the aorta and pulmonary trunk.

9. OpenStax College. (2013). *2008_Internal_Anatomy_of_the_HeartN* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2008_Internal_Anatomy_of_the_HeartN.jpg

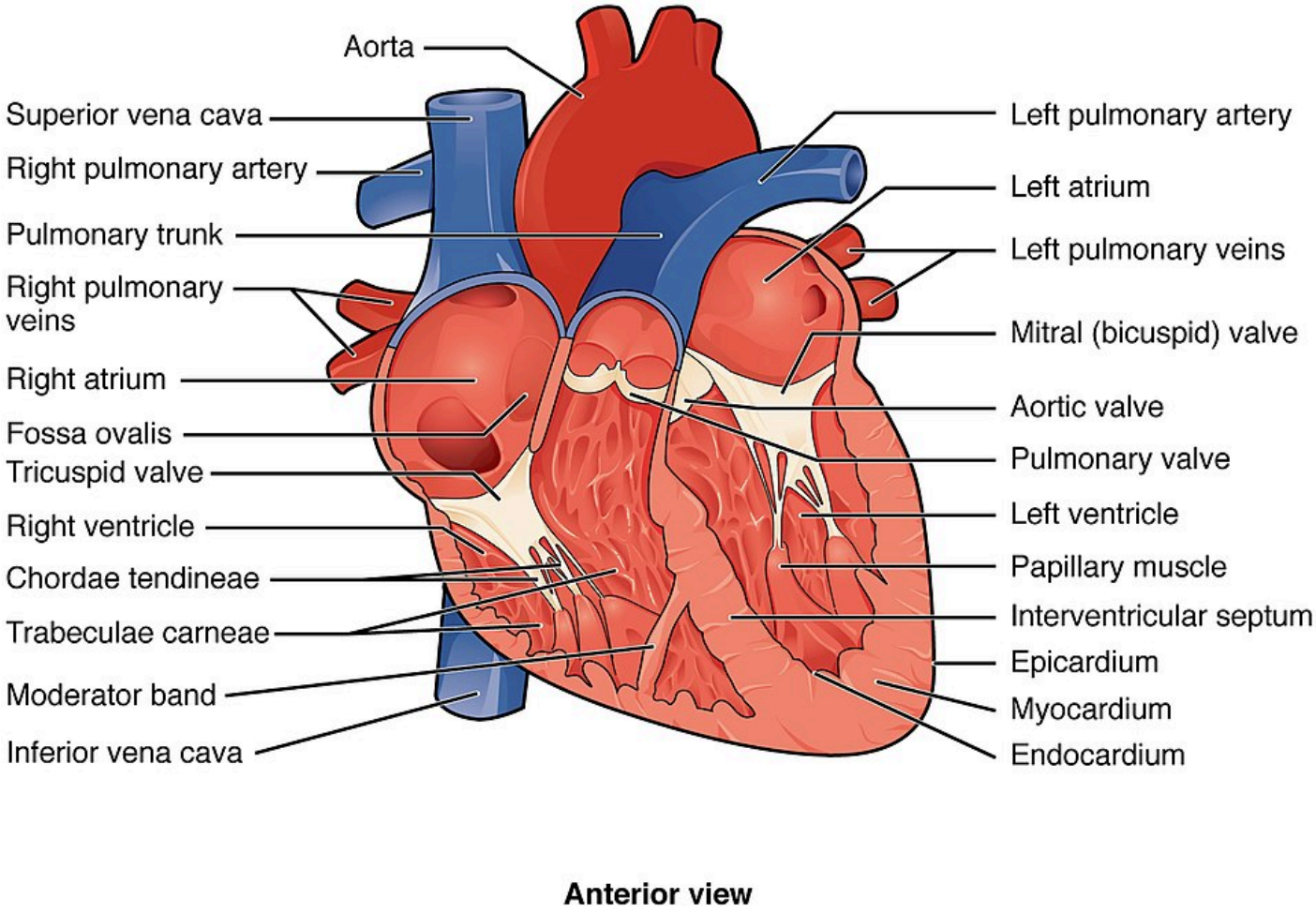


Figure 11.5 Internal Structures of the Heart

The **atrioventricular septum** has four openings that allow blood to move from the atria into the ventricles and from the ventricles into the pulmonary trunk and aorta. Located in each of these openings between the atria and ventricles is a **valve**, a specialized structure that ensures one-way flow of blood. Because these openings and valves structurally weaken the atrioventricular septum, the remaining tissue is reinforced with dense connective tissue called the cardiac **fibrous skeleton of the heart**. It includes four rings that surround the openings between the atria and ventricles and the openings to the pulmonary trunk and aorta, and serve as the point of attachment for the heart valves. The cardiac skeleton also provides an important boundary in the heart's electrical conduction system. Heart valves are further discussed in the "Heart Valve Structure and Function" subsection.[10]

10. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Right Atrium

The **right atrium** serves as the receiving chamber for deoxygenated blood returning to the heart from the body (systemic circulation). The two major systemic veins (the superior vena cava and the inferior vena cava) and the coronary sinus (a large coronary vein whose walls can't change diameter) transport deoxygenated blood to the right atrium.

The **superior vena cava** receives deoxygenated blood from the head, neck, upper limbs, and the chest region. It empties into the superior portion of the right atrium. The **inferior vena cava** receives deoxygenated blood from the lower limbs and abdominopelvic region of the body. It empties into the right atrium below the opening of the superior vena cava. Refer back to Figure 11.4 on the "Surface Features of the Heart" for an illustration of the superior and inferior vena cavae entering the right atrium.

On the posterior surface of the right atrium is the opening of the **coronary sinus**. This thin-walled vessel receives deoxygenated blood from most of the **coronary veins**, the systemic veins that receive deoxygenated blood from the heart muscle itself.[11]

Special Features of the Right Atrium

While most of the inner surface of the right atrium is smooth, there are a few areas that are not. A small oval-shaped depression on the interatrial septum is the **fossa ovalis**, which marks the former location of the **foramen ovale**, the opening in the fetal heart that allowed blood to flow directly from the right atrium to the left atrium and bypass pulmonary circulation. Read more about the foramen ovale in the "Fetal Circulation" subsection.

The other special features of the right atrium are prominent or rough ridges of muscle called **pectinate muscles** on the inner surface of the anterior right atrium. The right auricle also has pectinate muscles.[12]

11. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

12. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Right Ventricle

The right ventricle receives blood from the right atrium through the **tricuspid valve**. Each flap of the valve is attached to strong cords of connective tissue called the **chordae tendineae**, literally translated as "tendinous cords," or sometimes more poetically referred to as the "heart strings." The chordae tendineae connect each of the flaps to a **papillary muscle** that extends from the inferior ventricular wall.

When the myocardium of the ventricle contracts, pressure within the ventricle rises. Blood, like any fluid, flows from higher pressure to lower pressure, so in this case it moves upward toward the pulmonary trunk and the atrium. To prevent any potential backflow into the right atrium, the papillary muscles also contract, pulling on the chordae tendineae. This prevents the flaps of the valves and blood from being forced back up into the atria during ventricular contraction. See Figure 11.6[13] for a photo of the papillary muscles and chordae tendineae attached to the tricuspid valve.

13. PV KS. (2011). *Papillary muscle. 220/365* [Photograph]. Flickr. CC BY 2.0. https://www.flickr.com/photos/tworubies/5578474086/

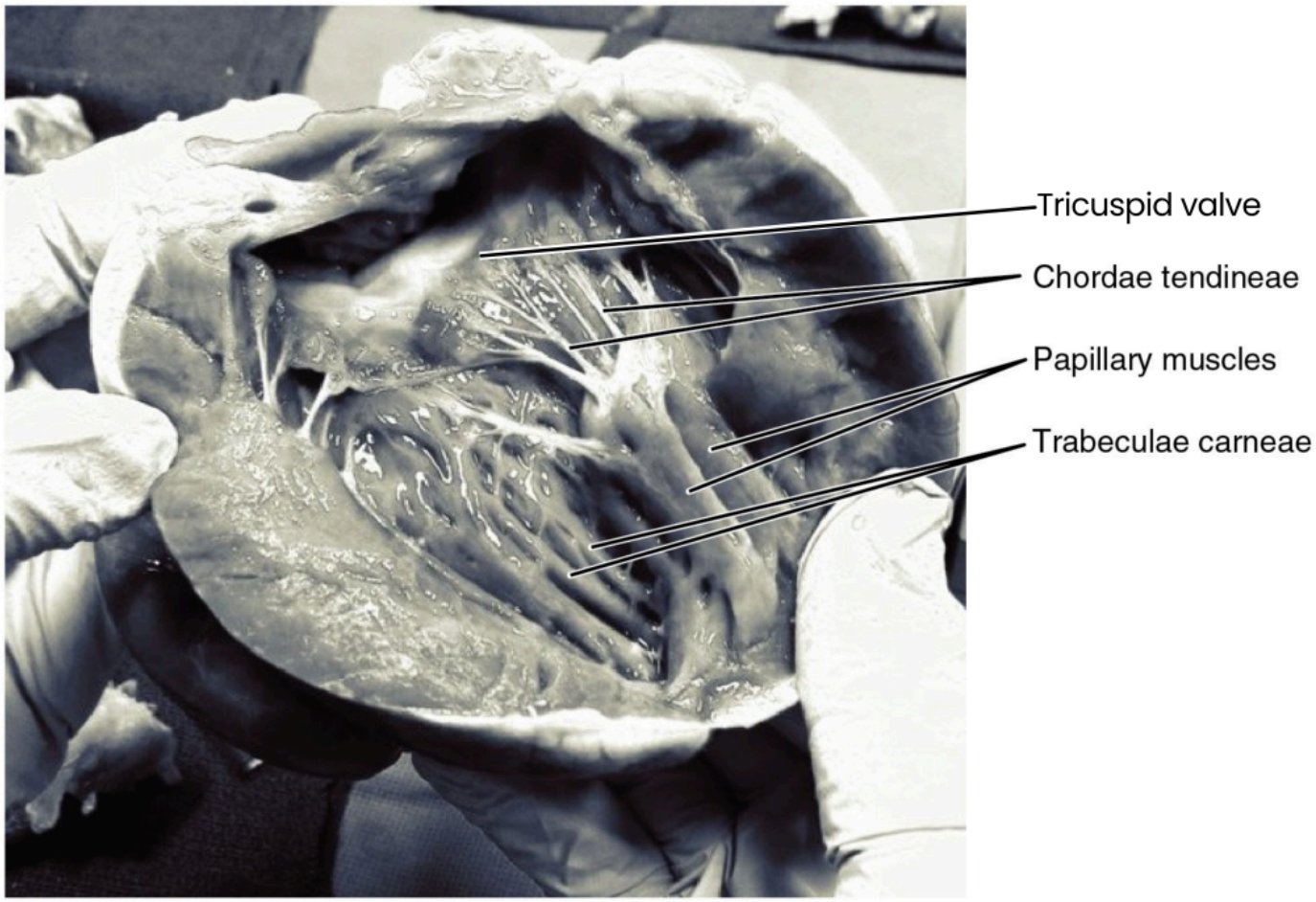


Figure 11.6 Chordae Tendineae and Papillary Muscles

When the right ventricle contracts, it ejects blood through the pulmonary valve and into the **pulmonary trunk**, a large artery that carries blood out away from the right ventricle. The pulmonary trunk divides into the left and right **pulmonary arteries**, which carry the deoxygenated blood to the lungs.[14]

Special Features of the Right Ventricle

The walls of the right ventricle are lined with **trabeculae carneae**, ridges of cardiac muscle covered by endocardium. In addition to these muscular ridges, there is a band of cardiac muscle known as the **moderator band**, which reinforces the thin walls of

14. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

the right ventricle and plays a crucial role in cardiac conduction. The moderator band crosses from the lower interventricular septum to the inferior papillary muscle. Refer back to Figure 11.5 for an illustration of the trabeculae carneae and the moderator band in the right ventricle.[15]

Left Atrium

After oxygen is picked up and carbon dioxide is dropped off in the pulmonary capillaries of the lungs, freshly oxygenated blood returns to the left atrium of the heart through the four pulmonary veins. Most blood flows passively into the heart while both the atria and ventricles are relaxed, but toward the end of the ventricular relaxation period, the left atrium will contract, pumping blood into the ventricle. This atrial contraction accounts for approximately 20% of ventricular filling.

While the left atrium does not contain pectinate muscles, it does have an auricle that includes these pectinate ridges.[16]

Left Ventricle

Oxygenated blood flows into the left ventricle through the mitral (bicuspid) valve. The **mitral valve** is connected to papillary muscles by chordae tendineae. There are two papillary muscles in the left ventricle—the anterior and posterior—as opposed to three papillary muscles in the right ventricle. When the myocardium of the left ventricle contracts, it pushes blood up and through the aortic valve and into the aorta.

Although the ventricles on the right and left sides of the heart pump the same volume of blood per contraction, the myocardium of the left ventricle is much thicker and well-developed than the myocardium in the right ventricle. This is because the left ventricle has to generate more pressure to pump blood through the entire body (systemic circulation). The right ventricle does not need to generate as much pressure, as

15. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

16. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

it only has to pump blood to the lungs and back (pulmonary circulation). See Figure 11.7[17] for an illustration of the difference in thickness between the right and left ventricles.[18]

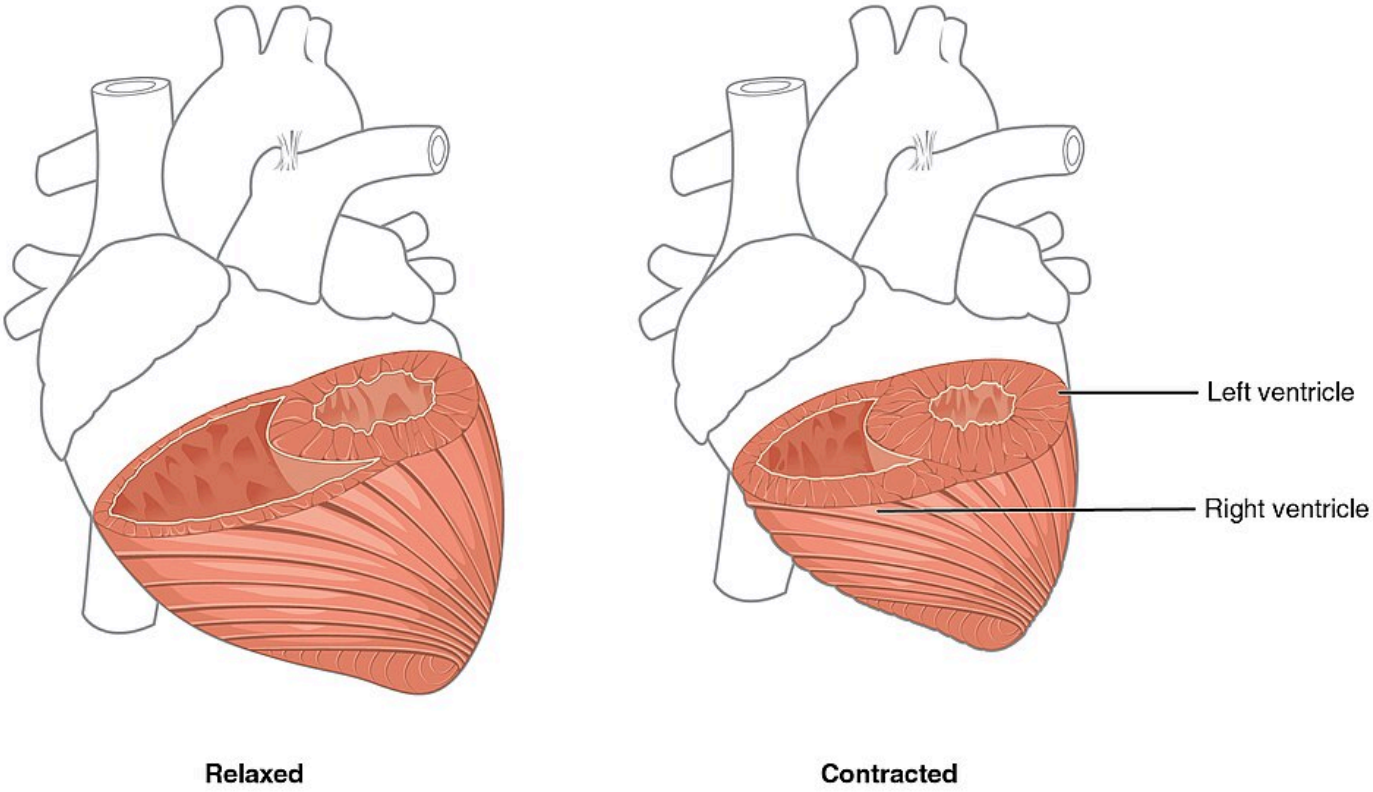


Figure 11.7 Differences in Ventricular Muscle Thickness

Heart Valve Structure and Function

There are two sets of valves found in the heart, the atrioventricular (AV) valves and the semilunar valves. The valves ensure that blood flows in one direction through the heart. See Figure 11.8[19] for an illustration of the heart valves.[20]

17. OpenStax College. (2013). *2007_Ventricular_Muscle_Thickness* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2007_Ventricular_Muscle_Thickness.jpg
18. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
19. OpenStax College. (2013). *2011_Heart_Valves* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2011_Heart_Valves.jpg
20. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

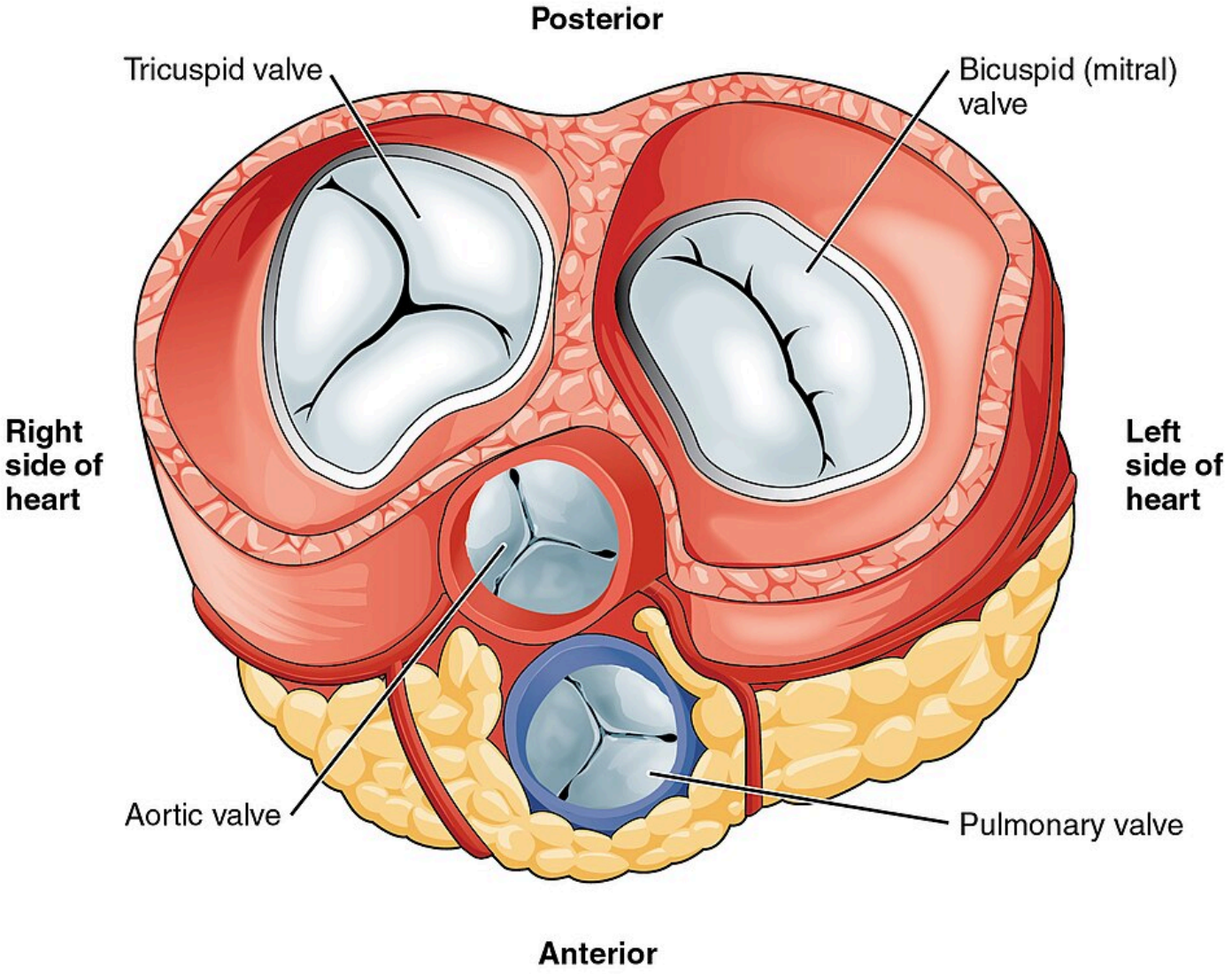


Figure 11.8 Heart Valves

Atrioventricular (AV) Valves

The two one-way valves between the atria and ventricles are known as **atrioventricular valves**. The AV valve on the right side of the heart is called the tricuspid valve, and the one on the left side is the mitral (bicuspid) valve. The first heartbeat sound ("lub") is caused by the closing of the AV valves.

When the ventricles begin to contract, pressure within the ventricles rises, and blood

flows toward the area of lowest pressure, which is initially in the atria. This backflow causes the cusps of the tricuspid and mitral (bicuspid) valves to close.[21]

Tricuspid Valve

The tricuspid valve is located between the right atrium and the right ventricle and is also known as the right atrioventricular valve. It consists of three leaflets (flaps) made of endocardium reinforced with additional connective tissue. The flaps are connected by chordae tendineae to the papillary muscles, which control the opening and closing of the valves.

Mitral (Bicuspid) Valve

The **mitral valve**, also called the bicuspid valve or the left atrioventricular valve, is located between the left atrium and left ventricle. Structurally, this valve consists of two cusps, compared to the three cusps of the tricuspid valve. The two cusps of the mitral valve are attached by chordae tendineae to two papillary muscles that project from the wall of the ventricle.

Semilunar Valves

The valves at the openings in the heart that lead to the pulmonary trunk and the aorta are known generically as **semilunar valves**. The semilunar valves are composed of three flaps of endothelium reinforced with connective tissue but lack the chordae tendineae and papillary muscles associated with the atrioventricular valves. Instead, they consist of pocket-like folds of endocardium reinforced with additional connective tissue. These flaps resemble a half-moon, and that is why they're called semilunar (*semi* = half, *lunar* = moon) valves. When the ventricles relax, and the change in pressure forces the blood toward the ventricles, the blood presses against these cusps and seals the openings. The two semilunar valves are the pulmonary valve and the aortic valve.[22]

21. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

22. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Pulmonary Valve

The **pulmonary valve**, also known as the pulmonic valve, pulmonary semilunar valve, or the right semilunar valve, emerges from the right ventricle at the base of the pulmonary trunk. When the right ventricle relaxes, the pressure differential causes blood to flow backward from the pulmonary trunk. This flow of blood fills the pocket-like flaps of the pulmonary valve, causing the valve to close and produce an audible sound that can be heard as the second sound in the heartbeat ("dub").

Aortic Valve

The aortic valve, also called the aortic semilunar valve or the left semilunar valve, is at the base of the aorta and prevents backflow of blood from the aorta. When the ventricle relaxes and blood attempts to flow back into the left ventricle from the aorta, blood will fill the cusps of the valve, causing it to close and produce an audible sound that is also part of the "dub" sound in the heartbeat.

See Figure 11.9[23] for an illustration of blood flow from the left atrium to the left ventricle. When the mitral valve is open, it allows blood to move from the left atrium to the left ventricle. The aortic valve is closed to prevent backflow of blood from the aorta to the left ventricle.

23. OpenStax College. (2013). *2012_Blood_Flow_Relaxed_Ventricles* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2012_Blood_Flow_Relaxed_Ventricles.jpg

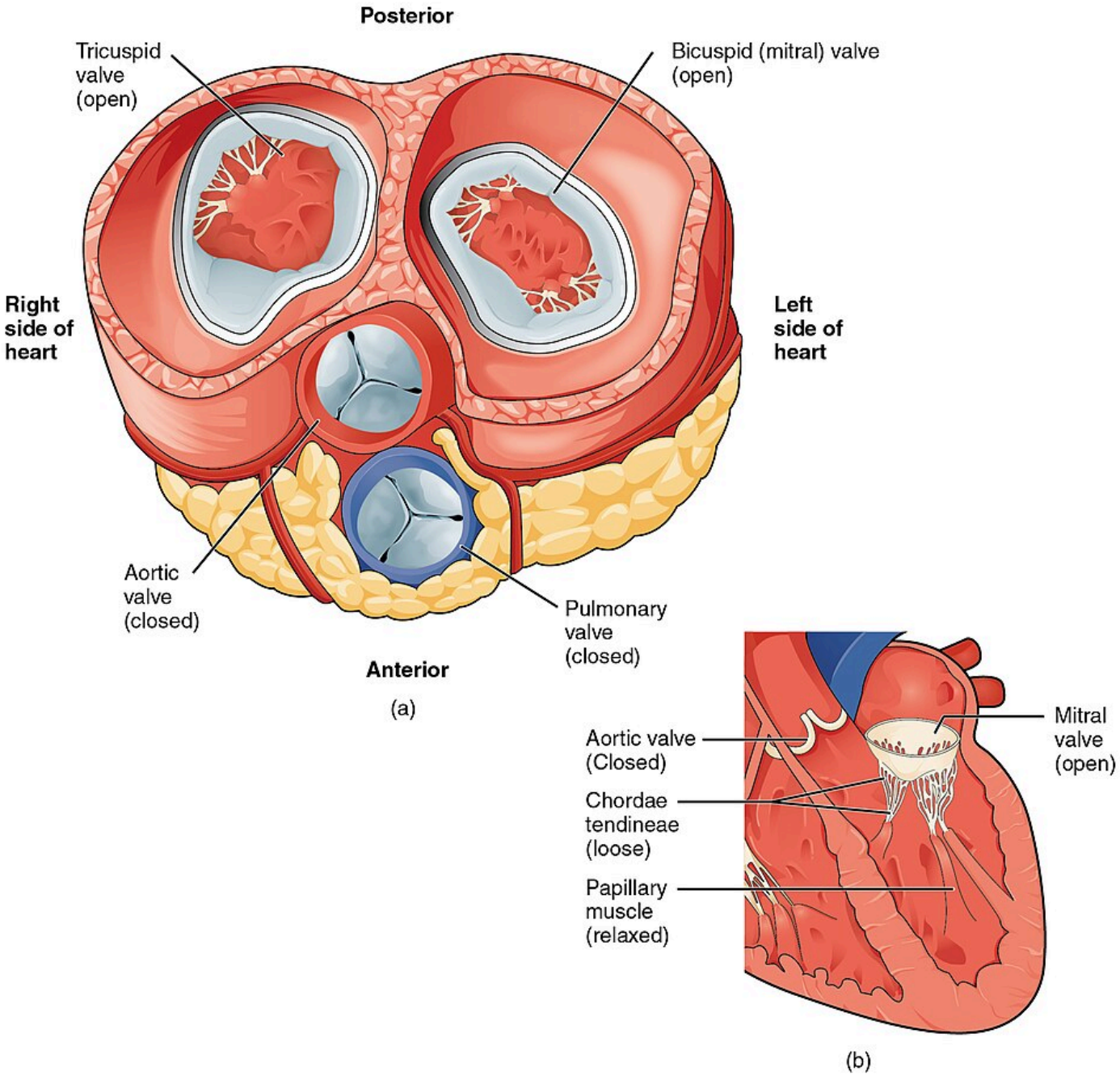


Figure 11.9 Blood Flow from the Left Atrium to the Left Ventricle: (a) the Two Atrioventricular Valves Are Open, and the Two Semilunar Valves Are Closed; (b) The Mitral Valve Is Open, and the Aortic Valve Is Closed to Prevent Backflow of Blood

Videos

Watch the video "The Anatomy of the Heart" below to learn about the structure

of the heart, including its chambers, valves, and how it pumps blood throughout the body.[24]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Cardiac Muscle Cells

Cardiomyocytes (cardiac muscle cells) share a few characteristics with both skeletal muscle and smooth muscle, but they also have some unique properties of their own. One of these unique characteristics is its ability to initiate an electrical impulse that spreads rapidly from cell to cell to trigger contraction. This property is known as autorhythmicity. However, even though cardiac muscle has **autorhythmicity**, heart rate is influenced by the endocrine and nervous systems.[25]

Structure of Cardiac Muscle

Cardiomyocytes are considerably shorter with much smaller diameters compared to the long cylinders of skeletal muscle fibers. Like skeletal muscle, cardiac muscle is also striated. Mitochondria are plentiful, providing energy for the continuous contractions of the heart. Typically, cardiomyocytes have a single, central nucleus, but two or more nuclei may be found in some cells.

24. Wisc-Online. (2016, December 14.). *The anatomy of the heart* [Video]. YouTube. All rights reserved. https://youtu.be/R_127Tew7N4

25. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Cardiomyocytes branch freely. A junction between two adjoining cells is marked by a structure called an **intercalated disc**, which helps coordinate the synchronized contraction of the heart muscle so that cells contract together to pump the blood. See Figure 11.10[26] for an illustration of cardiac muscle cells.

26. Alexander G. Cheroske. (2019). *Cardiac_muscle_histology_400x* [Photograph]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Cardiac_muscle_histology_400x.jpg

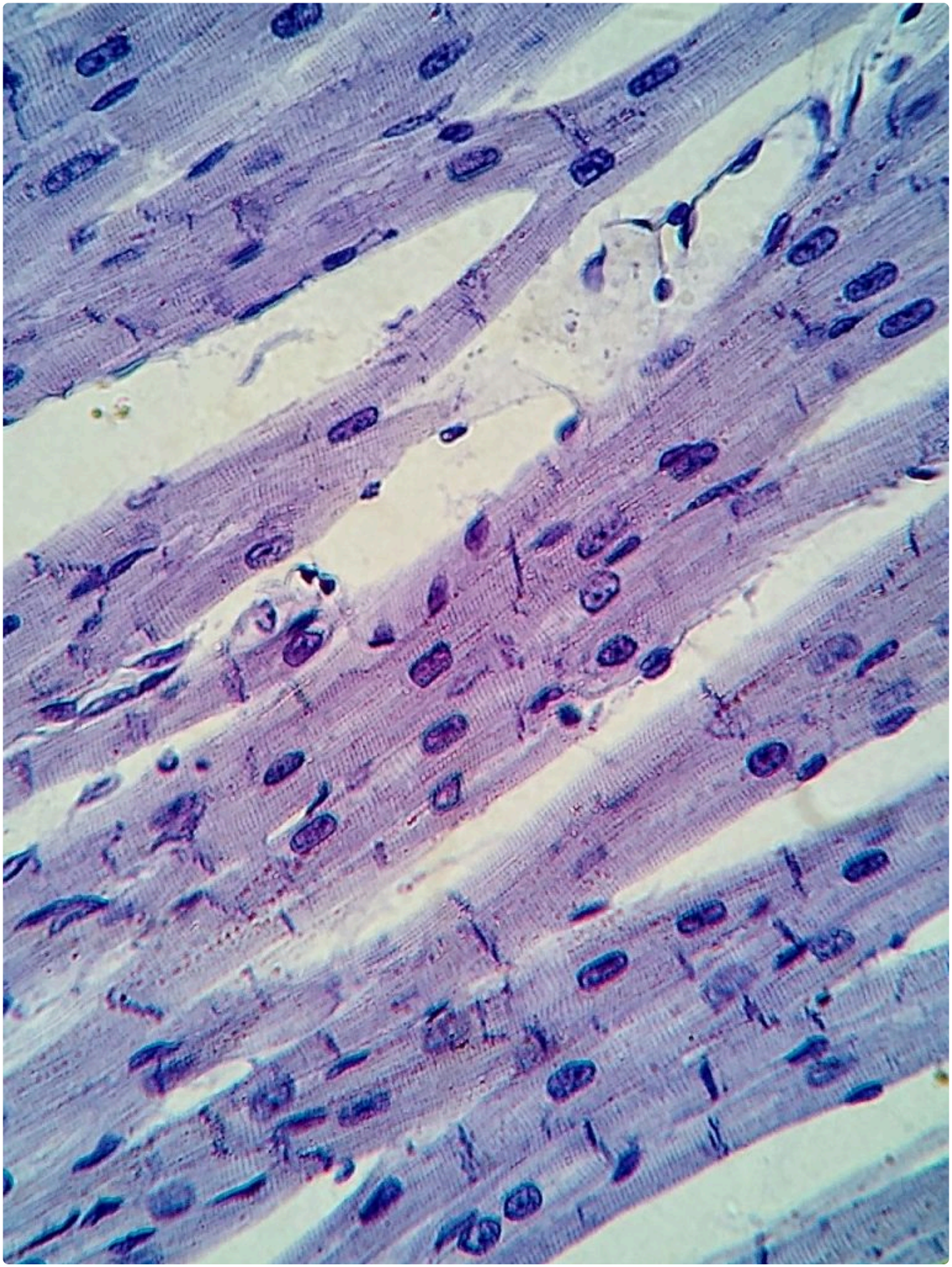


Figure 11.10 Cardiac Muscle Tissue

Repair and Replacement of Cardiac Muscle Cells

If an individual has a myocardial infarction (commonly known as a heart attack), cardiac muscle cells are damaged and can die from a lack of oxygenated blood flow. Damaged cardiac muscle cells have extremely limited abilities to repair or replace themselves. Dead cardiac muscle cells are replaced by patches of scar tissue. Research indicates that some stem cells remain within the heart that continue to divide and potentially replace dead cells, but these newly formed cells are rarely as functional as the original cells, which reduces cardiac function. If future research can unlock the mechanism that generates new cardiac muscle cells and restores full mitotic capabilities, the prognosis for heart attack survivors will be greatly enhanced.[27]

Pulmonary and Systemic Circulation of Blood

The heart acts as a double pump, simultaneously pumping blood to and from the lungs (pulmonary) and to and from the remainder of the body tissues (systemic). There are two distinct but connected circuits of blood circulation, called pulmonary and systemic circulation. When learning about circulation, it is important to understand the function of **arteries**, vessels that carry blood away from the heart, and **veins**, vessels that bring blood back to the heart.

Pulmonary circulation transports deoxygenated blood to the lungs to pick up oxygen and drop off carbon dioxide for exhalation. Pulmonary circulation begins when the right ventricle pumps deoxygenated blood through the pulmonary trunk, which splits into the right and left pulmonary arteries to take the blood to each lung. Note: The pulmonary trunk and the left and right pulmonary arteries and their branches are the only arteries in the body after birth that carry deoxygenated blood. These pulmonary arteries divide many times before reaching the pulmonary capillaries, where oxygen is picked up, and carbon dioxide is dropped off and exhaled. Freshly oxygenated blood then travels back to the left side of the heart via two right and two left pulmonary veins, which all carry blood to the left atrium. Note: The pulmonary veins are the only veins in

27. Terashvil, M., & Bosnjak, Z. J. (2019). Stem cell therapies in cardiovascular disease. *Journal of Cardiothoracic Vascular Anesthesia, 33(*1), 209-222. https://doi.org/10.1053/j.jvca.2018.04.048

the body after birth that carry highly oxygenated blood. Additional information about the pulmonary circulation is described in the "Pulmonary Circulation" subsection of the "**Blood Vessels**" section.

Systemic circulation transports oxygenated blood to almost all tissues of the body and returns deoxygenated blood to the heart to be sent through the pulmonary circulation. Systemic circulation begins when the left ventricle pumps oxygenated blood through the aortic valve and into the aorta. Blood then travels through numerous systemic arteries to systemic arterioles (tiny arteries) and then to systemic capillaries, where oxygen is dropped off for the tissues to use and carbon dioxide (a cellular waste product) is picked up. The now deoxygenated blood makes its way back to the heart via systemic venules (tiny veins), which merge together into larger systemic veins, and eventually flow into the superior and inferior venae cavae that return the deoxygenated blood back to the right atrium of the heart. Additional information about arteries and veins in the systemic circulation is described in the "Systemic Circulation" subsection of the "**Blood Vessels**" section.[28]

See Figure 11.11[29] for an illustration showing pulmonary and systemic circulation. Note that the color blue is used to show deoxygenated blood, and the color red is used to show oxygenated blood.

28. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

29. OpenStax College. (2013). *2003_Dual_System_of_Human_Circulation* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2003_Dual_System_of_Human_Circulation.jpg

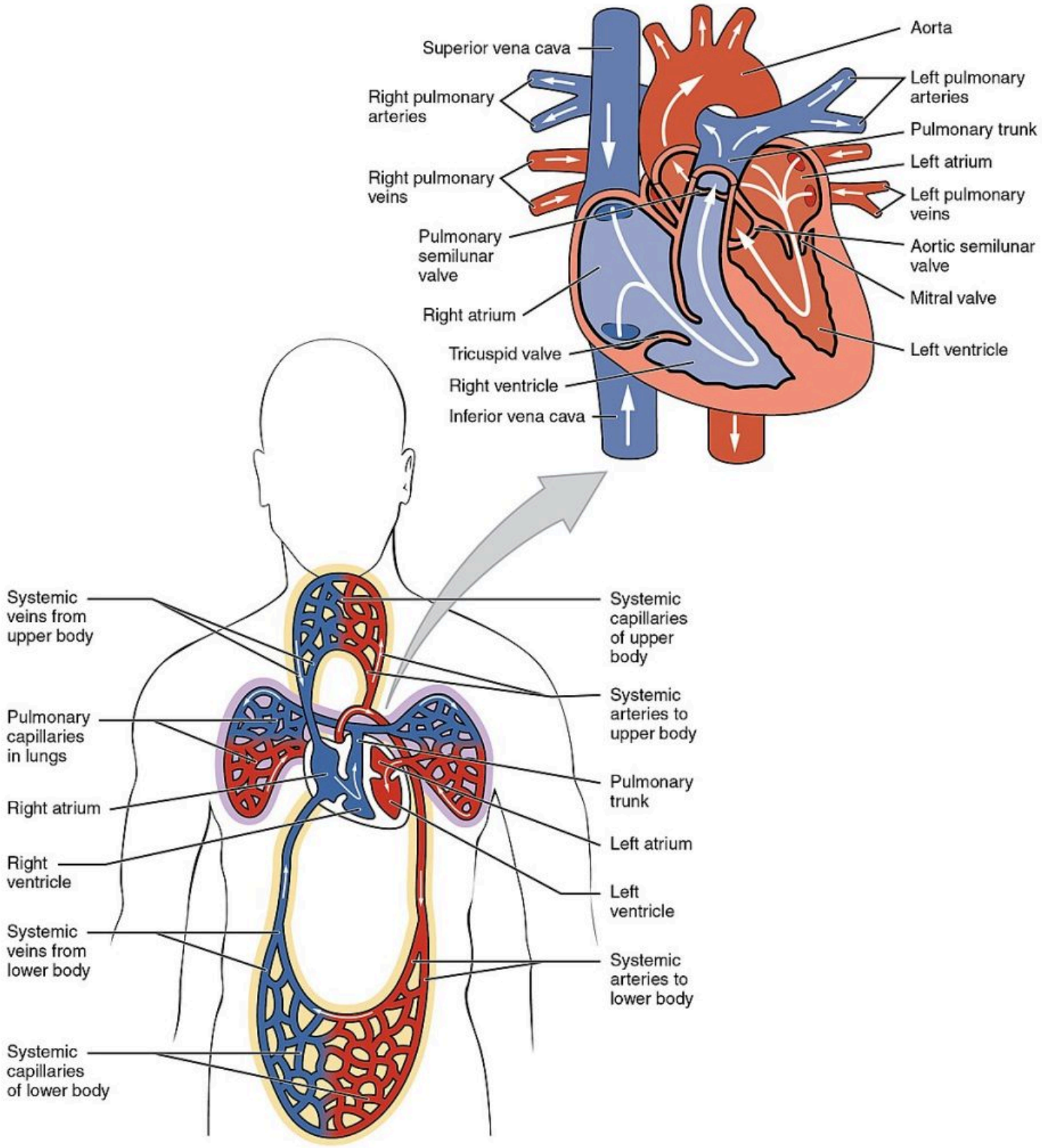


Figure 11.11 Pulmonary and Systemic Circulation of Blood

See Figure 11.12[30] for an illustration of the circulation of blood flow.

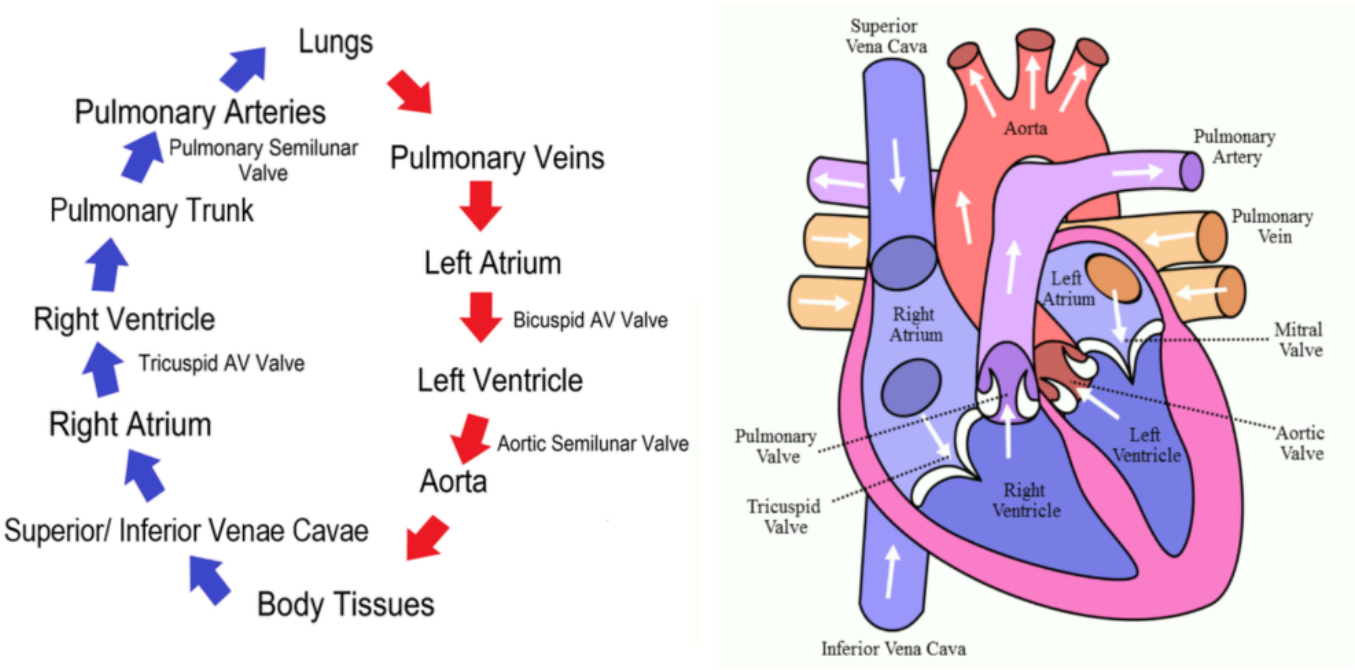


Figure 11.12 Circulation of Blood Flow

Coronary Circulation

The heart is composed of cardiac muscle cells (cardiomyocytes) that are constantly active throughout life. Like all other cells, a cardiomyocyte requires a constant supply of oxygen and nutrients and a way to remove wastes.[31]

Coronary Arteries and Veins

Coronary arteries supply oxygenated blood to the myocardium of the heart. The left and right coronary arteries originate from the base or root of the aorta as it leaves the left ventricle. The left coronary artery divides into smaller arteries and feeds the left atrium, left ventricle, and the interventricular septum. The right coronary artery also divides into

30. Christinelmiller. (2020). *Circulation_of_blood_through_the_heart* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. commons.wikimedia.org/wiki/File:Circulation_of_blood_through_the_heart.png

31. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

smaller arteries and feeds the right atrium, portions of both ventricles, and the cardiac conduction system. Additional information will be discussed in the "**Conduction System of the Heart**" section.

Coronary veins collect deoxygenated blood from the myocardium. These veins are generally found parallel to the coronary arteries. Most of the coronary veins send blood to a large vein called the coronary sinus. The **coronary sinus** is a large, thin-walled vein on the posterior surface of the heart lying within the atrioventricular sulcus that empties blood directly into the right atrium. A sinus' walls can't change diameter to vasoconstrict or vasodilate like other vessels.

See Figure 11.13[32] for an illustration of the arteries and veins involved in coronary circulation from both the anterior and posterior views.

32. OpenStax College. (2013). *2014ab_Coronary_Blood_Vessels* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2014ab_Coronary_Blood_Vessels.jpg

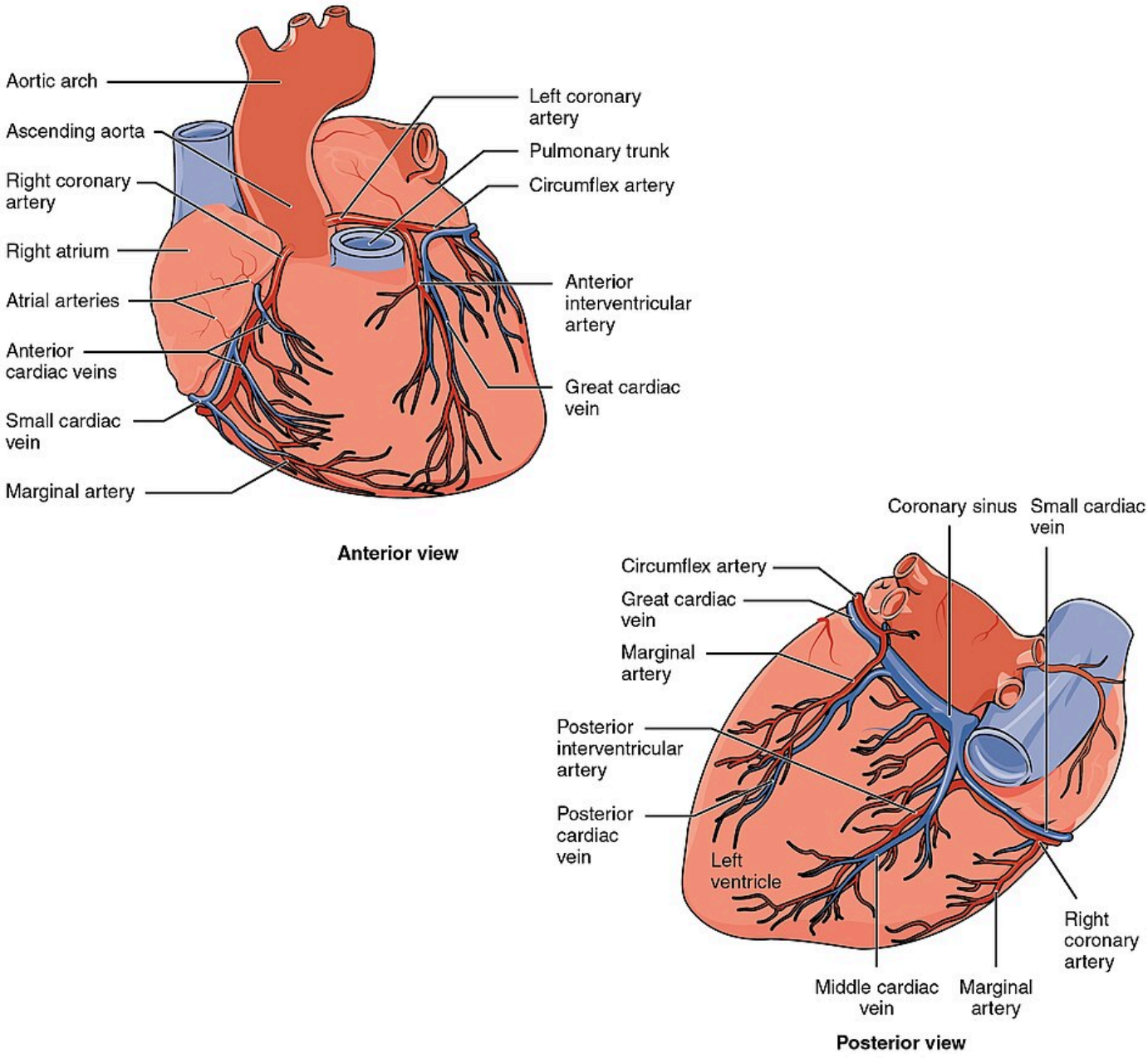


Figure 11.13. Coronary Circulation

The left and right coronary arteries branch into smaller vessels that interconnect with other branches, forming anastomoses. An **anastomosis** is a connection between two vessels that both supply the same region. It allows blood flow to a region even if there is a partial blockage in another branch.

Videos

Watch the video "Cardiovascular System Overview, Animation" below to learn about the structure and function of the cardiovascular system, including the heart, blood vessels, and the circulation of blood throughout the body.[33]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Watch the video "Circulatory System and Pathway of Blood Through the Heart" below to learn how blood flows through the heart and circulatory system, delivering oxygen and nutrients throughout the body.[34]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

33. Alila Medical Media. (2019, May 13). *Cardiovascular system overview, animation* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=28CYhgjrBLA

34. Amoeba Sisters. (2020, August 26). *Circulatory system and pathway of blood through the heart* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=_vZ0lefPg_0

11.3 Conduction System of the Heart

The heart generates its own electrical impulse as part of the **cardiac conduction system**. The components of the cardiac conduction system include the sinoatrial node, the atrioventricular node, the atrioventricular bundle, the bundle branches, and the Purkinje fibers.[1] See Figure 11.14[2] for an illustration of the cardiac conduction system.

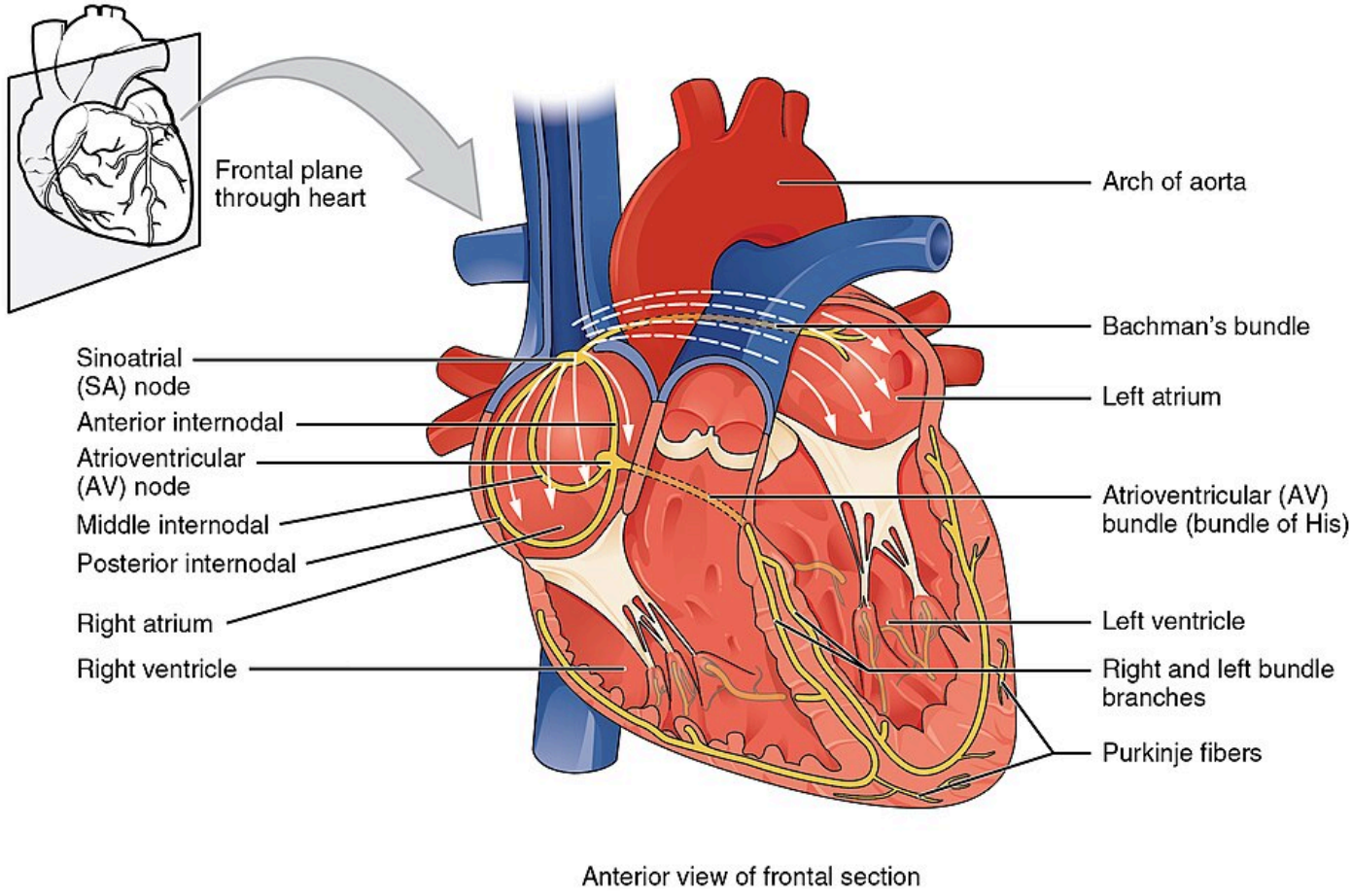


Figure 11.14 Cardiac Conduction System

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. OpenStax College. (2013). *2018_Conduction_System_of_Heart* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2018_Conduction_System_of_Heart.jpg

Sinoatrial (SA) Node

Normal cardiac rhythm is established by the **sinoatrial (SA) node**, a specialized clump of myocardial conducting cells that initiate and propagate the electrical impulse that travels throughout the heart. This allows the SA node to be self-depolarizing, which means it generates its own electrical signal, stimulating the heart to beat. Unlike skeletal muscle, cardiac muscle doesn't need a motor neuron to stimulate contraction. Because of this, the SA node is known as the pacemaker of the heart. It is located in the wall of the upper right atrium close to the opening of the superior vena cava.

Once the SA node fires, the impulse spreads throughout the atria and causes them to contract. The signal also spreads to the atrioventricular node. The fibrous cardiac skeleton prevents the impulse from spreading into the myocardial cells in the ventricles except at the atrioventricular node.

Atrioventricular (AV) Node

The **atrioventricular (AV)** node is a second clump of specialized conductive cells located in the inferior portion of the right atrium within the atrioventricular septum. The septum prevents the impulse from spreading directly to the ventricles without passing through the AV node first. There is a pause before the AV node transmits the impulse to the atrioventricular bundle (below). This pause is critical to heart function, as it allows the atrial cardiomyocytes to finish emptying blood into the ventricles before the impulse is transmitted to the cells of the ventricle.

Atrioventricular Bundle (Bundle of His), Bundle Branches, and Purkinje Fibers

Arising from the AV node, the **atrioventricular (AV) bundle**, or **bundle of His**, proceeds through the interventricular septum before dividing into the right and left **bundle branches**. The left bundle branch supplies the left ventricle, and the right bundle branch supplies the right ventricle. Because the left ventricle is much larger than the right, the left bundle branch is also considerably larger than the right. Both bundle branches descend and reach the apex of the heart, where they connect with the Purkinje fibers.

The **Purkinje fibers** are additional conductive fibers that spread the impulse to the contractile cells in the ventricles. They extend throughout the myocardium from the apex of the heart up the ventricles. Because the electrical stimulus begins at the apex, contraction of the ventricles also begins at the apex and travels up toward the base of the heart, similar to squeezing a tube of toothpaste from the bottom. This allows the blood to be pumped out of the ventricles and into the aorta and pulmonary trunk. See Figure 11.15[3] for an illustration of cardiac conduction.

3. OpenStax College. (2013). *2019 Cardiac ConductionN* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2019_Cardiac_ConductionN.jpg

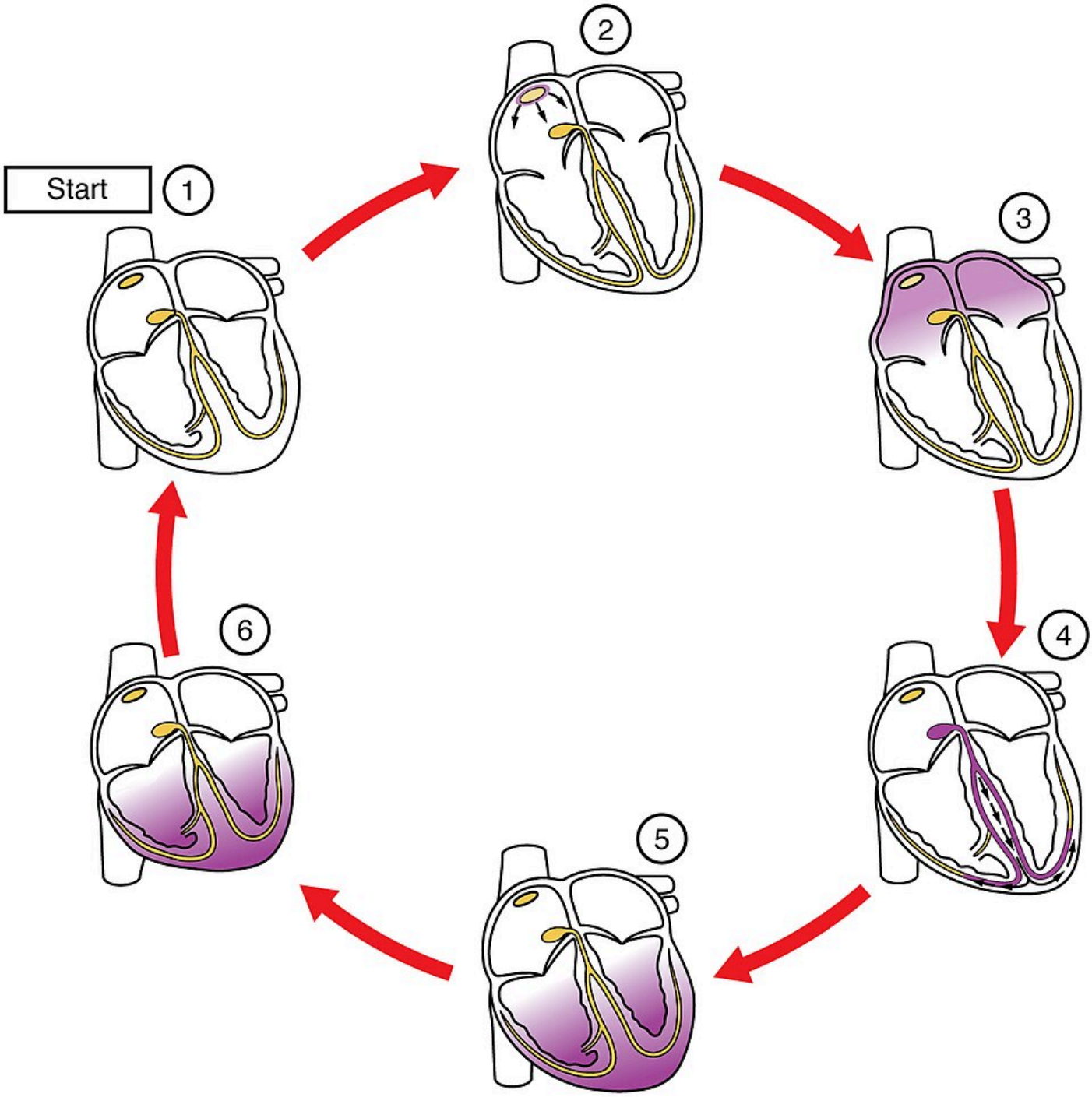


Figure 11.15 Cardiac Conduction: (1) the Sinoatrial (SA) Node and the Remainder of the Conduction System Are at Rest; (2) the SA Node Initiates the Action Potential, Which Sweeps Across the Atria; (3) After Reaching the Atrioventricular Node, the Impulse Is Transmitted to the Atrioventricular Bundle; (4) the Impulse Travels Through the Atrioventricular Bundle and Bundle Branches to the Purkinje Fibers; (5) the Impulse Spreads to the Contractile Fibers of the Ventricle; (6) Ventricular Contraction Begins

Video

Watch the video “Cardiac Conduction System” using the link below to learn how electrical signals travel through the heart to regulate heartbeat and coordinate contraction.[4]

- Open the MedlinePlus cardiac conduction system video webpage

Electrocardiogram

By placing electrodes on the skin in specific locations, we can record the heart’s electrical activity using an **electrocardiogram (ECG)**, also commonly abbreviated EKG (“K” for *kardiology*, the German term for *cardiology*). Figure 11.16[5] shows a 6-second ECG strip depicting normal sinus rhythm (NSR).



Figure 11.16 A 6-Second ECG Strip Depicting Normal Sinus Rhythm (NSR)

Careful analysis of the ECG reveals a detailed picture of both normal and abnormal heart function and is an important clinical diagnostic tool. A 12-lead electrocardiograph

4. MedlinePlus. (n.d.). *Cardiac conduction system* [Video]. U.S. National Library of Medicine. All rights reserved. Link: https://medlineplus.gov/ency/anatomyvideos/000021.htm
5. Rocuronium Bromide. (2024). *Normal Sinus Rhythm (6 seconds)* [Image]. Wikimedia Commons. CC0 1.0. https://commons.wikimedia.org/wiki/File:Normal_Sinus_Rhythm_(6_seconds).svg

uses electrodes placed in standard locations on the patient's skin, as illustrated in Figure 11.17.[6]

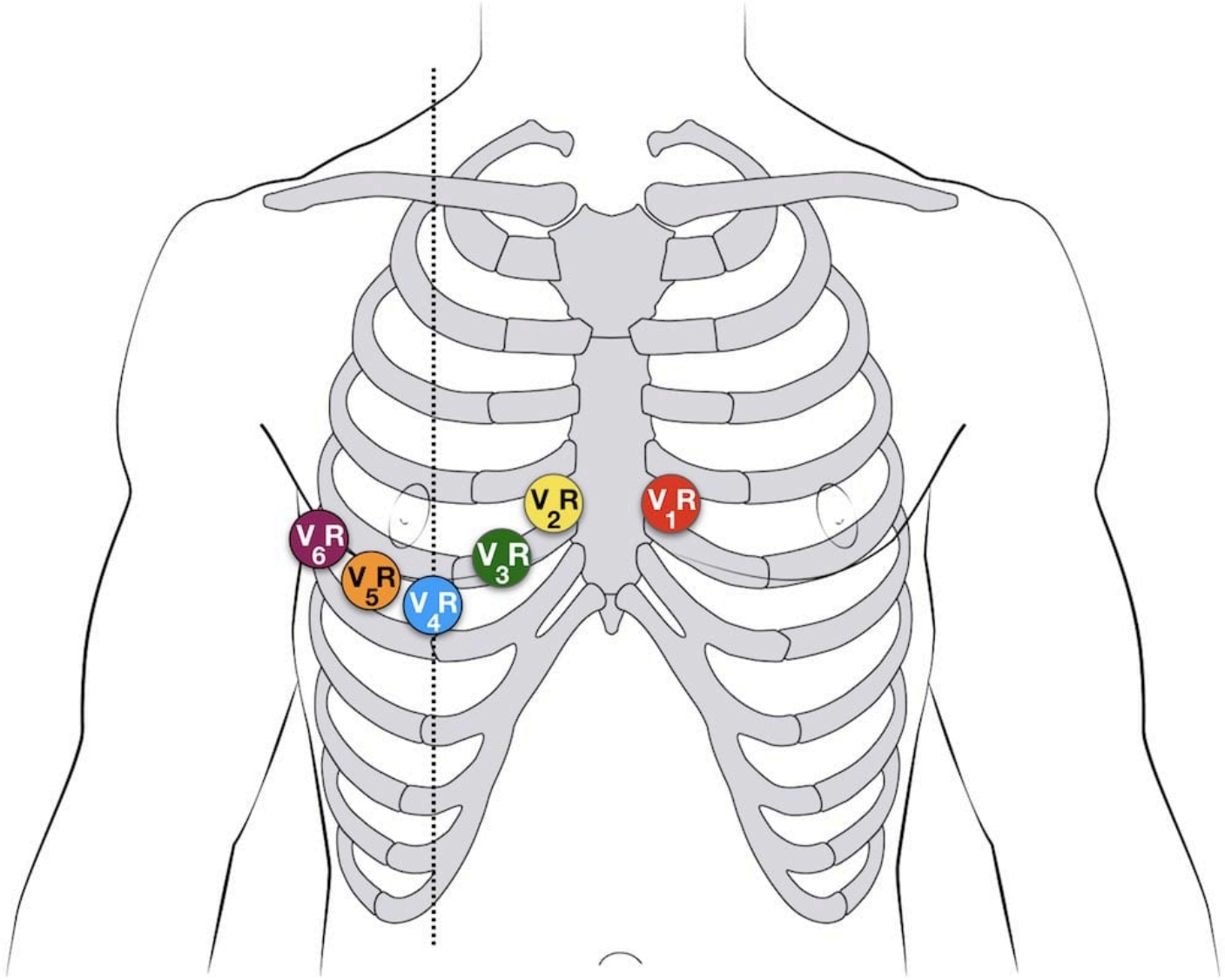


Figure 11.17 Standard 12-Lead ECG Placement

Sometimes it is useful to monitor a patient's cardiac activity over a longer period of time. A Holter monitor is a small, portable, battery-operated device that continuously monitors a patient's cardiac electrical activity over a longer period of time during their normal daily routine. It is used to detect irregular heart rhythms.

6. Cadogan, M. (2021). *Right-sided-12-lead-ECG-lead-placement* [Diagram]. Life in the Fast Lane. CC BY-NC-SA 4.0. https://litfl.com/ecg-lead-positioning/

11.4 Cardiac Cycle

The period of time that begins with contraction of the atria and ends with ventricular relaxation is known as the **cardiac cycle**. One cardiac cycle consists of contraction and relaxation of the atria and contraction and relaxation of the ventricles.

Contraction of the heart is called **systole**. Systole pumps the blood out of the chambers. The period of relaxation that occurs as the chambers fill with blood is called **diastole**. Both the atria and ventricles undergo systole and diastole, and it is essential that these components be carefully regulated and coordinated to ensure blood is pumped efficiently to the body. The phases of the cardiac cycle are further described in the following subsections.[1]

Phases of the Cardiac Cycle

At the beginning of the cardiac cycle, both the atria and ventricles are relaxed (or in diastole). Blood flows into the right atrium from the superior vena cava, the inferior vena cava, and the coronary sinus. At the same time, blood flows into the left atrium from the four pulmonary veins. During the first half of diastole, the AV valves are closed, and only the atria fill. As blood volume and pressure increase in the atria, the AV valves are forced open to start ventricular filling during the second part of diastole.

Atrial Systole and Diastole

At the start of atrial systole, the ventricles are normally filled with approximately 70–80 percent of blood due to inflow during diastole. Atrial contraction, also referred to as the "atrial kick," contributes the remaining 20–30 percent of filling for the ventricles. Contraction of the atria follows **depolarization**. As the atrial muscles contract from the superior portion of the atria, pressure rises within them, and blood is pumped into the ventricles through the open atrioventricular valves. Atrial systole lasts approximately 100

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

milliseconds (ms) and ends prior to ventricular systole, as the atrial muscle returns to diastole and blood flow into the atria resumes.

Ventricular Systole

Ventricular systole follows the depolarization of the ventricles. It may be conveniently divided into two phases, lasting a total of 270 milliseconds (ms). At the end of atrial systole and just before ventricular contraction, the ventricles contain approximately 130 milliliters (mL) of blood in a resting adult in a standing position. This volume is known as the **end diastolic volume (EDV)** or **preload**.

Initially, as the muscles in the ventricle contract, the pressure of the blood within the chamber rises, but it is not yet high enough to open the semilunar (pulmonary and aortic) valves and be ejected from the heart. However, blood pressure quickly rises above that of the atria, which are now relaxed and in diastole. This increase in pressure causes blood to flow back toward the atria, closing the tricuspid and mitral valves. Because blood is not being ejected from the ventricles at this early stage, the volume of blood within the ventricles remains constant. Consequently, this initial phase of ventricular systole is known as **isovolumetric contraction**.

In the second phase of ventricular systole, the **ventricular ejection phase**, the contraction of the ventricular muscle raises the pressure within the ventricle to the point that it is greater than the pressures in the pulmonary trunk and the aorta. Blood is pumped from the heart as it pushes open the pulmonary and aortic semilunar valves. Pressure generated by the left ventricle will be appreciably greater than the pressure generated by the right ventricle because the existing pressure in the aorta will be so much higher. Nevertheless, both ventricles pump the same volume of blood. This quantity is referred to as stroke volume. Stroke volume will normally be in the range of 70–80 mL. Because ventricular systole begins with an end diastolic volume (EDV) of approximately 130 mL of blood, this means that there is still 50–60 mL of blood remaining in the ventricle following contraction, known as the **end systolic volume (ESV)**.

Ventricular Diastole

Ventricular relaxation, or diastole, follows **repolarization** of the ventricles. It is divided into two distinct phases and lasts approximately 430 milliseconds (ms).

During the early phase of ventricular diastole, as the ventricular muscle relaxes, blood

pressure within the ventricle begins to fall. When pressure within the ventricles drops below pressure in both the pulmonary trunk and aorta, blood flows back toward the heart, producing the dicrotic notch (small dip) seen in blood pressure tracings. The semilunar valves close to prevent backflow into the heart. Because the atrioventricular valves remain closed at this point, there is no change in the volume of blood in the ventricles, so the early phase of ventricular diastole is called the **isovolumetric ventricular relaxation phase**.

In the second phase of ventricular diastole, called late ventricular diastole, as the ventricular muscle relaxes, pressure on the blood within the ventricles drops even further. Eventually, it drops below the pressure in the atria. When this occurs, blood flows from the atria into the ventricles as it pushes open the tricuspid and mitral valves. All four chambers are in diastole, the atrioventricular valves are open, and the semilunar valves remain closed. The cardiac cycle is complete.

See Figure 11.18[2] for an illustration of the cardiac cycle.

2. OpenStax College. (2013). *2027_Phases_of_the_Cardiac_Cycle* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2027_Phases_of_the_Cardiac_Cycle.jpg

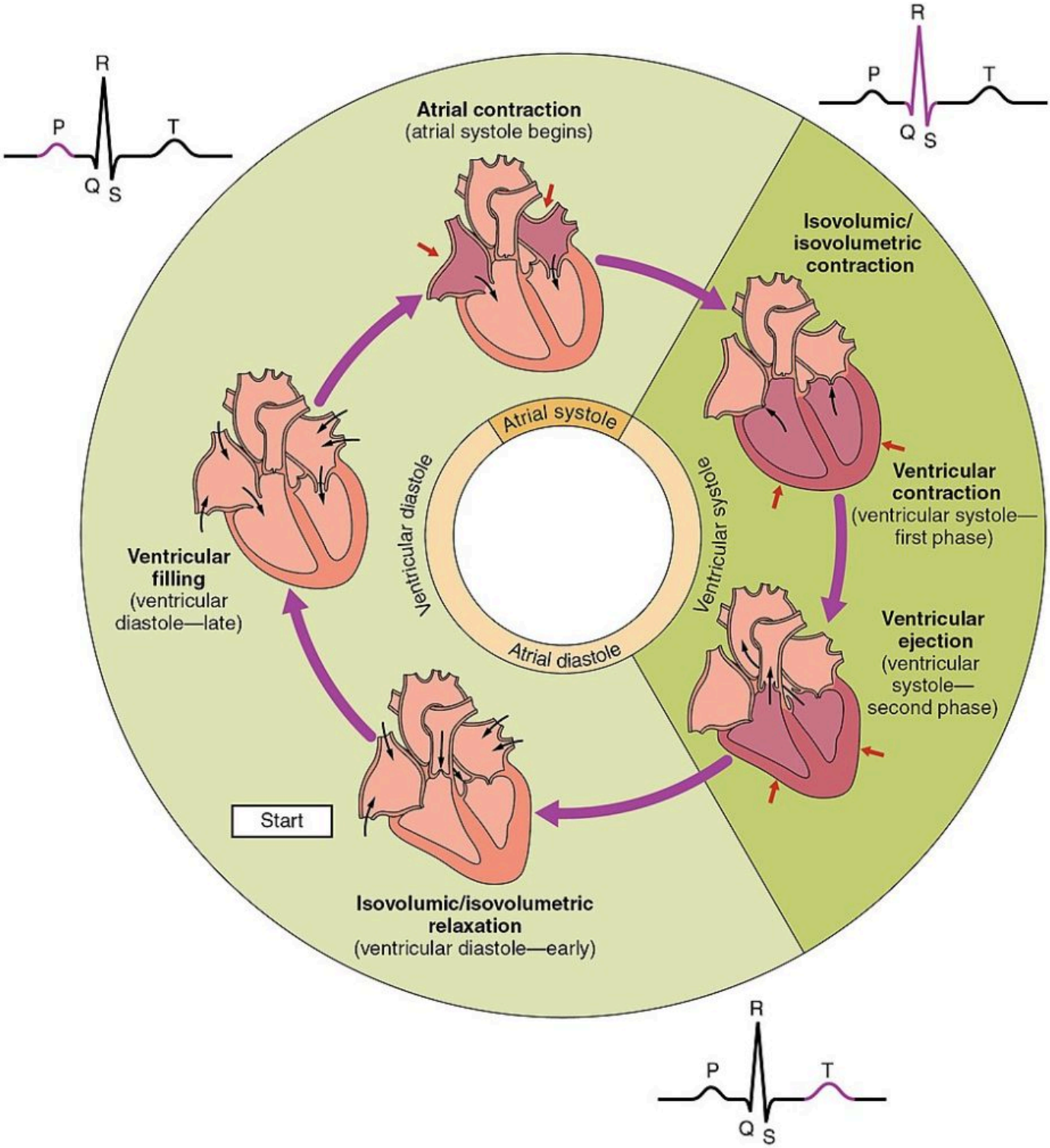


Figure 11.18 Overview of the Cardiac Cycle

Heart Sounds

Health professionals commonly assess the status of a patient's heart by auscultating (listening) to heart sounds using a stethoscope. In a normal, healthy heart, there are only two audible **heart sounds**: S1 and S2. S1 is the sound created by the closing of the atrioventricular valves during ventricular systole and is normally described as a "lub," or first heart sound. The second heart sound, S2, is the sound of the closing of the semilunar valves during ventricular diastole and is described as a "dub." See Figure 11.19[3] for stethoscope placement for auscultation of heart sounds over locations where valve sounds can best be heard.

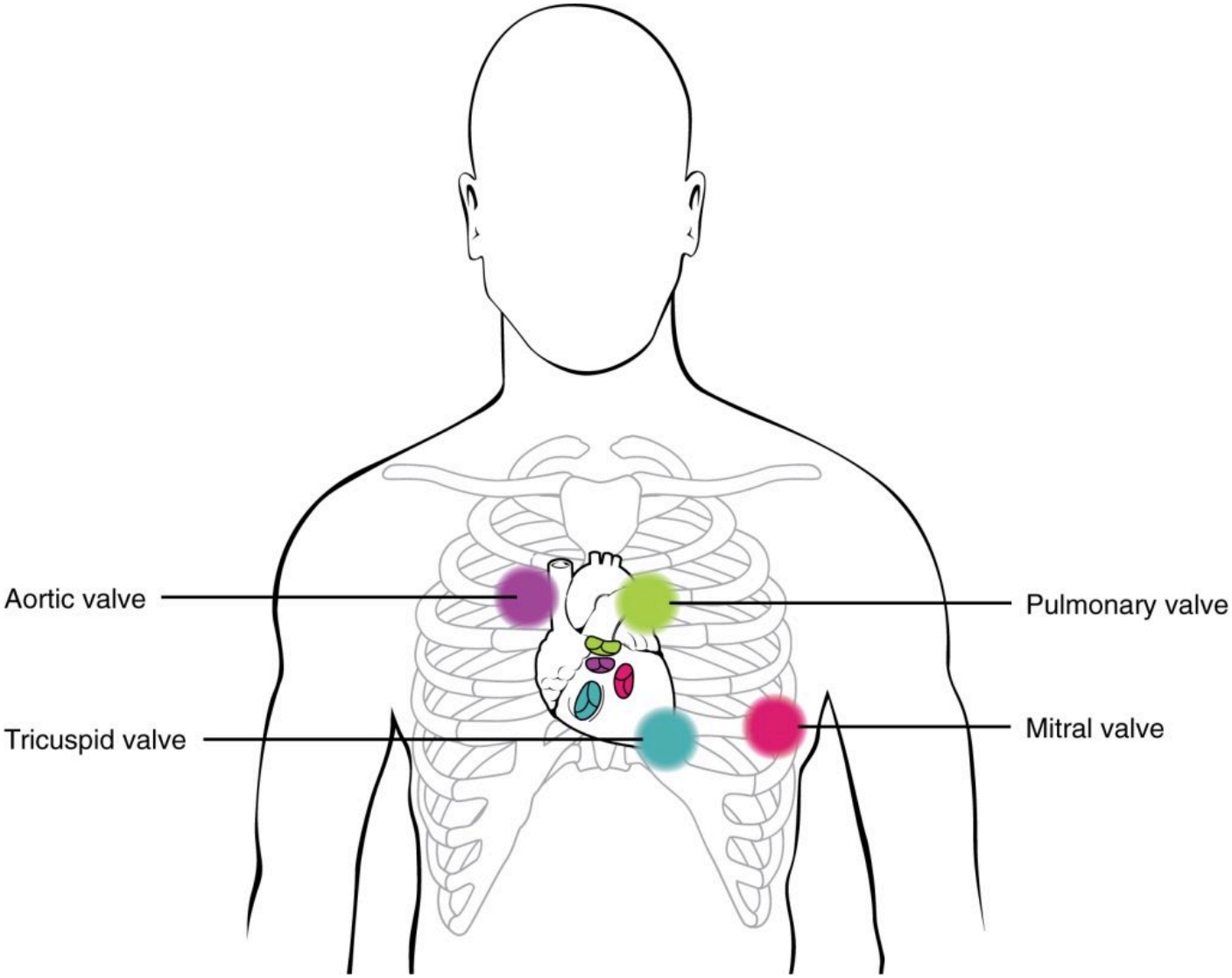


Figure 11.19 Stethoscope Placement for Auscultation

3. OpenStax College. (2013). *2030 Stethoscope Placement* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:2030_Stethoscope_Placement.jpg

The term **murmur** is used to describe an unusual sound coming from a heart valve that is caused by the turbulent flow of blood. Murmurs are graded on a scale of 1 to 6, with 1 being common, difficult to detect, and not serious, and 6 being the most severe.

Cardiac Output

Cardiac output (CO) is the amount of blood pumped by each ventricle in one minute. To calculate this value, multiply **stroke volume (SV)**, the amount of blood pumped by each ventricle, by **heart rate (HR)** per minute (or beats per minute, bpm). It can be represented mathematically by the following equation:

$$CO = HR \times SV$$

The normal range for SV is 55–100 mL. The average resting HR is 75 beats per minute (bpm) with a normal range from 60–100 bpm. Using these numbers, the average CO is 5.25 L/min, with a normal range of 4.0–8.0 L/min from each ventricle. Major factors influencing CO are summarized in Figure 11.20.[4]

4. OpenStax College. (2013). *2031_Factors_in_Cardiac_Output* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2031_Factors_in_Cardiac_Output.jpg

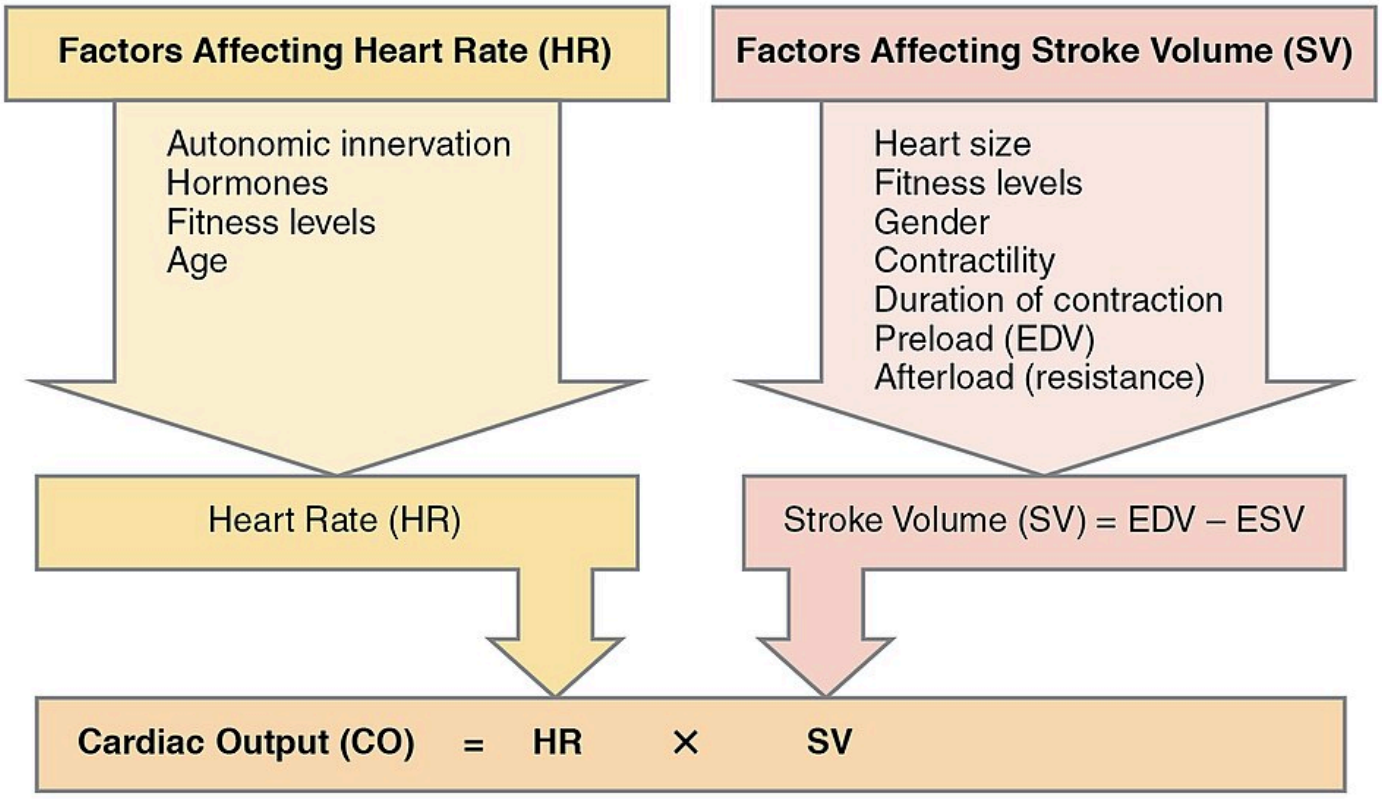


Figure 11.20 Major Factors Influencing Cardiac Output

Heart Rate

Heart rate across individuals varies considerably due to factors such as age and fitness levels. For example, a normal resting heart rate for an adult is 60-100 bpm, but a normal heart rate for a healthy newborn is 100-160 bpm. Heart rate gradually decreases until young adulthood.[5]

Abnormal Heart Rates

Bradycardia is a condition in which the resting heart rate for an adult drops below 60 bpm. If the patient is not exhibiting other symptoms, such as weakness, fatigue, dizziness, fainting, chest discomfort, palpitations, or respiratory distress, bradycardia is not considered clinically significant. In fact, trained athletes typically have heart rates

5. Charbek, E. (2024). *Normal vital signs*. Medscape. https://emedicine.medscape.com/article/2172054-author?form=fpf

below 60 bpm. However, if symptoms are present, they may indicate that the heart is not providing sufficient oxygenated blood to the tissues. Bradycardia can be caused by many factors, including side effects of medications, age, electrolyte imbalances, and a variety of medical conditions.[6]

Tachycardia is a condition in which the resting heart rate for an adult is greater than 100 bpm. Symptoms of tachycardia may include dizziness, shortness of breath, lightheadedness, heart palpitations, chest pain, or fainting (syncope). Tachycardia can be caused by a variety of factors, ranging from exercise, fever, anxiety, caffeine intake, electrolyte imbalances, side effects of medications, or underlying medical conditions.[7]

6. Begum, J., & King, L. (2024). *Bradycardia: Causes, symptoms, treatment*. WebMD. https://www.webmd.com/heart-disease/atrial-fibrillation/bradycardia

7. Yale Medicine. (n.d.). *Tachycardia*. https://www.yalemedicine.org/conditions/tachycardia

11.5 Blood Vessels

Blood is carried through the body by blood vessels. An **artery** is a blood vessel that carries blood *away* from the heart, where it branches into ever-smaller vessels. Eventually, the smallest arteries, called **arterioles**, branch into tiny **capillaries**, where gases, nutrients, and wastes are exchanged. Capillaries turn into **venules**, small veins, which carry blood to **veins**. Veins merge and eventually become the largest veins in the body, called the superior and inferior venae cavae, which return blood *to* the heart. As discussed previously in this chapter, arteries and veins transport blood in two distinct circuits: the systemic circuit and the pulmonary circuit. Systemic arteries provide blood rich in oxygen to the body's tissues. The blood returned to the heart through systemic veins has less oxygen because oxygen carried by the arteries has been delivered to the cells. In contrast, in the pulmonary circuit, arteries carry blood low in oxygen to the lungs for gas exchange. Pulmonary veins then return freshly oxygenated blood from the lungs to the heart to be pumped back out into systemic circulation.[1] See Figure 11.21[2] for an illustration of blood flow through the systemic and pulmonary circuits in vessels carrying oxygenated blood and deoxygenated blood.

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

2. OpenStax College. (2013). *2101_Blood_Flow_Through_the_Heart* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2101_Blood_Flow_Through_the_Heart.jpg

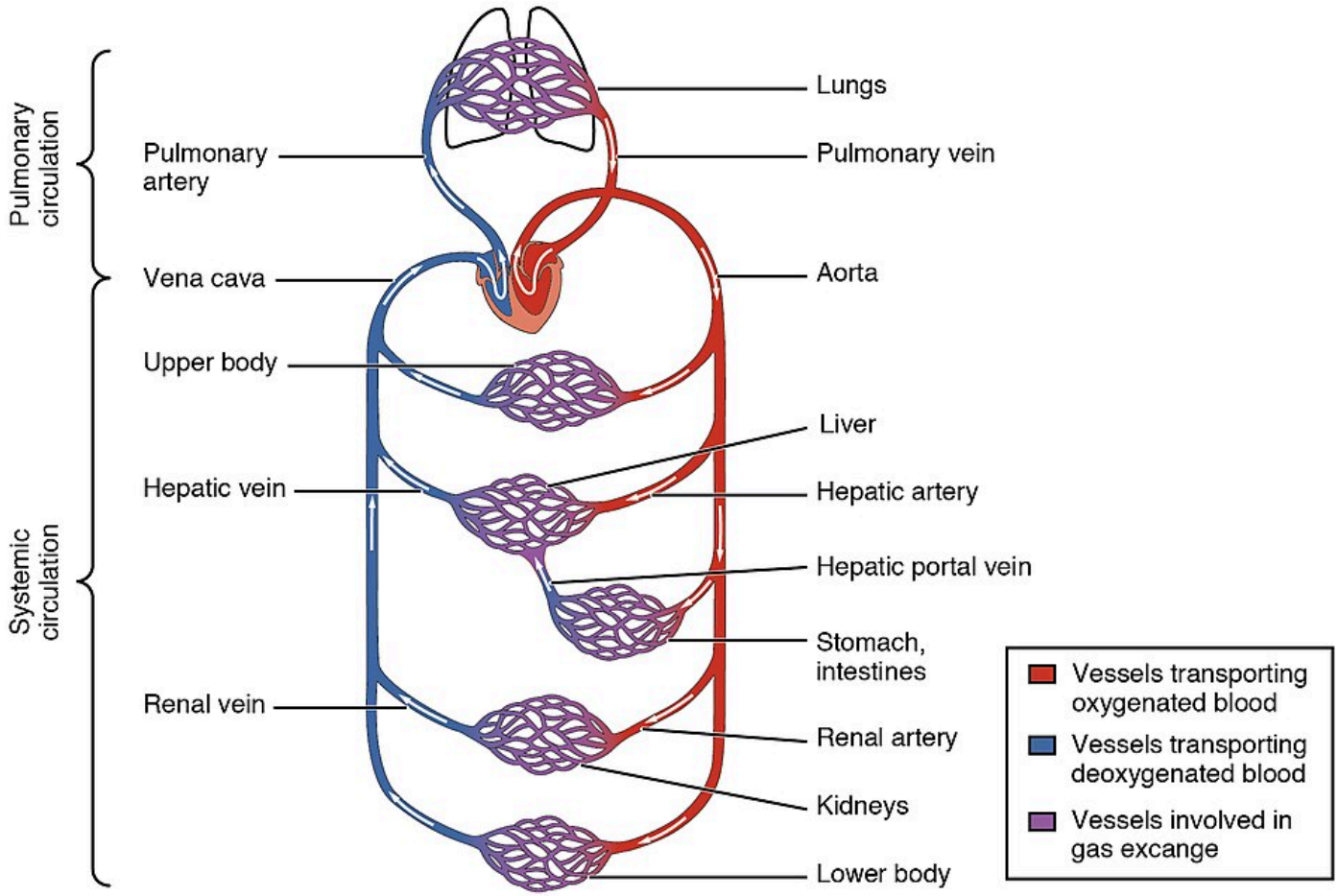


Figure 11.21 Vessels Transporting Oxygenated and Deoxygenated Blood in Pulmonary and Systemic Circulation

Shared Features of Arteries and Veins

Although arteries and veins differ structurally and functionally, they share certain features. Arteries and arterioles have thicker walls than veins and venules because they are closer to the heart and receive blood that is surging at a far greater pressure.

Each type of vessel has a **lumen**—a hollow central passageway through which blood flows. Arteries have smaller lumens than veins, a characteristic that helps to maintain the pressure of blood moving through the system. Together, their thicker walls and smaller diameters give arterial lumens a more rounded appearance in cross-section than the lumens of veins.

By the time blood has passed through capillaries and entered venules, the pressure initially generated by heart contraction has diminished. In comparison to arteries, venules and veins have a much lower pressure from the blood that flows through them.

Their walls are considerably thinner, and their lumens are larger in diameter, allowing more blood to flow with less vessel resistance. In addition, many veins of the body, particularly those of the limbs, contain valves that assist the flow of blood toward the heart. This is critical because blood flow becomes sluggish in the extremities as a result of the lower pressure and the effects of gravity.

Both arteries and veins have the same three distinct tissue layers, called **tunics** (from the Latin term *tunica*) for the garments first worn by ancient Romans. From the inner to outer layers, these tunics are the tunica interna (also known as tunica intima), the tunica media, and the tunica externa.[3]

See Figure 11.22[4] for an illustration showing these three layers and comparing the differences in the walls of arteries and veins.

3. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

4. OpenStax College. (2013). *2102_Comparison_of_Artery_and_Vein* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2102_Comparison_of_Artery_and_Vein.jpg

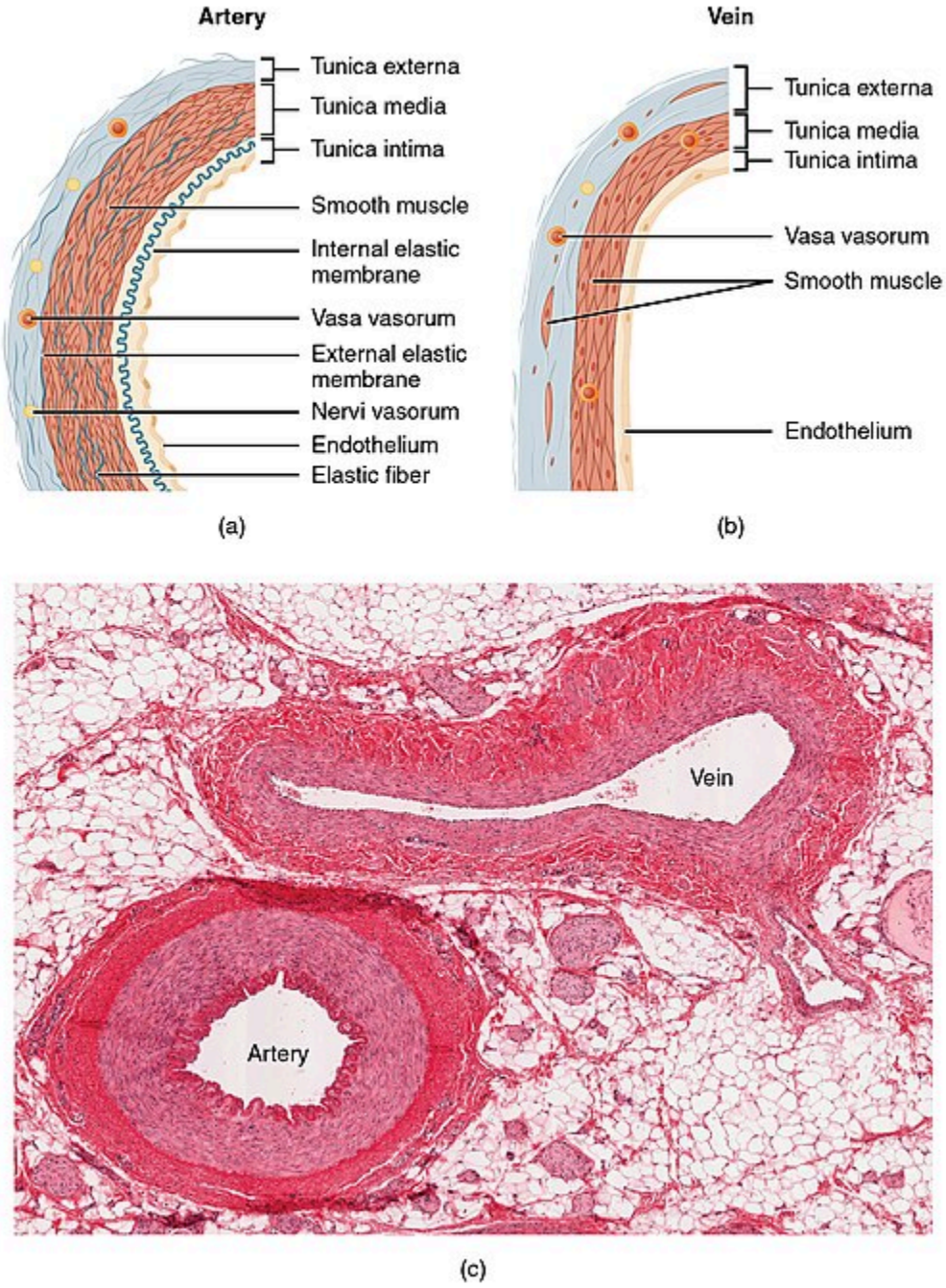


Figure 11.22 Comparison of the Walls Arteries and Veins: (a) Arteries, (b) Veins, and (c) Micrograph of Arteries and Veins

Tunica Interna

The **tunica interna** (also called the tunica intima) is composed of smooth epithelial and connective tissue layers. Lining the tunica interna is the specialized simple squamous epithelium called the endothelium, which is continuous throughout the

entire vascular system, including the lining of the chambers of the heart. Damage to this endothelial lining and exposure of blood to the deep collagenous fibers are primary causes of clot formation.

Under the microscope, the lumen and the entire tunica interna of a vein will appear smooth, whereas those of an artery will normally appear wavy because of the partial constriction of the smooth muscle in the tunica media.

Tunica Media

The **tunica media** is the middle layer of the vessel wall. It is generally the thickest layer in arteries. Arteries also have a thicker tunica media compared to veins. The tunica media consists of layers of smooth muscle supported by connective tissue that is primarily made up of elastic fibers, most of which are arranged in circular sheets. Toward the outer portion of the tunic, there are also layers of longitudinal muscle. Contraction and relaxation of the circular muscles decrease and increase the diameter of the vessel lumen, respectively.

Specifically in arteries, **vasoconstriction** decreases blood flow as the smooth muscle in the walls of the tunica media contracts, making the lumen narrower and increasing blood pressure. Similarly, **vasodilation** increases blood flow as the smooth muscle relaxes, allowing the lumen to widen and blood pressure to drop.

Tunica Externa

The outer tunic, the **tunica externa** (also called the tunica adventitia), is a sheath of connective tissue composed primarily of collagenous fibers. Some bands of elastic fibers are found here as well. This is normally the thickest tunic in veins and may be thicker than the tunica media in some larger arteries. The outer layers of the tunica externa are not distinct but rather blend with the surrounding connective tissue outside the vessel, helping to hold the vessel in position. If you are able to palpate some of the superficial veins in your upper limbs and try to move them, you will find that the tunica externa prevents this. If the tunica externa did not hold the vessel in place, any movement would likely result in disruption of blood flow.

Table 11.5a compares and contrasts the tunics of the arteries and veins. Figure 11.23[5] compares the appearance of arteries, capillaries, and veins.

Table 11.5a. Comparison of Tunics in Arteries and Veins[6]

Feature	Arteries	Veins
General Appearance	• Thick walls with small lumens • Generally appear rounded	• Thin walls with large lumens • Generally appear flattened
Tunica Interna	• Endothelium usually appears wavy due to the constriction of smooth muscle • An internal elastic membrane is present in larger vessels	• Endothelium appears flat and smooth • Internal elastic membrane absent
Tunica Media	• Normally the thickest layer in the arteries • Smooth muscle cells and elastic fibers predominate; the proportions vary with distance from the heart • An external elastic membrane is present in larger vessels	• Normally thinner than the tunica externa • Smooth muscle cells and collagenous fibers predominate
Tunica Externa	• Normally thinner than the tunica media in all but the largest arteries • Collagenous and elastic fibers	• Normally the thickest layer in veins • Collagenous and smooth muscle fibers predominate

5. Christinelmiller. (2020). *Artery vein capillary comparison* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Artery_Vein_Capillary_Comparison.png

6. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

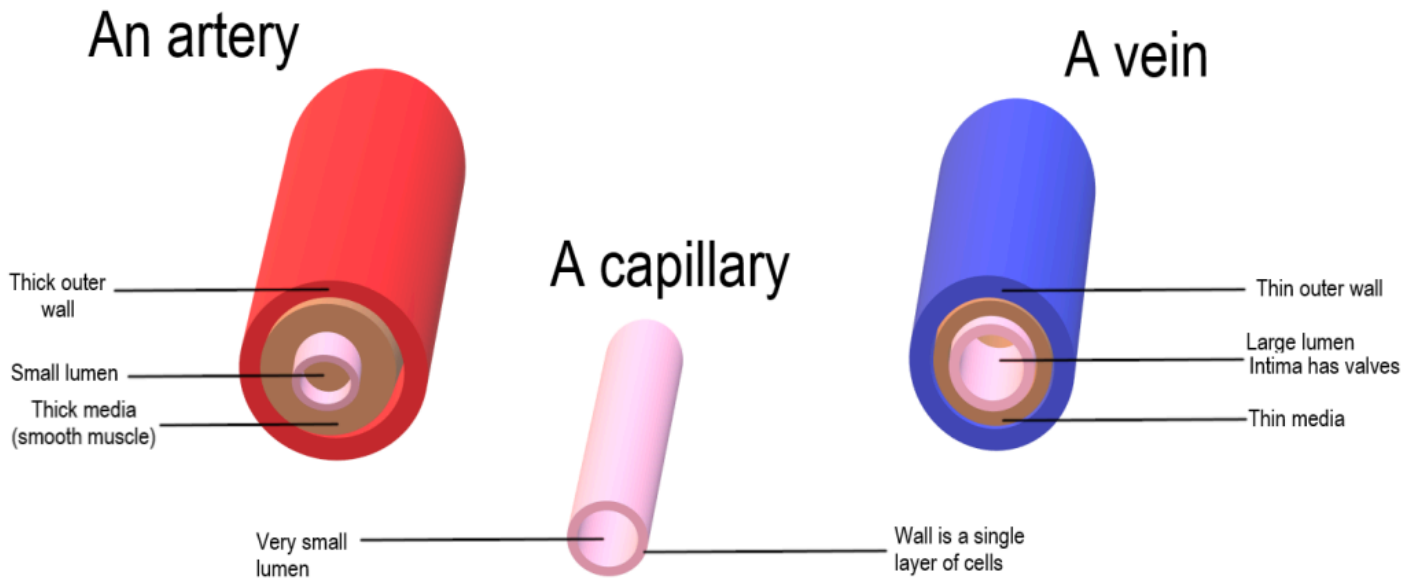


Figure 11.23 Comparison of Arteries, Capillaries, and Veins

Artery Types

As previously discussed in this chapter, arteries have relatively thick walls that can withstand the high pressure of blood pumped from the heart. Arteries closest to the heart have the thickest walls, containing a high percentage of elastic fibers in all three of their tunics. This type of artery is known as an **elastic artery**.

Vessels larger than 10 mm in diameter are typically elastic. Their abundant elastic fibers allow them to expand, as blood pumped from the ventricles passes through them, and then to recoil after the surge has passed. If artery walls were rigid and unable to expand and recoil, their resistance to blood flow would greatly increase, and blood pressure would be higher, which would require the heart to pump harder to maintain adequate pressure and flow. Artery walls would have to become even thicker in response to this increased pressure. An elastic artery is also known as a conducting artery because the large diameter of the lumen enables it to accept a large volume of blood from the heart and conduct it to smaller branches.

Farther from the heart, where the surge of blood has dampened, the percentage of elastic fibers in an artery's tunica interna decreases, and the amount of smooth muscle in its tunica media increases. The artery at this point is described as a **muscular artery**. The diameter of muscular arteries typically ranges from 0.1 mm to 10 mm. Their thick tunica media allows muscular arteries to play a leading role in vasoconstriction.

In contrast, their decreased quantity of elastic fibers limits their ability to expand. Fortunately, because the blood pressure has eased by the time it reaches these more distant vessels, elasticity is less important.

Notice that although the distinctions between elastic and muscular arteries are important, there is no clear boundary where an elastic artery suddenly becomes muscular. Rather, there is a gradual transition as the vascular tree repeatedly branches. In turn, muscular arteries branch to distribute blood to the vast network of arterioles. For this reason, a muscular artery is also known as a distributing artery.

An **arteriole** is a very small artery that leads to a capillary. Arterioles have the same three tunics as the larger vessels, but the thickness of each is greatly diminished. The critical endothelial lining of the tunica interna is intact. The tunica media is restricted to one or two smooth muscle cell layers in thickness. The tunica externa remains, but is very thin. With a lumen averaging 30 micrometers or less in diameter, arterioles are critical in slowing down—or resisting—blood flow and causing a substantial drop in blood pressure. The importance of the arterioles is that they will be the primary site of both resistance and regulation of blood pressure.[7]

See Figure 11.24[8] for an illustration comparing the walls of an elastic artery, muscular artery, and arteriole.

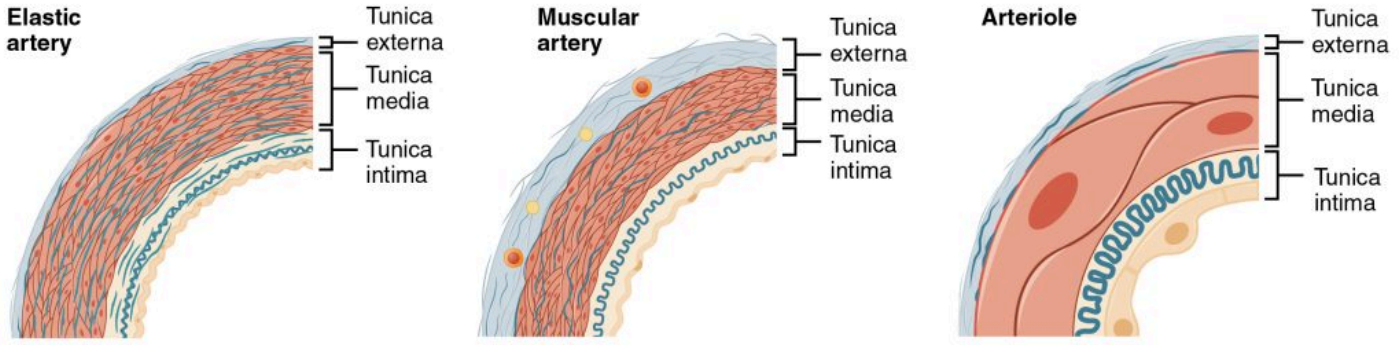


Figure 11.24 Comparison of Walls of an Elastic Artery, Muscular Artery, and Arteriole

7. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

8. OpenStax College. (2013). *2103_Muscular_and_Elastic_Artery_Arteriole* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2103_Muscular_and_Elastic_Artery_Arteriole.jpg

Capillaries

A **capillary** is a microscopic vessel that supplies blood to the tissues, a process called **perfusion**. Exchange of gases, nutrients, wastes, and other substances occurs between the blood in capillaries and the surrounding cells and their tissue fluid (interstitial fluid). The diameter of a capillary lumen ranges from 5 to 10 micrometers; the smallest capillaries are just barely wide enough for an erythrocyte to squeeze through. Flow through capillaries is often described as **microcirculation**.

The wall of a capillary consists of the endothelial layer surrounded by a basement membrane with occasional smooth muscle fibers. There is some variation in wall structure. In a large capillary, several endothelial cells bordering each other may line the lumen; in a small capillary, there may be only a single cell layer that wraps around to contact itself.[9]

Veins and Venules

Compared to arteries, veins are thin-walled vessels with large and irregular lumens. Because of the low blood pressure in veins, as well as the pull of gravity, larger veins are commonly equipped with valves that promote the unidirectional flow of blood toward the heart and prevent backflow toward the capillaries.

A **venule** is an extremely small vein, generally 8–100 micrometers in diameter. Once gas exchange has occurred in the capillaries, blood is ready to start its return to the heart. Venules are the small veins exiting the capillaries. Multiple venules join to form veins. The walls of venules consist of endothelium, a thin tunica media with a few muscle cells and elastic fibers, plus an outer layer of connective tissue fibers that constitute a very thin tunica externa.[10]

See Figure 11.25[11] for an illustration comparing large veins, medium veins, and venules.

9. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
10. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
11. OpenStax College. (2013). *2106_Large_Medium_Vein_Venule* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2106_Large_Medium_Vein_Venule.jpg

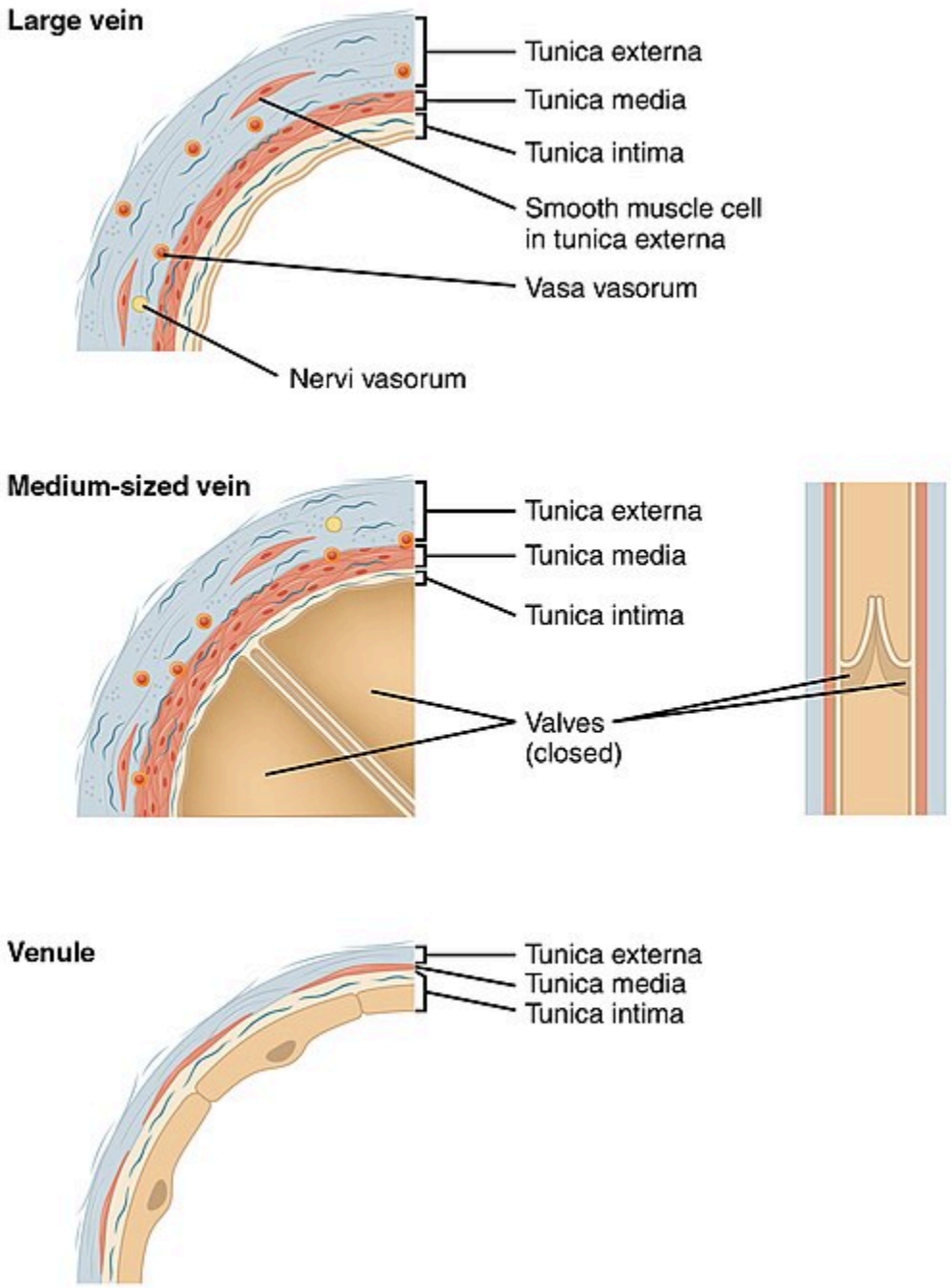


Figure 11.25 Comparison of Veins and Venules

Table 11.5b compares the features of arteries and veins.

Table 11.5b. Comparison of Arteries and Veins[12]

12. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Feature	Arteries	Veins
Direction of Blood Flow	Conducts blood away from the heart	Conducts blood toward the heart
General Appearance	Rounded	Irregular and often collapsed
Blood Pressure	High	Low
Wall Thickness	Thick	Thin
Relative Oxygen Concentration	• Higher in systemic arteries • Lower in pulmonary arteries	• Lower in systemic veins • Higher in pulmonary veins
Valves	Not present	Present most commonly in limb veins and in veins inferior to the heart

See Figure 10.26[13] for an illustration of arteries, arterioles, capillaries, venules, and veins.

13. Kelvinsong. (2013). *Blood_vessels-en* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Blood_vessels-en.svg

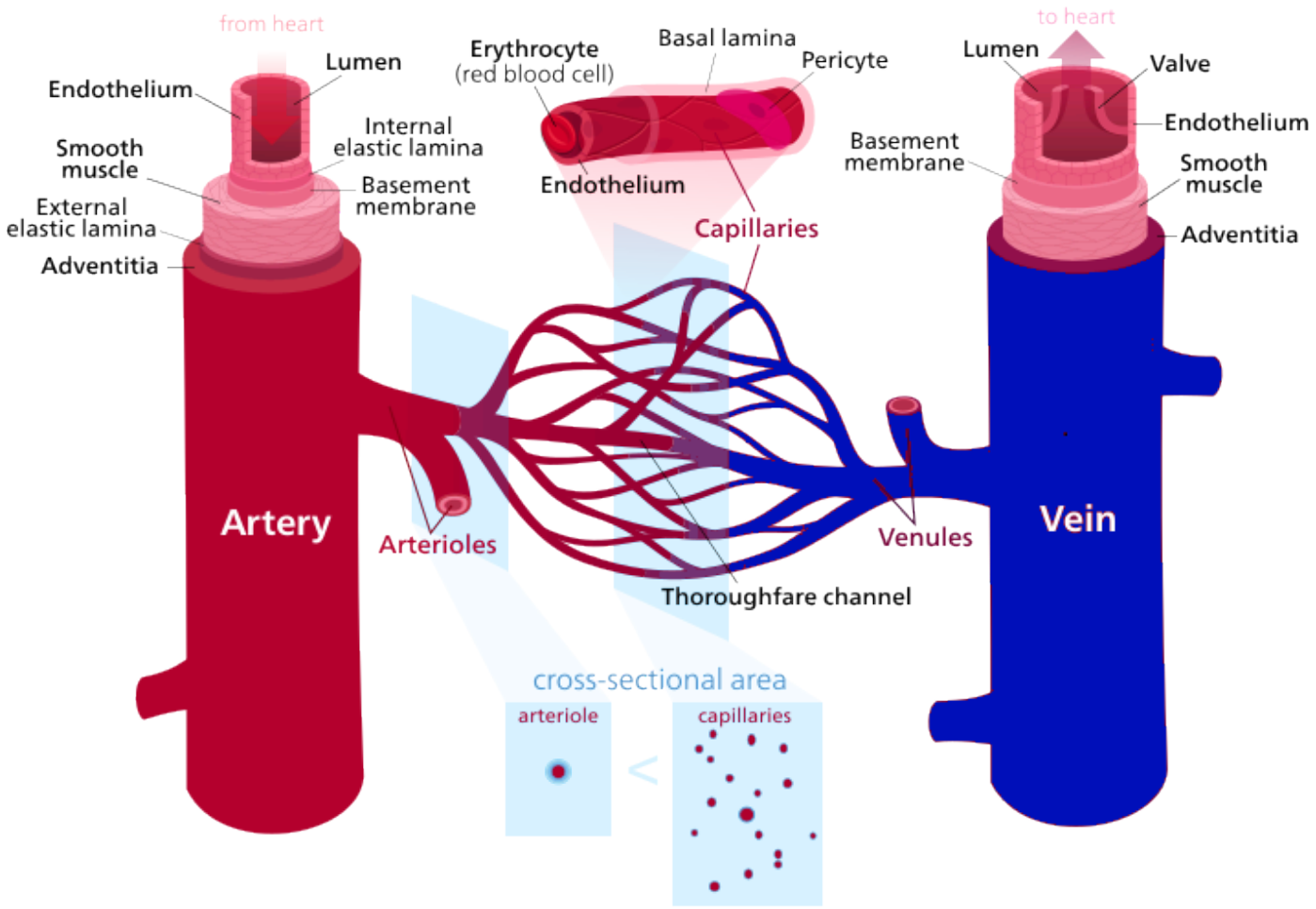


Figure 10.26 Arteries, Arterioles, Capillaries, Venules, and Veins

Blood Pressure

Blood flow initiated by the contraction of the ventricles of the heart and refers to the movement of blood through a vessel, tissue, or organ. Ventricular contraction ejects blood into the major arteries, resulting in flow from regions of higher pressure to regions of lower pressure, where blood encounters smaller arteries and arterioles, then capillaries, and then the venules and veins of the venous system.

Hydrostatic pressure is the force exerted by a fluid against the wall of the container in which it is located. One form of hydrostatic pressure is **blood pressure**, the force exerted by blood on the walls of the blood vessels or the chambers of the heart. Blood pressure typically refers to systemic arterial blood pressure—that is, the pressure of blood flowing in the arteries of the systemic circulation. In clinical practice, this pressure is measured in mmHg (millimeters of mercury) and is typically obtained by applying a sphygmomanometer (blood pressure cuff) on the brachial artery of a patient's arm.

When systemic arterial blood pressure is measured, it is recorded as a ratio of two numbers expressed as systolic pressure over diastolic pressure. For example, 120/80 mmHg is a normal adult blood pressure. The **systolic pressure** reflects the arterial pressure resulting from the ejection of blood during ventricular contraction (called systole). The **diastolic pressure** represents the arterial pressure of blood during ventricular relaxation (called diastole).[14]

Variables Affecting Blood Flow and Blood Pressure

Blood is pumped from the ventricles of the heart into the arteries at high pressure, and then blood pressure decreases as blood flows through the arteries, capillaries, and veins. See Figure 11.27[15] for an illustration of the changes in pressures through the circulatory system from the aorta to the venae cavae back into the heart.

14. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

15. OpenStax College. (2013). *2109_Systemic_Blood_Pressure* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2109_Systemic_Blood_Pressure.jpg

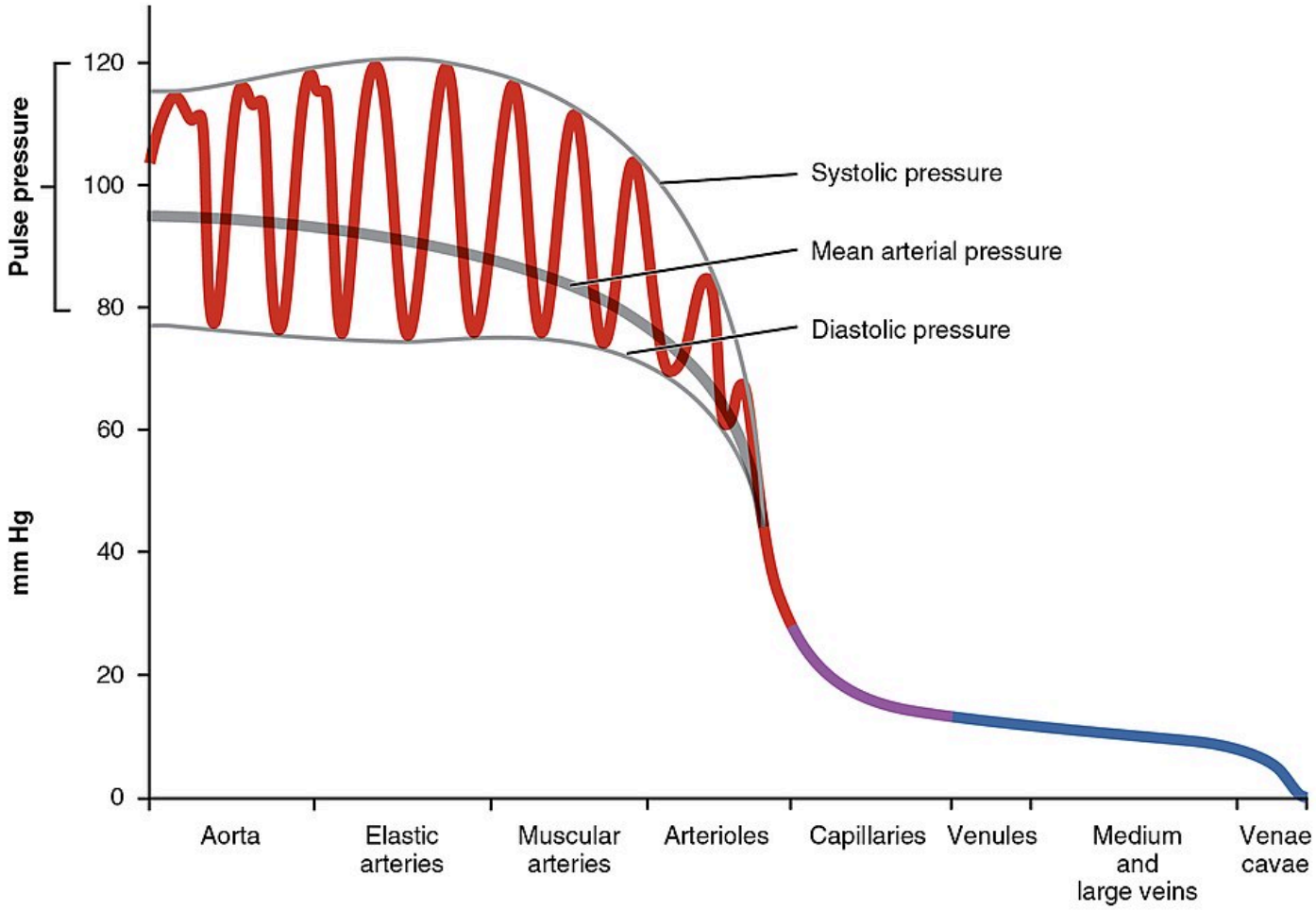


Figure 11.27 Systolic Blood Pressure Changes Through the Circulatory System

If the pressure inside the arteries increases and cardiac function does not compensate, blood flow decreases to tissues and organs. In the venous system, the opposite relationship is true. Increased pressure inside the veins (such as through the application of compression socks) increases blood flow back to the heart.

Five variables that influence blood flow and blood pressure are as follows:

- Cardiac output
- Compliance (the stretchiness/elasticity of the walls of the blood vessel)
- Blood volume
- Blood viscosity
- Blood vessel length and diameter

Cardiac Output

As previously discussed in this chapter, cardiac output is the measurement of blood flow from the heart through the ventricles and is usually measured in liters per minute. Any factor that causes cardiac output to increase, by elevating heart rate or stroke volume or both, will elevate blood pressure and promote blood flow. For example, sympathetic nervous system stimulation increases the heart rate and cardiac output. Conversely, factors that decrease cardiac output, by decreasing heart rate or stroke volume, will decrease arterial pressure and blood flow. For example, altered levels of potassium or calcium in the blood can cause decreased heart rate and cardiac output.

Compliance

Compliance is the ability to expand or stretch. The greater the compliance of an artery, the more effectively it can expand to accommodate surges in blood flow without increased resistance. (**Resistance** is anything that slows blood or counteracts blood flow). Veins are more compliant than arteries and can easily expand to hold more blood. However, when vascular disease causes stiffening of the arteries, compliance is reduced, and resistance to blood flow is increased, resulting in higher pressure within the vessel and reduced blood flow.

Blood Volume

Under normal circumstances, there is little variation in an individual's blood volume. However, if blood volume increases, blood pressure and blood flow increase. If blood volume decreases, blood pressure and blood flow decrease.

Low blood volume, called **hypovolemia**, can be caused by bleeding, dehydration, vomiting, severe burns, or side effects of certain medications. Regulatory mechanisms in the body are so effective at maintaining blood pressure that an individual may be asymptomatic until 10–20% of the blood volume has been lost. Treatment of hypovolemia includes treating the cause and typically includes intravenous fluid replacement.

Excessive blood volume, called **hypervolemia**, is caused by excessive retention of water and sodium that can be caused by heart failure, kidney disease, pregnancy, and side effects of steroid medications. Treatment of hypervolemia includes treating the

cause and typically includes medications called diuretics that increase the amount of urine produced by the kidneys to excrete excess water and sodium from the body.

Blood Viscosity

Viscosity is a measure of a fluid's thickness, which directly influences how easily it flows. Clean water, for example, is less viscous than mud. The viscosity of blood is directly proportional to resistance and inversely proportional to flow; therefore, any condition that causes viscosity to increase will also increase resistance and decrease blood flow. For example, imagine sipping milk and then a milkshake through the same-sized straw. There is more resistance and, therefore, less flow due to the increased viscosity of the milkshake. Conversely, any condition that causes viscosity to decrease (such as when the milkshake melts) will decrease resistance and increase flow.

Normally, the viscosity of blood does not change over short periods of time. The two primary determinants of blood viscosity are the formed elements and plasma proteins. Any condition causing increased levels of formed elements, such as polycythemia, can increase viscosity. Conversely, because most plasma proteins are produced by the liver, any condition affecting liver function, such as hepatitis or excessive alcohol intake, can decrease the viscosity of the blood.

Vessel Length and Diameter

Blood vessel length is directly proportional to its resistance, meaning the longer the vessel, the greater the resistance and the lower the flow. The length of blood vessels increases throughout childhood, but under normal physiological circumstances, it does not change in adulthood. However, the distribution of vessels is not the same in all tissues. Adipose tissue does not have an extensive vascular supply. One pound of adipose tissue contains approximately 200 miles of vessels, whereas skeletal muscle contains more than twice that. An individual weighing 150 pounds has approximately 60,000 miles of vessels in the body. Gaining about 10 pounds adds from 2,000 to 4,000 miles of vessels, depending on the nature of the gained tissue. Blood pressure has to be higher to move blood through the extra miles of vessels. One of the great benefits of weight reduction is the reduced stress to the heart and blood pressure, which does not have to overcome the resistance of as many miles of vessels.

In contrast to length, the diameter of blood vessels varies by vessel type and affects resistance differently. The diameter of any vessel also changes frequently throughout the day in response to neural and chemical signals that trigger contraction and

relaxation of smooth muscle, resulting in vasoconstriction or vasodilation of the vessel, respectively. Vessel diameter has an inverse effect on resistance. Vasodilation (widening of vessels) lowers resistance and increases blood flow, whereas vasoconstriction (narrowing of vessels) raises resistance and decreases flow.

See Figure 10.28[16] comparing blood flow in a normal artery versus a narrowed artery.

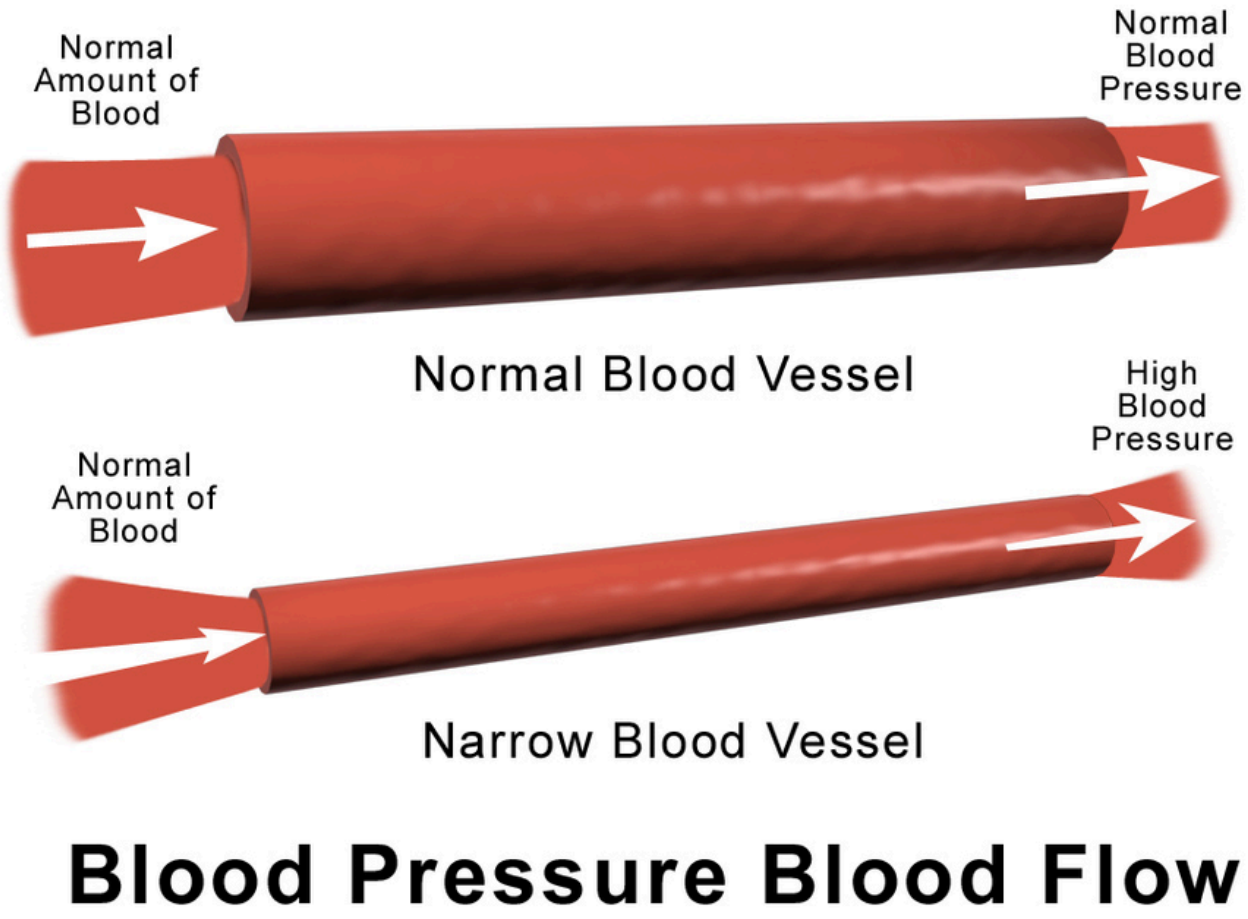


Figure 10.28 Blood Flow in a Normal Artery and a Narrowed Artery

Pulse

After blood is ejected from the heart, elastic fibers in the arteries help maintain

16. Blausen.com staff. (2013). *Blausen_0092_BloodPressureFlow* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Blausen_0092_BloodPressureFlow.png

a high-pressure gradient as they expand to accommodate the blood and then recoil. This expansion and recoiling effect, known as the **pulse**, can be palpated manually or measured electronically. Although the effect diminishes farther from the heart, elements of the systolic and diastolic components of the pulse are still evident down to the level of the arterioles.

Pulse is frequently measured clinically to assess a patient's state of health and is recorded as beats per minute (bpm). The rate and the strength of the pulse are both important clinical indicators of health. For example, a fast or irregular pulse may indicate an underlying heart condition. The pulse strength represents the strength of ventricular contraction and cardiac output. If the pulse is strong, then systolic pressure is high, but if it is weak, medical intervention may be required to improve cardiac output.

Pulse can be palpated manually by placing the tips of the fingers across an artery that runs close to the body surface and pressing lightly. This procedure is typically performed using the radial artery in the wrist or the common carotid artery in the neck, but other common sites include brachial arteries in the upper arms, femoral arteries in the thighs, popliteal arteries behind the knees, posterior tibial arteries near the ankles, and dorsalis pedis arteries in the feet.[17] See Figure 11.29[18] for an illustration of pulse sites.

17. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

18. CFCF. (2017). *Pulse sites-en* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://en.wikipedia.org/wiki/File%3APulse_sites-en.svg

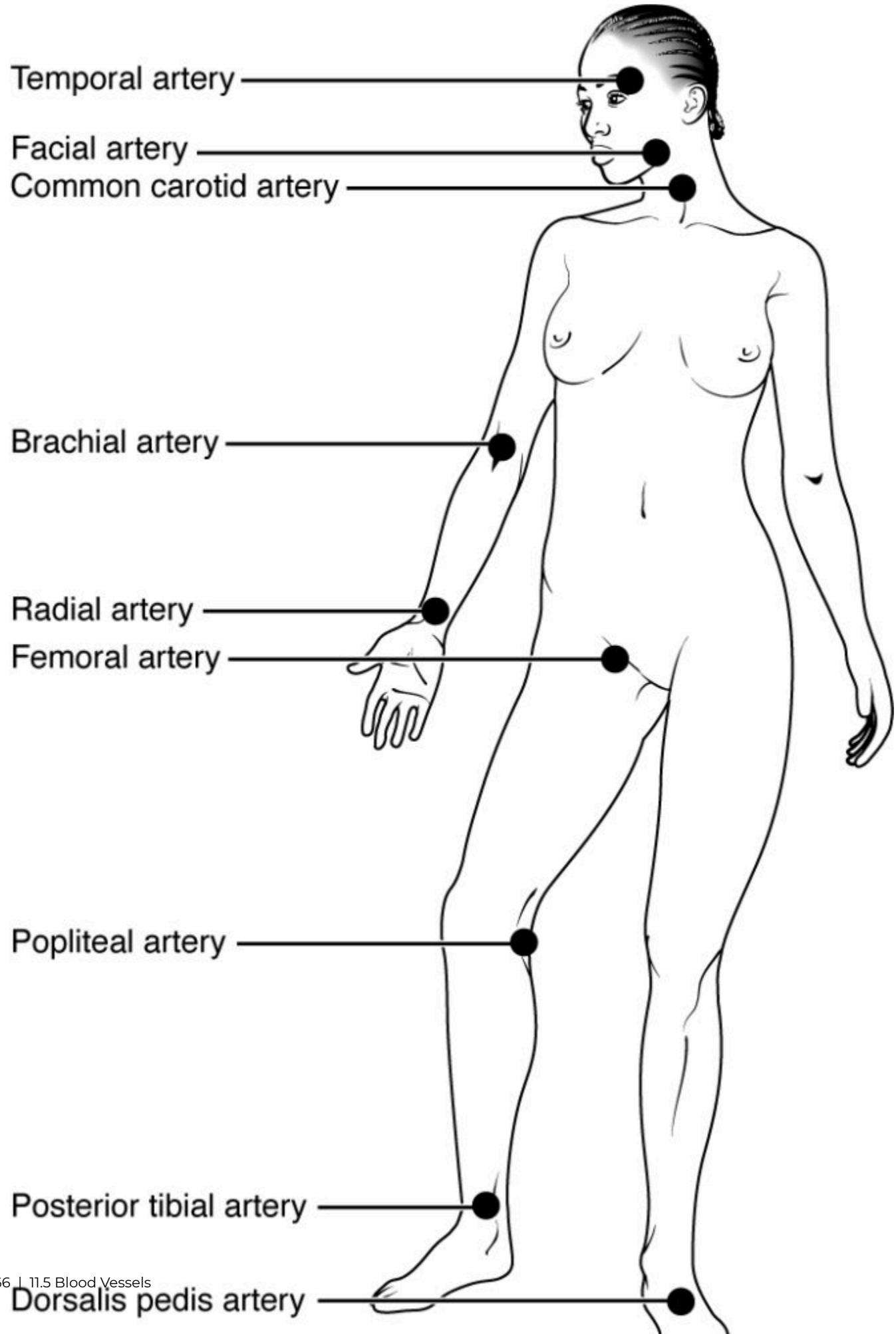

Temporal artery
Facial artery
Common carotid artery
Brachial artery
Radial artery
Femoral artery
Popliteal artery
Posterior tibial artery
Dorsalis pedis artery

Figure 11.29 Pulse Sites

Venous System Pressure

The pumping action of the heart propels the blood into the arteries from an area of higher pressure toward an area of lower pressure. For the blood to flow adequately from the veins back into the heart, the pressure in the veins must be greater than the pressure in the atria of the heart. Two factors help maintain this pressure gradient between the veins and the heart. First, the pressure in the atria during diastole is very low, often approaching zero when the atria are relaxed (atrial diastole). Second, two physiologic "pumps" increase pressure in the venous system: the skeletal muscle pump and the respiratory pump. These "pumps" help return blood to the heart.[19]

Skeletal Muscle Pump

In many body regions, the pressure within the veins can be enhanced by the contraction of the surrounding skeletal muscle. This mechanism, known as the **skeletal muscle pump**, helps the lower-pressure veins counteract the force of gravity, increasing pressure to return blood to the heart. As leg muscles contract, for example, during walking or running, they exert pressure on nearby veins with their numerous one-way valves. This increased pressure causes blood to flow against gravity, opening valves superior to the contracting muscles so blood flows through. Simultaneously, the valves inferior to the contracting muscles close, so blood does not flow back down toward the feet. See Figure 11.30[20] for an illustration of the skeletal muscle pump.

19. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

20. OpenStax College. (2013). *2114_Skeletal_Muscle_Vein_Pump* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2114_Skeletal_Muscle_Vein_Pump.jpg

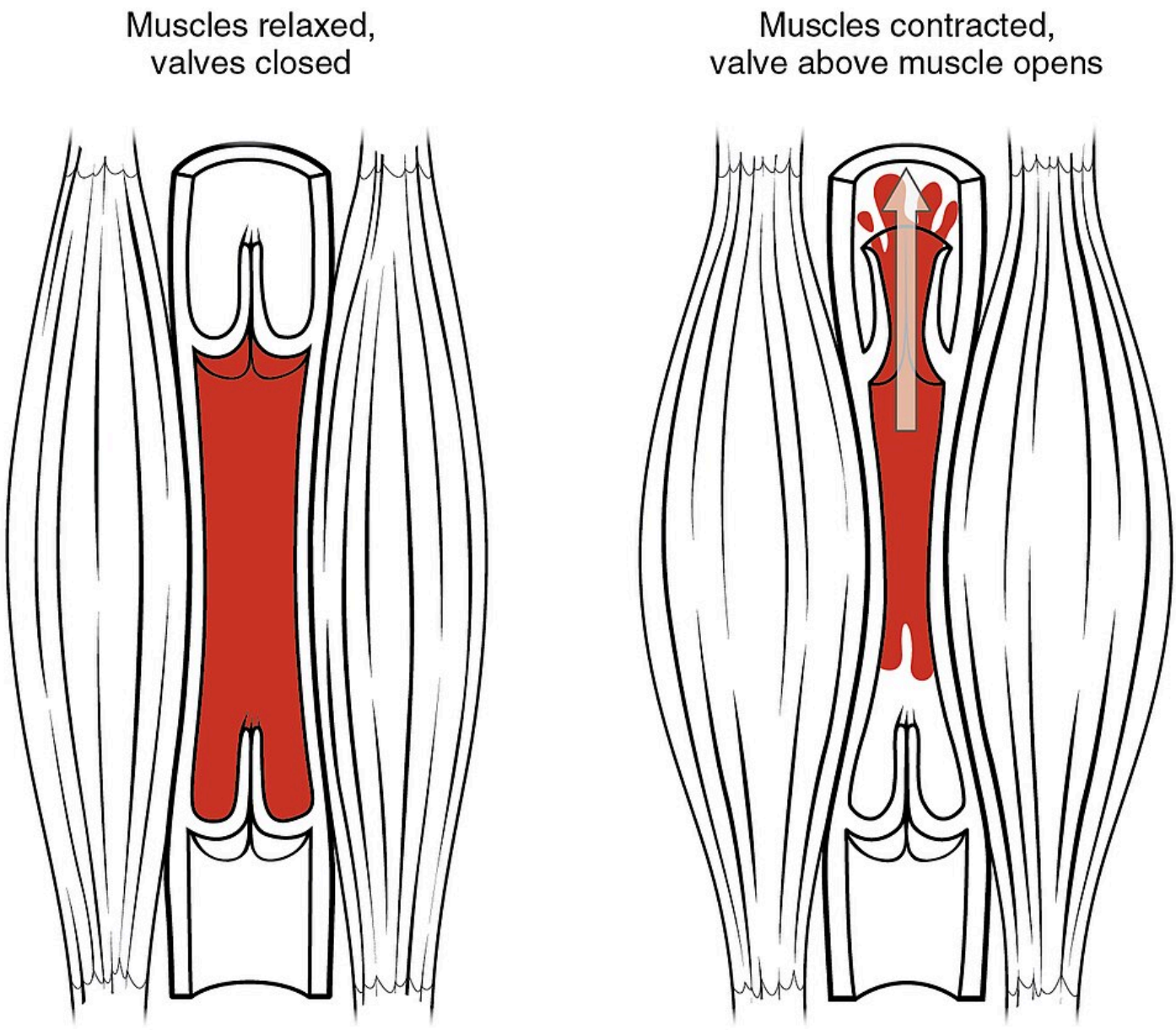


Figure 11.30 Skeletal Muscle Pump

Respiratory Pump

The **respiratory pump** aids blood flow through the veins of the chest and abdomen. During inhalation, the volume of the chest cavity increases, causing air pressure in the chest cavity to decrease and allowing us to inhale. As air pressure within the chest cavity drops, blood pressure in the thoracic veins also drops, falling below the pressure in the

abdominal veins. This causes blood to flow into the thoracic region, where pressure is now lower and promotes the return of blood from the thoracic veins to the atria.[21]

Relationships in the Circulatory System

The circulatory system affects nearly every cell, tissue, organ, and system in the body. This includes the generalized and more specialized functions of transport of materials, capillary exchange, maintenance of health by transporting white blood cells and various immunoglobulins (antibodies), hemostasis, regulation of body temperature, and assistance in maintaining acid-base balance. In addition to these shared functions, many systems enjoy a unique relationship with the circulatory system. Figure 11.31 summarizes these relationships.

21. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Body System	Role of the Circulatory System
Digestive	Absorbs nutrients and water; delivers nutrients (except most lipids) to the liver through the hepatic portal vein for processing; provides nutrients essential for hematopoiesis and hemoglobin production.
Endocrine	Transports hormones throughout the body, including atrial natriuretic hormone (ANH), epinephrine, angiotensin II, antidiuretic hormone (ADH), thyroxine, and estrogen. These hormones help regulate blood volume, blood pressure, fluid balance, and vascular health.
Integumentary	Carries clotting factors, platelets, and white blood cells for hemostasis, infection control, and tissue repair; regulates body temperature by controlling blood flow to the skin; contributes to skin coloration; serves as a blood reservoir.
Lymphatic	Transports white blood cells and immunoglobulins (antibodies) throughout the body; returns excess tissue fluid that cannot be reabsorbed by blood capillaries to the lymphatic system for processing.
Muscular	Provides nutrients and oxygen needed for muscle contraction; removes lactic acid; distributes heat generated by muscle activity; muscular contractions assist venous return; exercise supports cardiovascular health and helps prevent atherosclerosis.
Nervous	Supports circulation of cerebrospinal fluid (CSF); contributes to the blood-brain barrier; autonomic nervous system centers regulate cardiac output and blood vessel diameter to control blood flow.
Reproductive	Supports blood flow necessary for sexual arousal and erection; transports gonadotropic hormones that regulate reproductive functions.
Respiratory	Provides blood for gas exchange, delivering oxygen needed for cellular metabolism and removing carbon dioxide produced by metabolic processes.
Skeletal	Provides calcium, phosphate, and other minerals needed for bone formation; transports hormones involved in bone growth and remodeling; erythropoietin stimulates hematopoiesis; bones protect certain blood vessels.

Body System	Role of the Circulatory System
Urinary	Delivers approximately 20% of resting cardiac output to the kidneys for filtration, reabsorption, and secretion; helps regulate blood volume and blood pressure through urine production and the renin-angiotensin-aldosterone system (RAAS).

As you learn more about specific vessels of the body, notice that many arteries and veins share the same names, parallel one another throughout the body, and are very similar on the right and left sides of the body. For example, there are a pair of femoral arteries and a pair of femoral veins, with one vessel on each side of the body. In contrast, some vessels closer to the midline of the body, such as the aorta, are unique. Some superficial veins, such as the great saphenous vein in the femoral region, have no arterial counterpart.

Names of vessels can change with location. An artery or vein can change names as it passes an anatomical landmark. For example, the left subclavian artery becomes the axillary artery as it passes through the body wall and into the axillary region, and then becomes the brachial artery as it moves from the axillary region into the upper arm (or brachium).

As you read about circulatory pathways, notice that a large artery is referred to as a **trunk**, indicating that the vessel gives rise to several smaller arteries. For example, the celiac trunk gives rise to the left gastric, common hepatic, and splenic arteries.

As previously discussed in the "**Anatomy of the Heart**" section, the heart acts as a double pump, simultaneously pumping blood to and from the lungs (pulmonary circulation) and to and from the remainder of the body tissues (systemic circulation).[22] See Figure 10.32[23] for an illustration of the pulmonary and systemic circulation circuits. The vessels in these two circulation circuits will be further discussed in the following two subsections.

22. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

23. DataBase Center for Life Science. (2024). *202410 Systemic and Pulmonary Circulation* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:202410_Systemic_and_pulmonary_circulation.svg

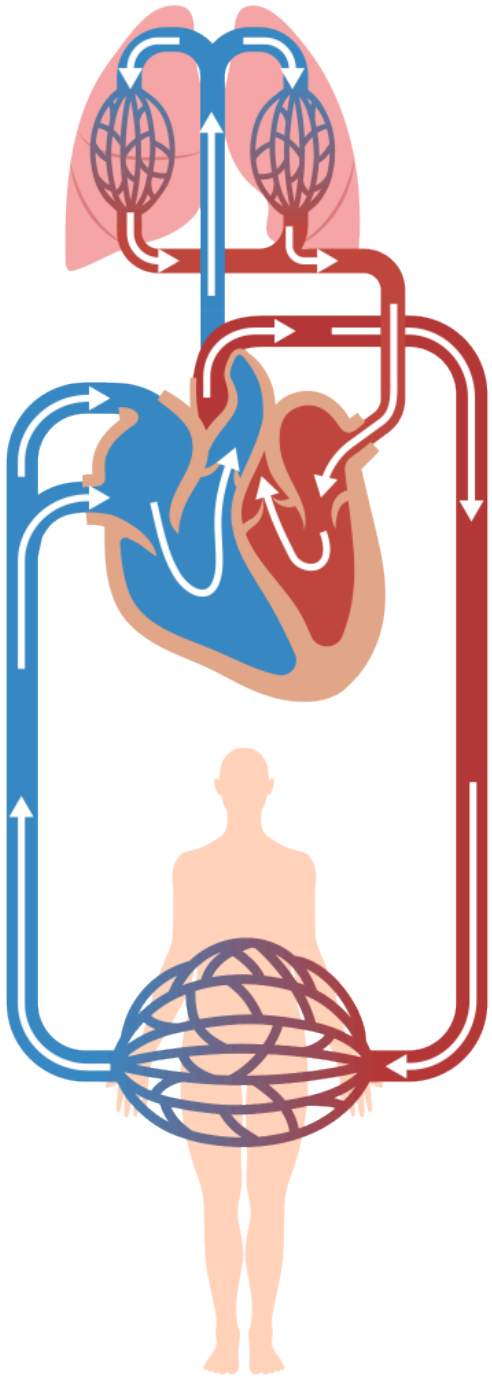


Figure 10.32 Relationship of Pulmonary and Systemic Circulation

Pulmonary Circulation

Blood returning from the systemic circuit enters the right atrium through the superior and inferior venae cavae, as well as the coronary sinus, which receives blood from the heart muscle. These vessels will be described more fully later in this section.

This blood is relatively low in oxygen and relatively high in carbon dioxide because much of the oxygen has been dropped off for use by the tissues, and carbon dioxide was picked up to be transported to the lungs for exhalation.

From the right atrium, blood moves into the right ventricle, which pumps it to the lungs for gas exchange. This system of vessels is referred to as the pulmonary circuit.

The single vessel exiting the right ventricle is the **pulmonary trunk**. At the base of the pulmonary trunk is the pulmonary valve, which prevents backflow of blood into the right ventricle during ventricular diastole. As the pulmonary trunk reaches the superior surface of the heart, it bifurcates (divides) into two branches, a left and a right **pulmonary artery**. The right pulmonary artery carries deoxygenated blood to the right lung, and the left pulmonary artery carries deoxygenated blood to the left lung.

The right and left pulmonary arteries, in turn, branch many times within each lung, forming a series of smaller arteries and arterioles that eventually lead to the **pulmonary capillaries**. The pulmonary capillaries surround structures known as alveoli, which are the sites of oxygen and carbon dioxide exchange.

Once gas exchange is completed, oxygenated blood flows from the pulmonary capillaries into a series of pulmonary venules that eventually lead to a series of larger **pulmonary veins**. Four pulmonary veins, two on the left and two on the right, return blood to the left atrium. At this point, the pulmonary circuit is complete.[24] See Figure 11.33[25] for an illustration of the pulmonary circuit.

24. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

25. OpenStax College. (2013). *2119_Pulmonary_Circuit* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2119_Pulmonary_Circuit.jpg

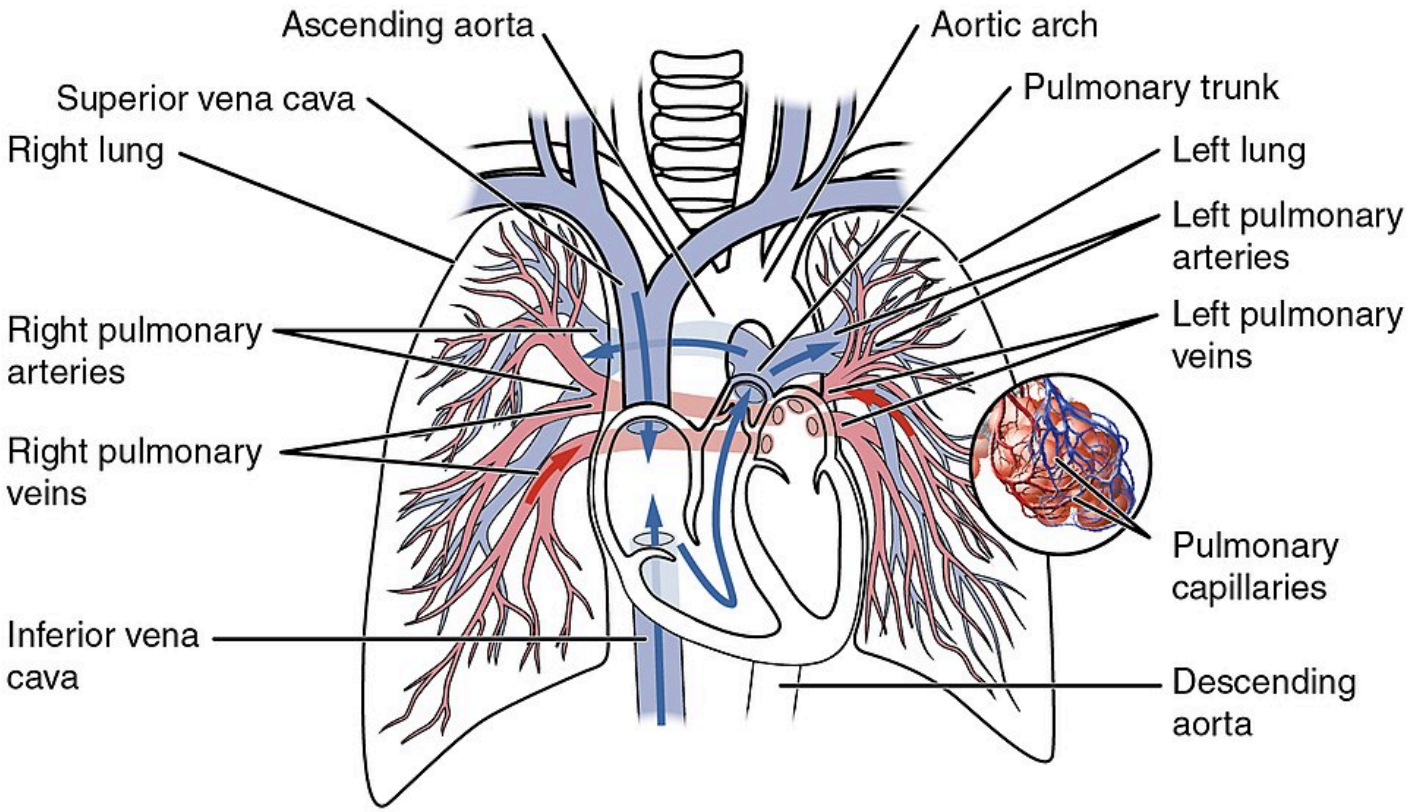


Figure 11.33 Pulmonary Circuit

Table 11.5c defines the major arteries and veins of the pulmonary circuit.

Table 11.5c. Pulmonary Trunk, Arteries, and Veins[26]

26. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Vessel	Description
Pulmonary Trunk	Single large vessel exiting the right ventricle that divides into the right and left pulmonary arteries
Pulmonary Arteries	Left and right arteries that take deoxygenated blood to each lung lead to smaller arterioles and eventually to the pulmonary capillaries
Pulmonary Veins	Two sets of paired veins—one pair on each side—that take newly oxygenated blood from the lungs to the left atrium of the heart

Systemic Circulation

From the left atrium, blood moves into the left ventricle, which pumps blood into the aorta. The aorta and its branches—the systemic arteries—send blood to virtually every organ of the body. After the systemic capillaries exchange gases, nutrients, and wastes, the systemic veins and superior vena cava and inferior vena cava return the blood to the right atrium.[27]

Systemic Arteries

A great approach to learning the vessels is to create simple line drawings, labeling each of the major vessels. It is beyond the scope of this text to name every vessel in the body, but this text will cover the major arteries and veins in the body.

See Figure 11.34[28] for an illustration of the major systemic arteries of the body.

27. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

28. OpenStax College. (2013). *2120_Major_Systemic_Artery* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2120_Major_Systemic_Artery.jpg

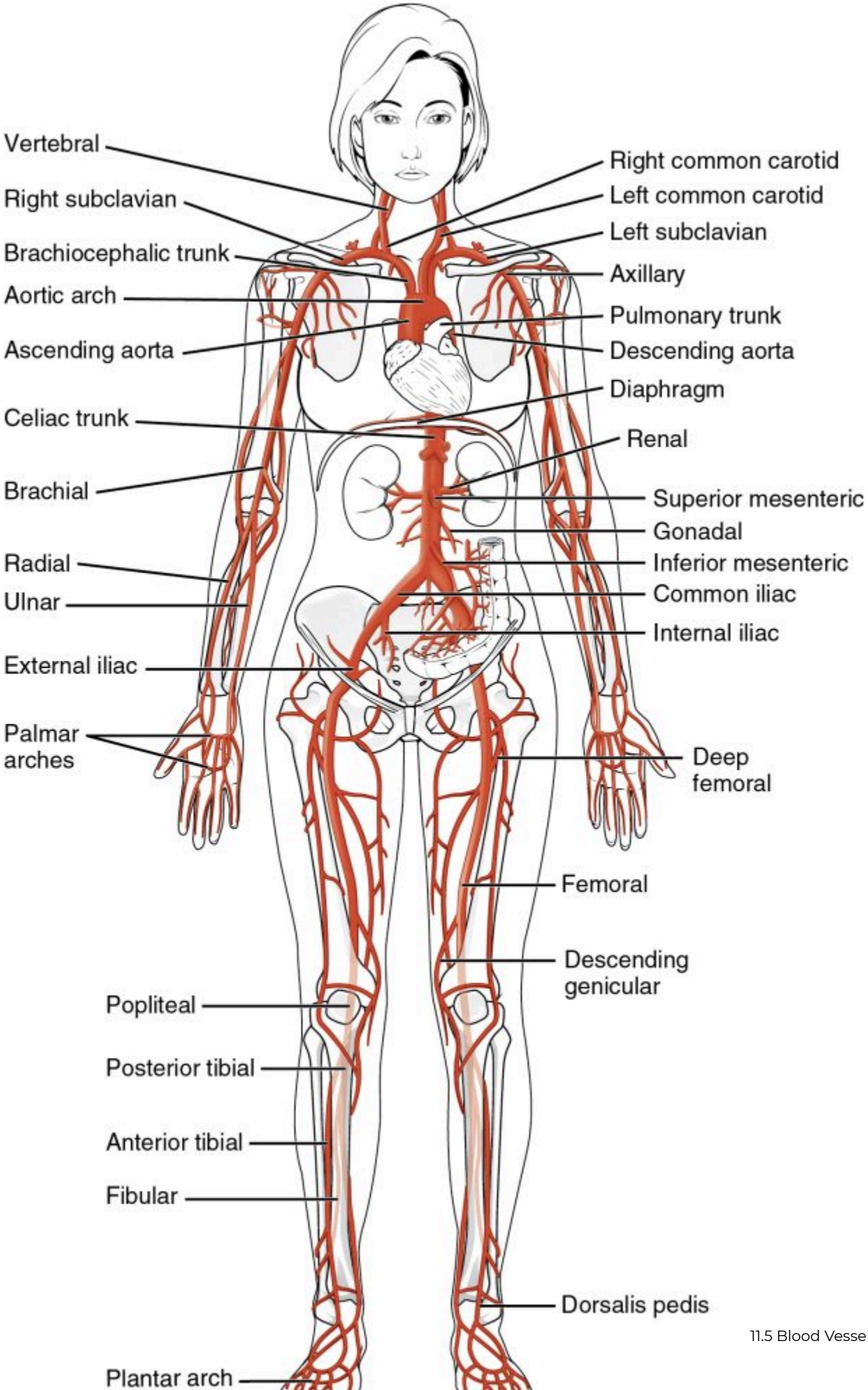

Vertebral
Right subclavian
Brachiocephalic trunk
Aortic arch
Ascending aorta
Celiac trunk
Brachial
Radial
Ulnar
External iliac
Palmar arches
Right common carotid
Left common carotid
Left subclavian
Axillary
Pulmonary trunk
Descending aorta
Diaphragm
Renal
Superior mesenteric
Gonadal
Inferior mesenteric
Common iliac
Internal iliac
Deep femoral
Femoral
Descending genicular
Popliteal
Posterior tibial
Anterior tibial
Fibular
Dorsalis pedis
Plantar arch

Figure 11.34 Major Systemic Arteries

Aorta

The **aorta** is the largest artery in the body. It arises from the left ventricle and eventually descends to the abdominal region, where it bifurcates (divides) at the level of the fourth lumbar vertebra into the two common iliac arteries.

The aorta consists of the ascending aorta (or aortic root), the aortic arch, and the descending aorta, which passes through the diaphragm, a large dome-shaped muscle that divides the thorax from the abdomen. The descending aorta in the chest is called the thoracic aorta. Once the aorta enters the abdominal region, it is called the abdominal aorta. Arteries originating from the aorta ultimately distribute blood to virtually all tissues of the body.

At the base of the aorta is the aortic valve, which prevents backflow of blood into the left ventricle while the heart is relaxing. After exiting the left ventricle, the **ascending aorta** moves in an upward direction. Following this ascent, it forms a graceful arc to the left, called the **aortic arch**. The aortic arch descends toward the abdomen and ends at the level of the intervertebral disk between the fourth and fifth thoracic vertebrae. Now called the **descending aorta**, it passes through an opening in the diaphragm known as the **aortic hiatus**. Superior to the diaphragm, the aorta is called the **thoracic aorta**, and inferior to the diaphragm, it is called the **abdominal aorta**. See Figure 11.35[29] for an illustration of the ascending aorta, the aortic arch, and the initial segment of the descending aorta plus major branches.

29. OpenStax College. (2013). *2121_Aorta* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2121_Aorta.jpg

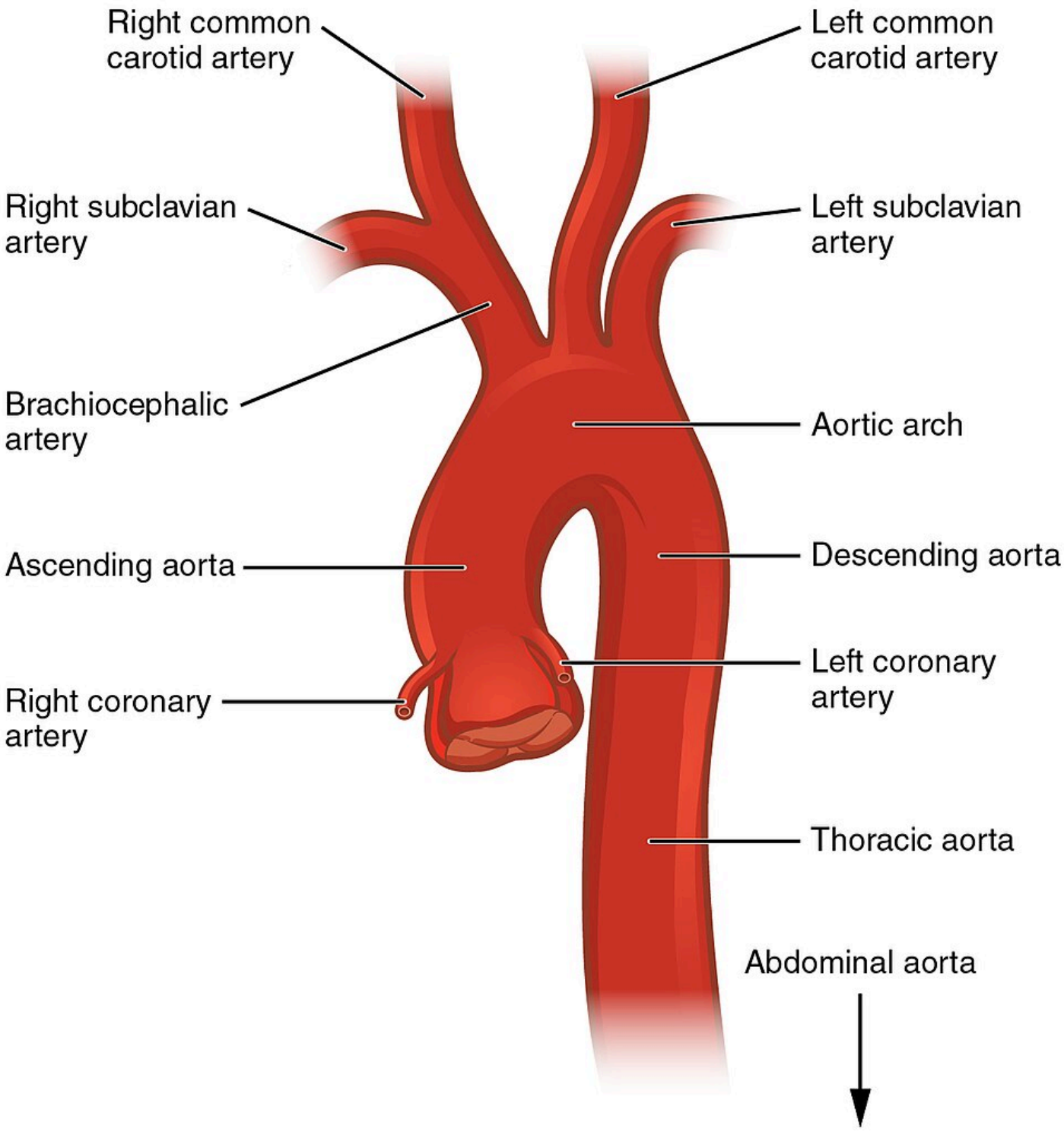


Figure 11.35 Regions of the Aorta

Table 11.5d summarizes the structures of the aorta.

Table 11.5d. Structures of the Aorta[30]

30. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Vessel	Description
Aorta	The largest artery in the body, originating from the left ventricle and descending to the abdominal region, where it divides into the common iliac arteries at the level of the fourth lumbar vertebra; arteries originating from the aorta distribute blood to virtually all tissues of the body
Ascending Aorta	Initial portion of the aorta, rising superiorly from the left ventricle for a distance of approximately 5 cm
Aortic Arch	Graceful arc to the left that connects the ascending aorta to the descending aorta; ends at the intervertebral disk between the fourth and fifth thoracic vertebrae
Descending Aorta	Portion of the aorta that continues inferiorly past the end of the aortic arch; subdivided into the thoracic aorta and the abdominal aorta
Thoracic Aorta	Portion of the descending aorta superior to the diaphragm
Abdominal Aorta	Portion of the descending aorta inferior to the diaphragm and superior to the common iliac arteries

Coronary Arteries

The first vessels that branch off the ascending aorta are the paired coronary arteries. Refer back to Figure 11.34 to view the coronary arteries emerging from the aorta. The coronary arteries encircle the heart, forming a ring-like structure that divides into the next level of branches that supply blood to the myocardium of the heart.

Aortic Arch Branches

There are three major branches from the aortic arch: the brachiocephalic artery, the left common carotid artery, and the left subclavian (literally "under the clavicle") artery:

- The **brachiocephalic artery** is located only on the right side of the body; there is no corresponding artery on the left. The brachiocephalic artery branches into the **right subclavian artery** and the **right common carotid artery**.
- The **left common carotid artery** branches directly from the aortic arch.
- The **left subclavian artery** branches directly from the aortic arch.

Refer back to Figure 11.34 to view these three major aortic arch branches emerging from the aortic arch.

The right and left **subclavian arteries** supply blood to the arms, chest, shoulders, back, and central nervous system. The right and left **common carotid arteries** divide into internal and external carotid arteries.

The **external carotid artery** supplies blood to numerous structures within the face, lower jaw, neck, esophagus, and larynx. These branches include the lingual, facial, occipital, maxillary, and superficial temporal arteries. The **internal carotid arteries**, along with the **vertebral arteries**, are the two primary suppliers of blood to the human brain. Given the central role and vital importance of the brain to life, it is critical that the blood supply to this organ remains uninterrupted. Both the carotid and vertebral arteries branch once they enter the cranial cavity, and some of these branches form a structure known as the **arterial circle (or circle of Willis)**, an anastomosis that is remarkably like a traffic circle that sends off branches (in this case, arterial branches to the brain). As a rule, branches to the anterior portion of the cerebrum are normally fed by the internal carotid arteries; the remainder of the brain receives blood flow from branches associated with

the vertebral arteries. See Figure 11.36[31] for an illustration of arteries supplying the head and neck, and Figure 11.37[32] for an illustration of arteries supplying the brain.

31. OpenStax College. (2013). *2122_Common_Carotid_Artery* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2122_Common_Carotid_Artery.jpg

32. OpenStax College. (2013). *2123_Arteries_of_the_Brain* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2123_Arteries_of_the_Brain.jpg

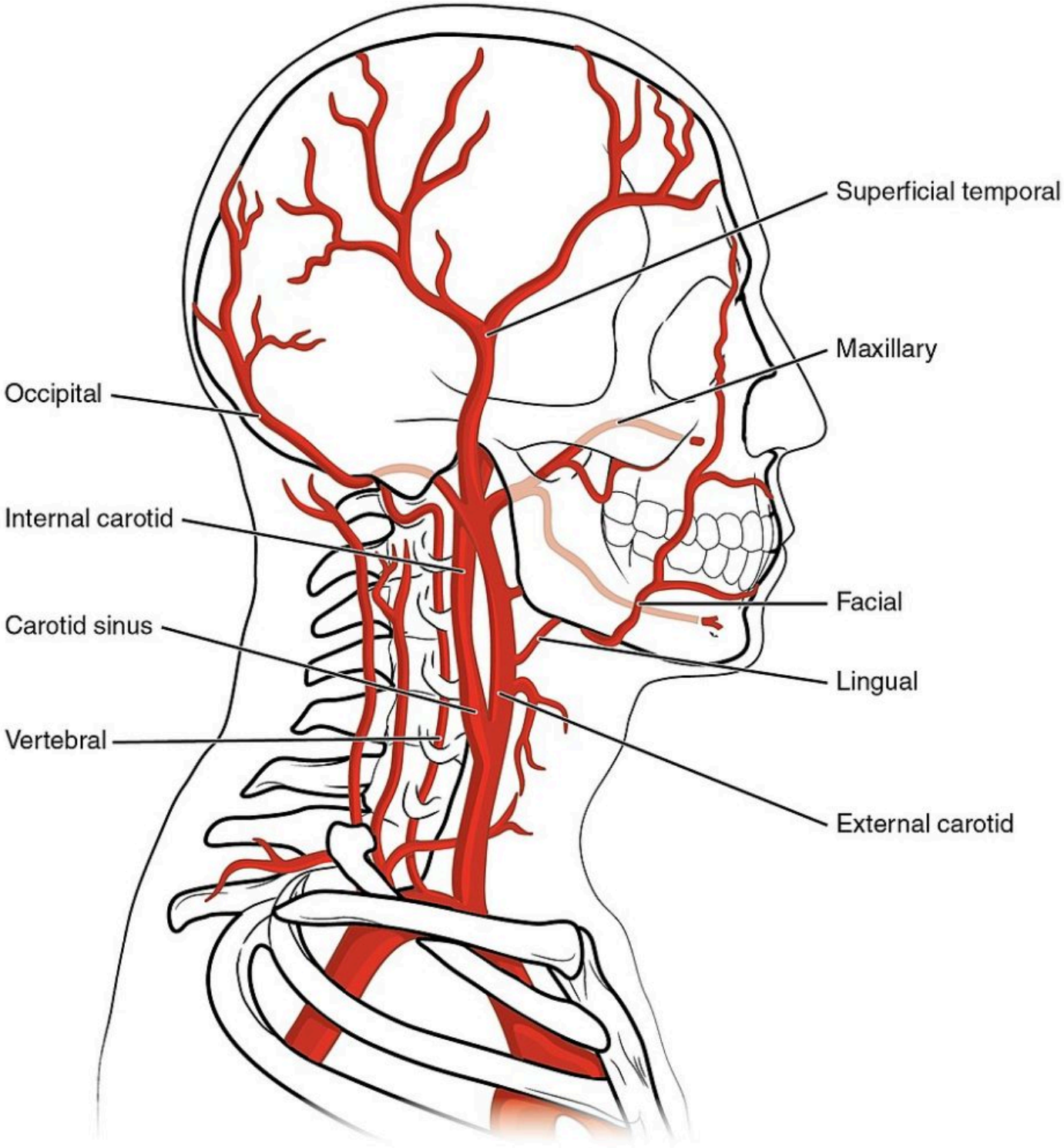


Figure 11.36 Arteries Supplying the Head and Neck

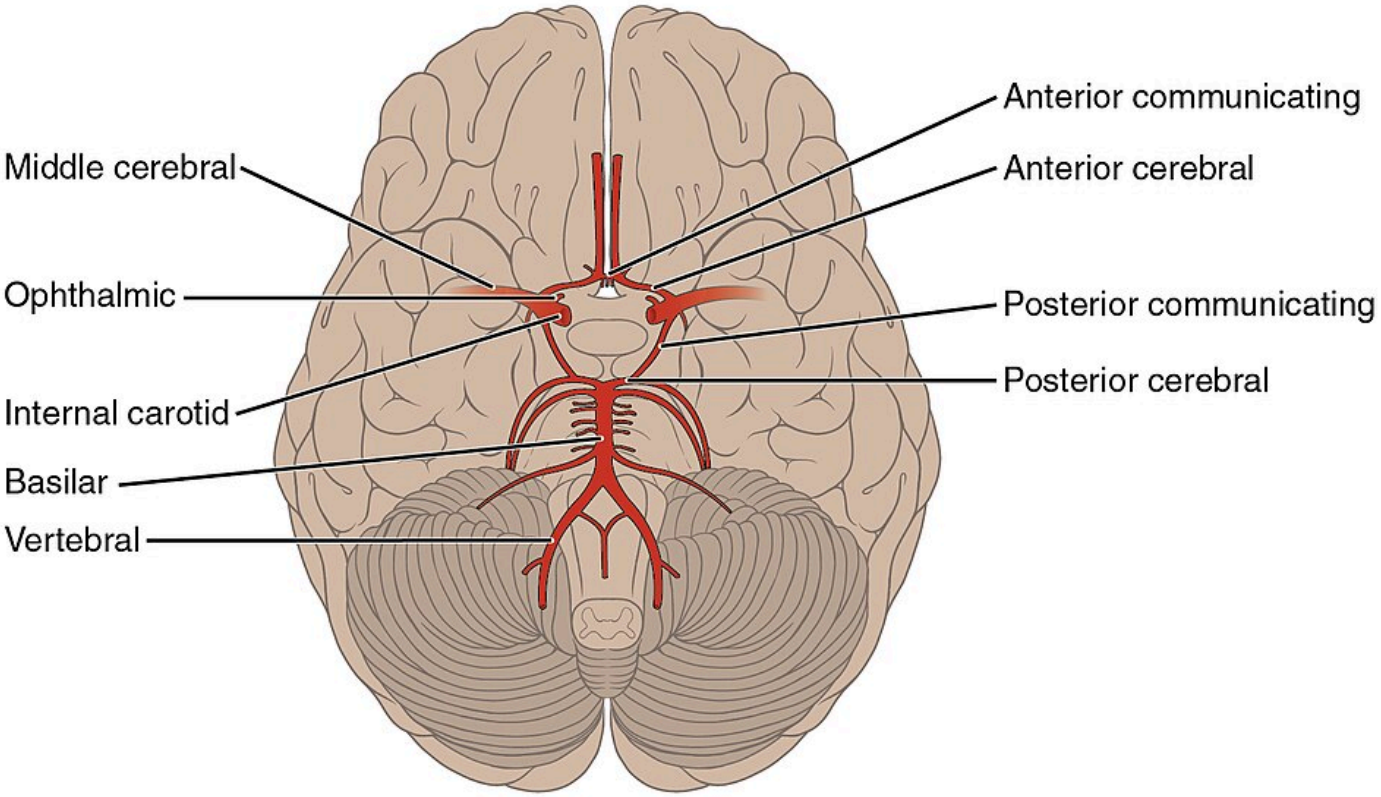


Figure 11.37 Arteries Supplying the Brain

Table 11.5e summarizes the aortic arch branches, including the major branches supplying the brain.

Table 11.5e. Major Aortic Arch Branches and Arteries Supplying the Brain[33]

33. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Vessel	Description
Brachiocephalic Artery	Single vessel located on the right side of the body; the first vessel branching from the aortic arch; gives rise to the right subclavian artery and the right common carotid artery; supplies blood to the head, neck, upper limb, and wall of the thoracic region
Subclavian Arteries	The right subclavian artery arises from the brachiocephalic artery, while the left subclavian artery arises from the aortic arch. It gives rise to the internal thoracic, vertebral, and thyrocervical arteries; supplies blood to the arms, chest, shoulders, back, and central nervous system
Vertebral Arteries	Arises from the subclavian artery and passes through the transverse foramina of the cervical vertebrae and then through the foramen magnum to the brain; it joins with the internal carotid artery to form the arterial circle; it supplies blood to the brain and spinal cord
Common Carotid Arteries	The right common carotid artery arises from the brachiocephalic artery, and the left common carotid artery arises from the aortic arch; each gives rise to the external and internal carotid arteries, and supplies the respective sides of the head and neck
External Carotid Arteries	Arises from the common carotid artery and supplies blood to numerous structures within the face, lower jaw, neck, esophagus, and larynx
Internal Carotid Arteries	Arises from the common carotid artery and begins with the carotid sinus; it goes through the carotid canal of the temporal bone to the base of the brain; it combines with the branches of the vertebral artery, forming the arterial circle; it supplies blood to the brain
Arterial Circle or Circle of Willis	An anastomosis located at the base of the brain that ensures a continual blood supply; formed from the branches of the internal carotid and vertebral arteries; supplies blood to the brain

Major Branches of the Thoracic Aorta

The thoracic aorta begins at the level of vertebra T5 and continues to the diaphragm. As it passes through the thoracic region, the thoracic aorta gives rise to several branches, which are collectively referred to as visceral branches and parietal branches. These branches supply various organs and muscles in the thoracic region. See Figure 11.38[34] for an illustration of major branches of the thoracic aorta.

34. OpenStax College. (2013). *2124_Thoracic_Abdominal_Arteries* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2124_Thoracic_Abdominal_Arteries.jpg

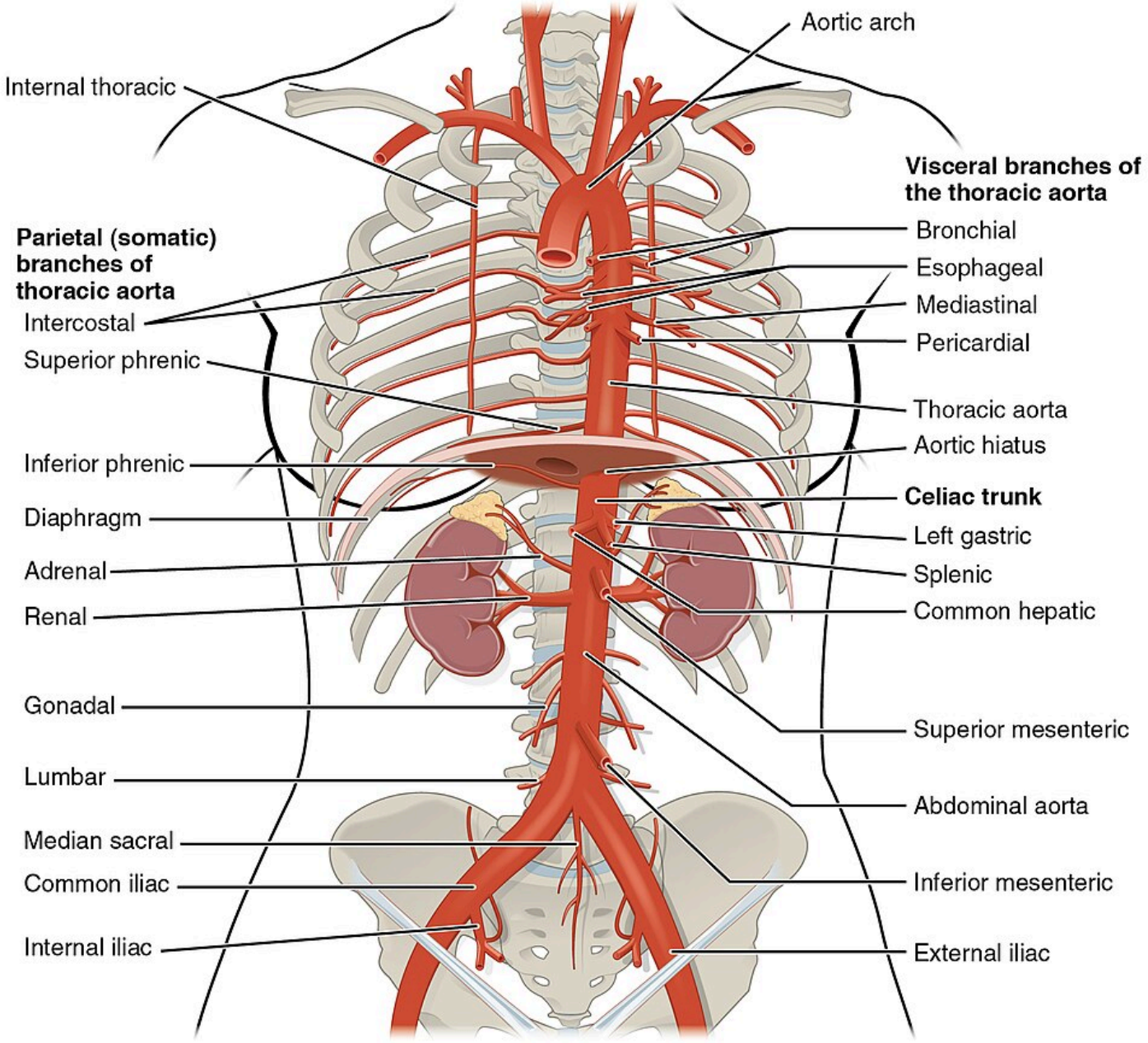


Figure 11.38 Major Branches of the Thoracic Aorta

Abdominal Aorta and Major Branches

After passing through the diaphragm, the thoracic aorta is called the abdominal aorta. It formally ends at approximately the level of vertebra L4, where it divides to form the common iliac arteries. The abdominal aorta gives rise to several important branches.

A single **celiac trunk** emerges and divides into the **left gastric artery** to supply blood

to the stomach and esophagus, the **splenic artery** supplies blood to the spleen, and the **common hepatic artery**, which, in turn, gives rise to the **hepatic artery proper** to supply blood to the liver.

Two additional single vessels arise from the abdominal aorta. These are the superior and inferior mesenteric arteries. The **superior mesenteric artery** arises approximately 2.5 cm inferior to the celiac trunk and branches into several major vessels that supply blood to the small intestine (duodenum, jejunum, and ileum), the pancreas, and a majority of the large intestine. The **inferior mesenteric artery** supplies blood to the distal segment of the large intestine, including the rectum. It arises approximately 5 cm superior to the common iliac arteries.

In addition to these single branches, the abdominal aorta gives rise to several significant paired arteries along the way. These include the inferior phrenic arteries, the adrenal arteries, the renal arteries, the gonadal arteries, and the lumbar arteries.

Each **inferior phrenic artery** is a counterpart of a superior phrenic artery and supplies blood to the inferior surface of the diaphragm. The **adrenal artery** supplies blood to the adrenal glands and arises near the superior mesenteric artery. Each **renal artery** branches approximately 2.5 cm inferior to the superior mesenteric arteries and supplies a kidney. The right renal artery is longer than the left because the aorta lies to the left of the vertebral column, and the vessel must travel a greater distance to reach its target. Renal arteries branch repeatedly to supply blood to the kidneys.

Each **gonadal artery** supplies blood to the gonads, or reproductive organs, and is also described as either an ovarian artery or a testicular artery, depending upon the sex of the individual. An **ovarian artery** supplies blood to an ovary, Fallopian tube, and the uterus, and is located within the suspensory ligament of the uterus. It is considerably shorter than a **testicular artery**, which ultimately travels outside the body cavity to the testes, forming one component of the spermatic cord. The gonadal arteries arise inferior to the renal arteries and are generally retroperitoneal. The ovarian artery continues to the uterus, where it forms an anastomosis with the uterine artery that supplies blood to the uterus. Both the uterine arteries and vaginal arteries, which distribute blood to the vagina, are branches of the internal iliac artery.

The aorta divides at approximately the level of vertebra L4 into a left and a right **common iliac** artery but continues as a small vessel, the **median sacral artery**, into the sacrum.

The common iliac arteries provide blood to the pelvic region and, ultimately, to the lower limbs. They split into external and internal iliac arteries approximately at the level of the lumbar-sacral articulation. Each **internal iliac artery** sends branches to the urinary bladder, the walls of the pelvis, the external genitalia, and the medial portion of the

femoral region. In females, they also provide blood to the uterus and vagina. The much larger **external iliac artery** supplies blood to each of the lower limbs. Figure 11.39[35] shows the distribution of the major branches of the aorta into the thoracic and abdominal regions.

35. OpenStax College. (2013). *2125_Thoracic_Abdominal_Arteries_Chart* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2125_Thoracic_Abdominal_Arteries_Chart.jpg

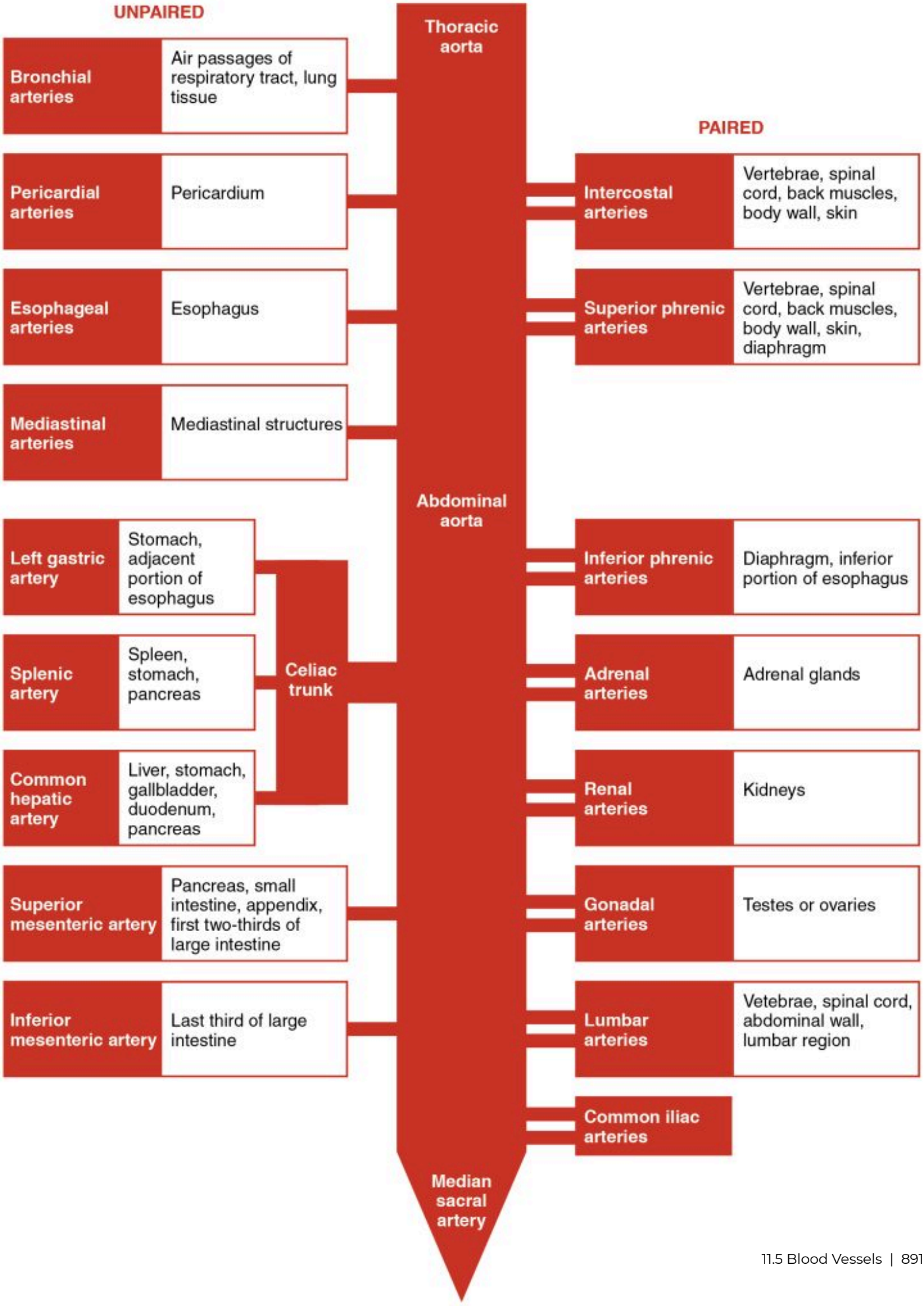

UNPAIRED
Bronchial arteries
Air passages of respiratory tract, lung tissue
Pericardial arteries
Pericardium
Esophageal arteries
Esophagus
Mediastinal arteries
Mediastinal structures
Left gastric artery
Stomach, adjacent portion of esophagus
Splenic artery
Spleen, stomach, pancreas
Common hepatic artery
Liver, stomach, gallbladder, duodenum, pancreas
Celiac trunk
Superior mesenteric artery
Pancreas, small intestine, appendix, first two-thirds of large intestine
Inferior mesenteric artery
Last third of large intestine
Thoracic aorta
Abdominal aorta
Median sacral artery
PAIRED
Intercostal arteries
Vertebrae, spinal cord, back muscles, body wall, skin
Superior phrenic arteries
Vertebrae, spinal cord, back muscles, body wall, skin, diaphragm
Inferior phrenic arteries
Diaphragm, inferior portion of esophagus
Adrenal arteries
Adrenal glands
Renal arteries
Kidneys
Gonadal arteries
Testes or ovaries
Lumbar arteries
Vetebrae, spinal cord, abdominal wall, lumbar region
Common iliac arteries

Figure 11.39 Major Branches of the Aorta

Figure 11.40[36] shows the distribution of the major branches of the common iliac arteries.

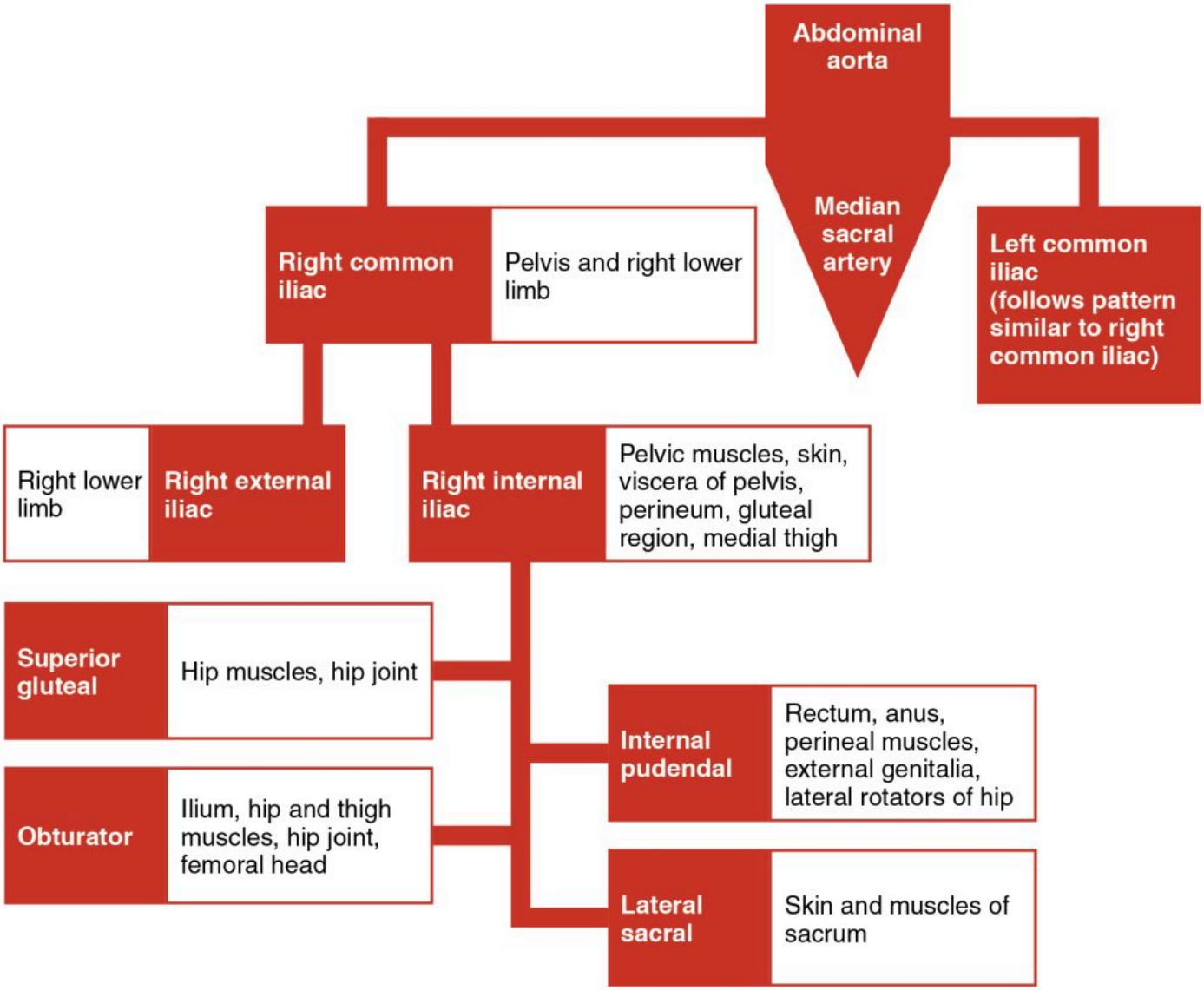


Figure 11.40 Major Branches of the Iliac Arteries

Table 11.5f summarizes the major branches of the abdominal aorta.

36. OpenStax College. (2013). *2126_Iliac_Artery_Branches_Chart* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2126_Iliac_Artery_Branches_Chart.jpg

Table 11.5f. Vessels of the Abdominal Aorta[37]

37. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Vessel	Description
Celiac Trunk	Also called the celiac artery; a major branch of the abdominal aorta; gives rise to the left gastric artery, the splenic artery, and the common hepatic artery
Left Gastric Artery	Branch of the celiac trunk; supplies blood to the stomach
Splenic Artery	Branch of the celiac trunk; supplies blood to the spleen
Common Hepatic Artery	Branch of the celiac trunk that forms the proper hepatic artery, the right gastric artery, and the gastroduodenal artery
Proper Hepatic Artery	Branch of the common hepatic artery; supplies systemic blood to the liver and gallbladder
Right Gastric Artery	Branch of the common hepatic artery; supplies blood to the stomach
Gastroduodenal Artery	Branch of the common hepatic artery; supplies blood to the stomach and duodenum
Superior Mesenteric Artery	Branch of the abdominal aorta; supplies blood to the small intestine (duodenum, jejunum, and ileum), the pancreas, and a majority of the large intestine
Inferior Mesenteric Artery	Branch of the abdominal aorta; supplies blood to the distal segment of the large intestine and rectum
Inferior Phrenic Arteries	Branches of the abdominal aorta; supply blood to the inferior surface of the diaphragm
Adrenal Arteries	Branch of the abdominal aorta; supplies blood to the adrenal (suprarenal) glands
Renal Arteries	Branch of the abdominal aorta; supplies blood to each kidney
Gonadal Arteries	Branch of the abdominal aorta; supplies blood to the gonads or reproductive organs; also described as ovarian arteries or testicular arteries, depending upon the sex of the individual

Ovarian Arteries	Branch of the abdominal aorta; supplies blood to the ovary, uterine (Fallopian) tube, and uterus
Testicular Arteries	Branch of the abdominal aorta; ultimately travels outside the body cavity to the testes and forms one component of the spermatic cord
Common Iliac Arteries	Branch of the aorta that leads to the internal and external iliac arteries
Median Sacral Artery	Continuation of the aorta into the sacrum
Internal Iliac Arteries	Branch from the common iliac arteries; supplies blood to the urinary bladder, walls of the pelvis, external genitalia, and the medial portion of the femoral region; in females, also provides blood to the uterus and vagina
External Iliac Arteries	Branch of the common iliac artery that leaves the body cavity and becomes a femoral artery; supplies blood to the lower limbs

Arteries Serving the Upper Limbs

As the subclavian artery exits the thorax into the axillary region, it is renamed the **axillary artery**. Although it does branch and supply blood to the region near the head of the humerus, the majority of the vessel continues into the upper arm, or brachium, and becomes the brachial artery.

The **brachial artery** supplies blood to much of the brachial region and divides at the elbow into several smaller branches, including the deep brachial arteries, which provide blood to the posterior surface of the arm, and the ulnar collateral arteries, which supply blood to the region of the elbow. As the brachial artery approaches the coronoid fossa, it bifurcates (divides) into the radial and ulnar arteries, which continue into the forearm, or antebrachium.

The **radial artery** and **ulnar artery** parallel their namesake bones, giving off smaller branches until they reach the wrist, or carpal region. At this level, they fuse to form the superficial and deep **palmar arches** that supply blood to the hand, as well as the **digital arteries** that supply blood to the digits.

See Figure 11.41[38] for an illustration of the major arteries of the upper limbs.

38. OpenStax College. (2013). *2127_Thoracic_Upper_Limb_Arteries* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2127_Thoracic_Upper_Limb_Arteries.jpg

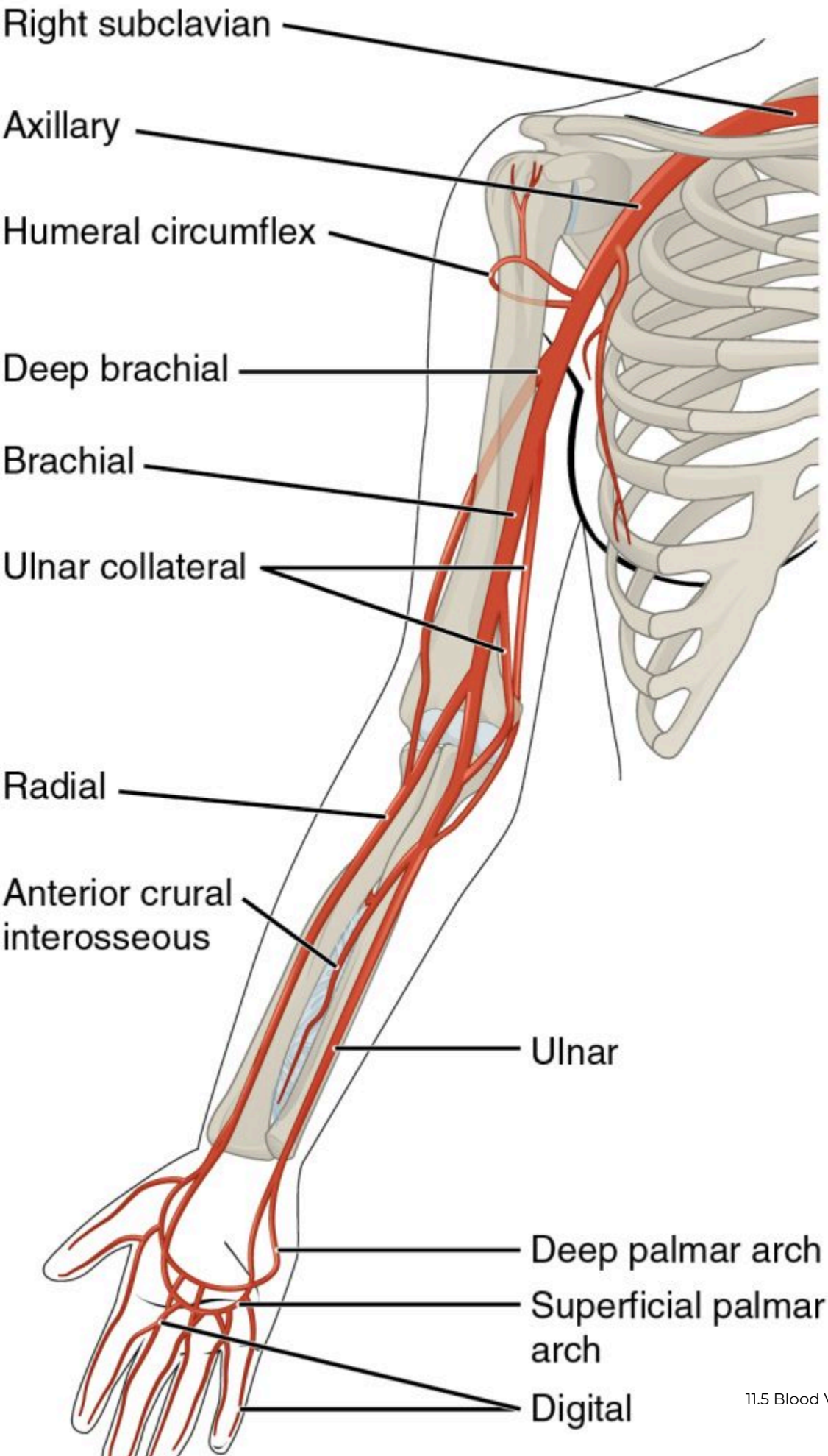

Right subclavian
Axillary
Humeral circumflex
Deep brachial
Brachial
Ulnar collateral
Radial
Anterior crural interosseous
Ulnar
Deep palmar arch
Superficial palmar arch
Digital

Figure 11.41 Major Arteries of the Upper Limb

Figure 11.42[39] shows the distribution of systemic arteries from the heart into the upper limb.

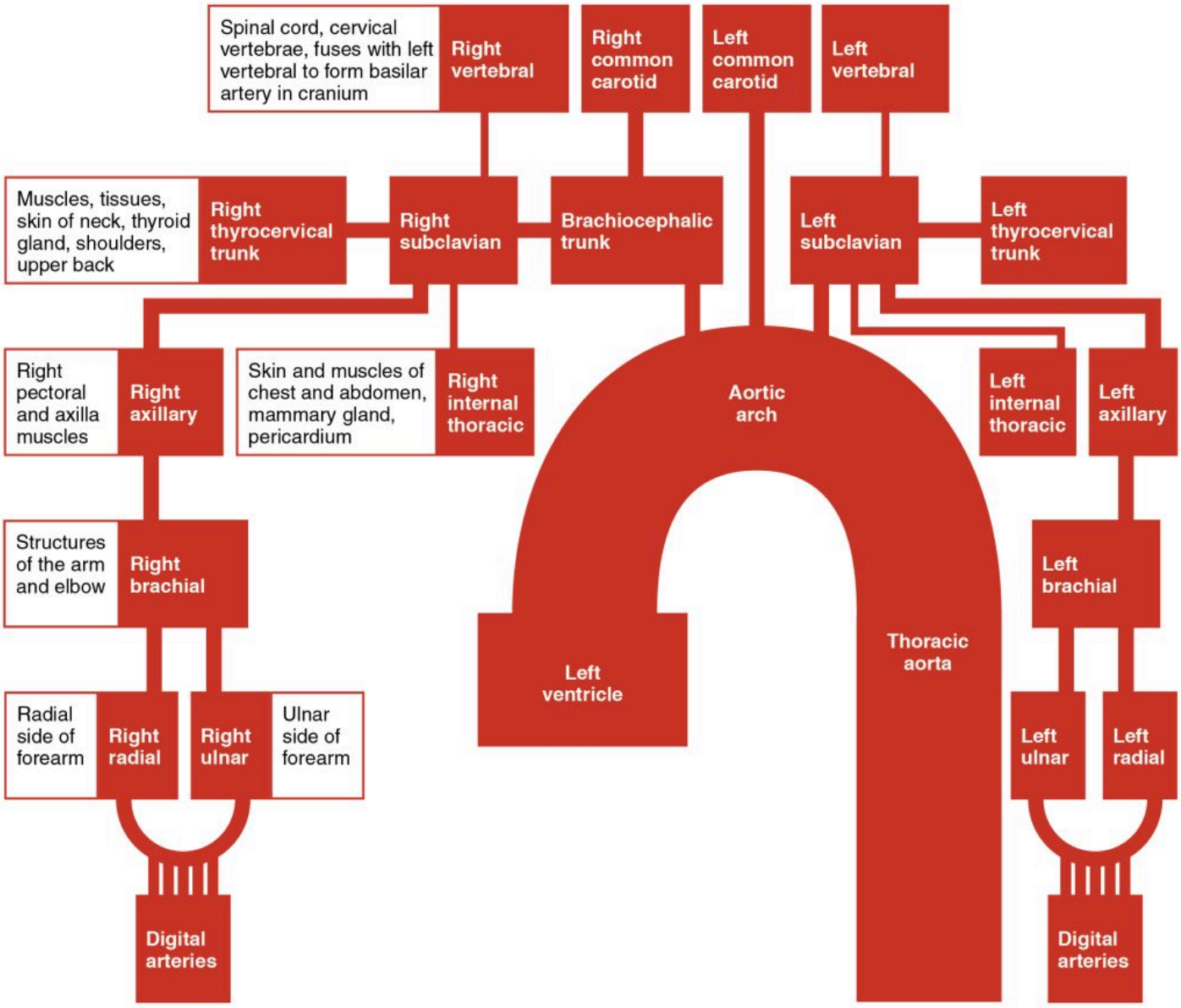


Figure 11.42 Major Arteries of the Upper Limb

39. OpenStax College. (2013). *2128_Thoracic_Upper_Limb_Arteries_Chart* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2128_Thoracic_Upper_Limb_Arteries_Chart.jpg

Table 11.5g summarizes the arteries serving the upper limbs.

Table 11.5g. Arteries Serving the Upper Limbs[40]

40. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Vessel	Description
Axillary Arteries	Continuation of the subclavian artery as it penetrates the body wall and enters the axillary region; supplies blood to the region near the head of the humerus (humeral circumflex arteries); the majority of the vessel continues into the brachium and becomes the brachial artery
Brachial Arteries	Continuation of the axillary artery in the brachium; supplies blood to much of the brachial region; gives off several smaller branches that provide blood to the posterior surface of the arm in the region of the elbow; bifurcates into the radial and ulnar arteries at the coronoid fossa
Radial Arteries	Formed at the bifurcation of the brachial artery; parallels the radius; gives off smaller branches until it reaches the carpal region, where it fuses with the ulnar artery to form the superficial and deep palmar arches; supplies blood to the lower arm and carpal region
Ulnar Arteries	Formed at the bifurcation of the brachial artery; parallels the ulna, gives off smaller branches until it reaches the carpal region, where it fuses with the radial artery to form the superficial and deep palmar arches; supplies blood to the lower arm and carpal region
Palmar Arches (Superficial and Deep)	Formed from anastomosis of the radial and ulnar arteries, they supply blood to the hand and digital arteries
Digital Arteries	Formed from the superficial and deep palmar arches; supply blood to the digits

Arteries Serving the Lower Limbs

The external iliac artery exits the body cavity and enters the femoral region of the lower leg. When it enters the thigh, it is renamed the **femoral artery**. It gives off several smaller branches, as well as the lateral **deep femoral artery** that, in turn, gives rise to a **lateral circumflex artery**. These arteries supply blood to the deep muscles of the thigh, as well as the ventral and lateral regions of the integument. The femoral artery also gives rise to the **genicular artery**, which provides blood to the region of the knee. As the femoral artery passes posterior to the knee near the popliteal fossa, it is called the **popliteal artery**. The popliteal artery branches into the anterior and posterior tibial arteries.

The **anterior tibial artery** is located between the tibia and fibula and supplies blood to the muscles and skin of the anterior tibial region. Upon reaching the tarsal region, it becomes the **dorsalis pedis artery**, which branches repeatedly and provides blood to the tarsal and dorsal regions of the foot.

The **posterior tibial artery** provides blood to the muscles and skin on the posterior surface of the tibial region. The fibular or peroneal artery branches from the posterior tibial artery. It bifurcates (divides) and becomes the **medial plantar artery** and **lateral plantar artery**, providing blood to the plantar surfaces.

There is an anastomosis with the dorsalis pedis artery and the medial and lateral plantar arteries that form two arches called the **dorsal arch** (also called the arcuate arch) and the **plantar arch**, which provide blood to the remainder of the foot and toes.

See Figure 11.43[41] for an illustration of the major arteries in the leg.

41. OpenStax College. (2013). *2129ab_Lower_Limb_Arteries_Anterior_Posterior* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2129ab_Lower_Limb_Arteries_Anterior_Posterior.jpg

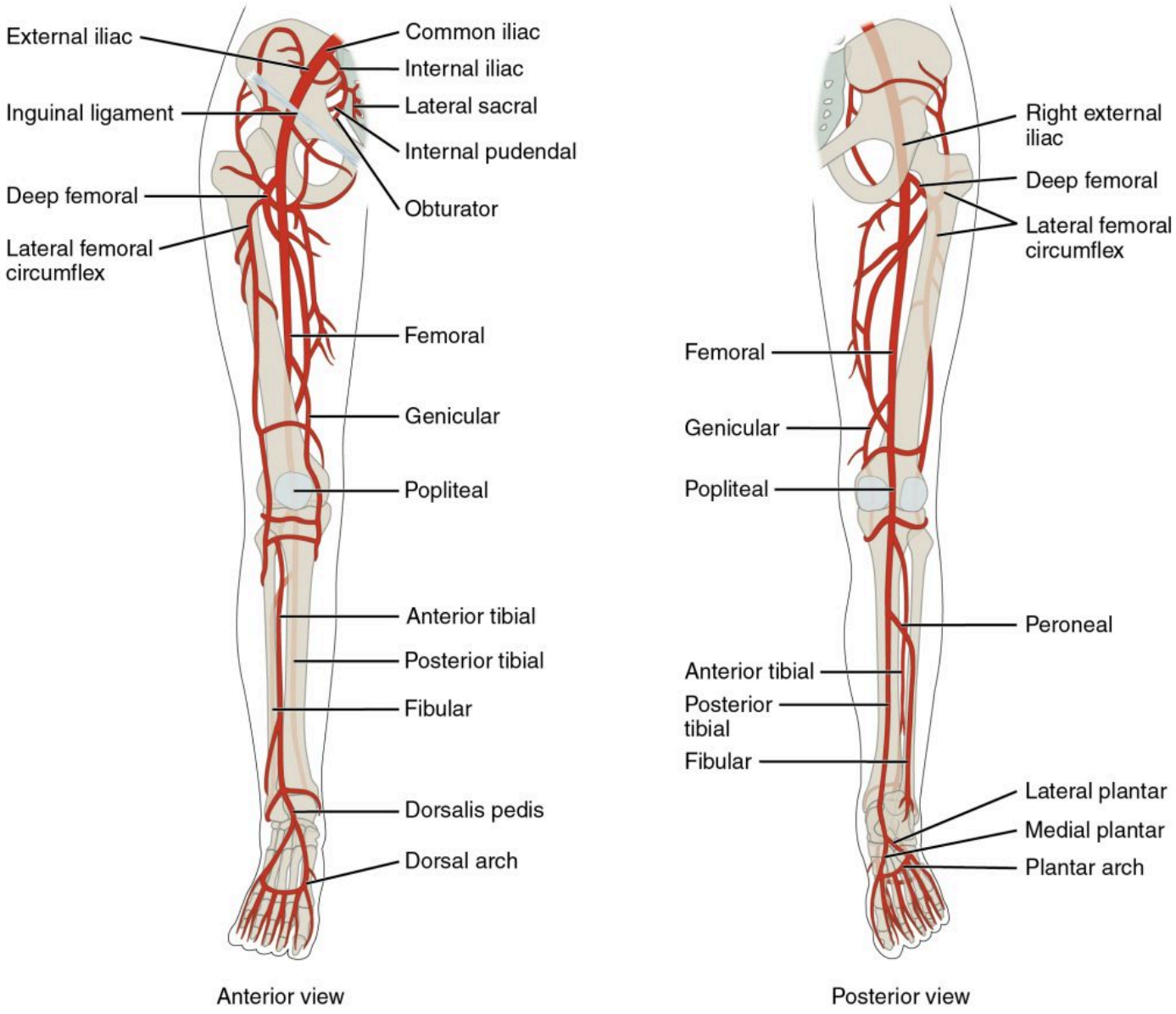


Figure 11.43 Major Arteries Serving the Lower Limb

Figure 11.44[42] shows the distribution of the major systemic arteries in the lower limb.

42. OpenStax College. (2013). *2130_Lower_Limb_Arteries_Chart* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2130_Lower_Limb_Arteries_Chart.jpg

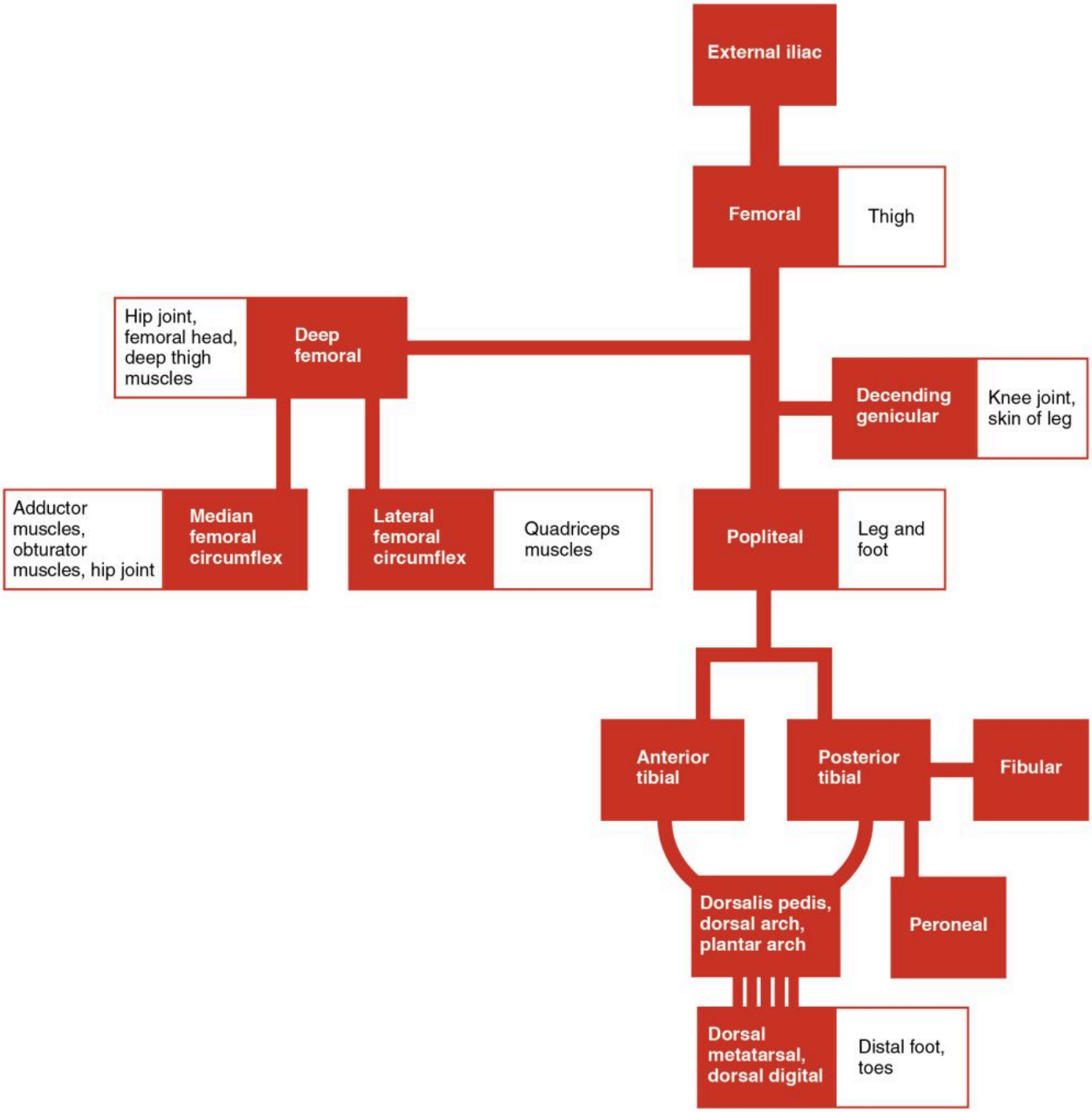


Figure 11.44 Systemic Arteries of the Lower Limb

Table 11.5h summarizes the major arteries serving the lower limbs.

Table 11.5h. Arteries Serving the Lower Limbs[43]

43. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young,

K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Vessel	Description
Femoral Arteries	Continuation of the external iliac artery after it enters the thigh; divides into several smaller branches, the lateral deep femoral artery and the genicular artery; becomes the popliteal artery as it passes posterior to the knee
Deep Femoral Arteries	Branch of the femoral artery; gives rise to the lateral circumflex arteries
Popliteal Arteries	Continuation of the femoral artery posterior to the knee; branches into the anterior and posterior tibial arteries
Anterior Tibial Arteries	Branches from the popliteal artery; supplies blood to the anterior tibial region; becomes the dorsalis pedis artery
Dorsalis Pedis Arteries	Forms from the anterior tibial artery; branches repeatedly to supply blood to the tarsal and dorsal regions of the foot
Posterior Tibial Arteries	Branches from the popliteal artery and gives rise to the fibular or peroneal artery; supplies blood to the posterior tibial region
Medial Plantar Arteries	Arises from the bifurcation of the posterior tibial arteries; supplies blood to the medial plantar surfaces of the foot
Lateral Plantar Arteries	Arises from the bifurcation of the posterior tibial arteries; supplies blood to the lateral plantar surfaces of the foot
Dorsal or Arcuate Arches	Formed from the anastomosis of the dorsalis pedis artery and the medial and plantar arteries; branches supply the distal portions of the foot and digits
Plantar Arches	Formed from the anastomosis of the dorsalis pedis artery and the medial and plantar arteries; branches supply the distal portions of the foot and digits

Systemic Veins

Systemic veins return blood to the right atrium. Because the blood has already passed through the systemic capillaries, it will be relatively low in oxygen concentration. In many cases, there will be veins draining organs and regions of the body with the same name as the arteries that supply these regions, and the two often parallel one another. This is often described as a "complementary" pattern. However, there is a great deal more variability in the venous circulation than normally occurs in the arteries.

In both the neck and limb regions, there are often both superficial and deeper veins. The deeper veins generally correspond to their complementary arteries. The superficial veins do not normally have direct arterial counterparts, but in addition to returning blood, they also contribute to maintaining body temperature. When the ambient temperature is warm, more blood is diverted to the superficial veins, where heat can be more easily dissipated to the environment. In colder weather, there is more constriction of the superficial veins, and blood is diverted deeper, where the body can retain more of the heat.

See Figure 11.45[44] for an illustration of the major systemic veins from an anterior view.

44. OpenStax College. (2013). *2131_Major_Systematic_Veins* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2131_Major_Systematic_Veins.jpg

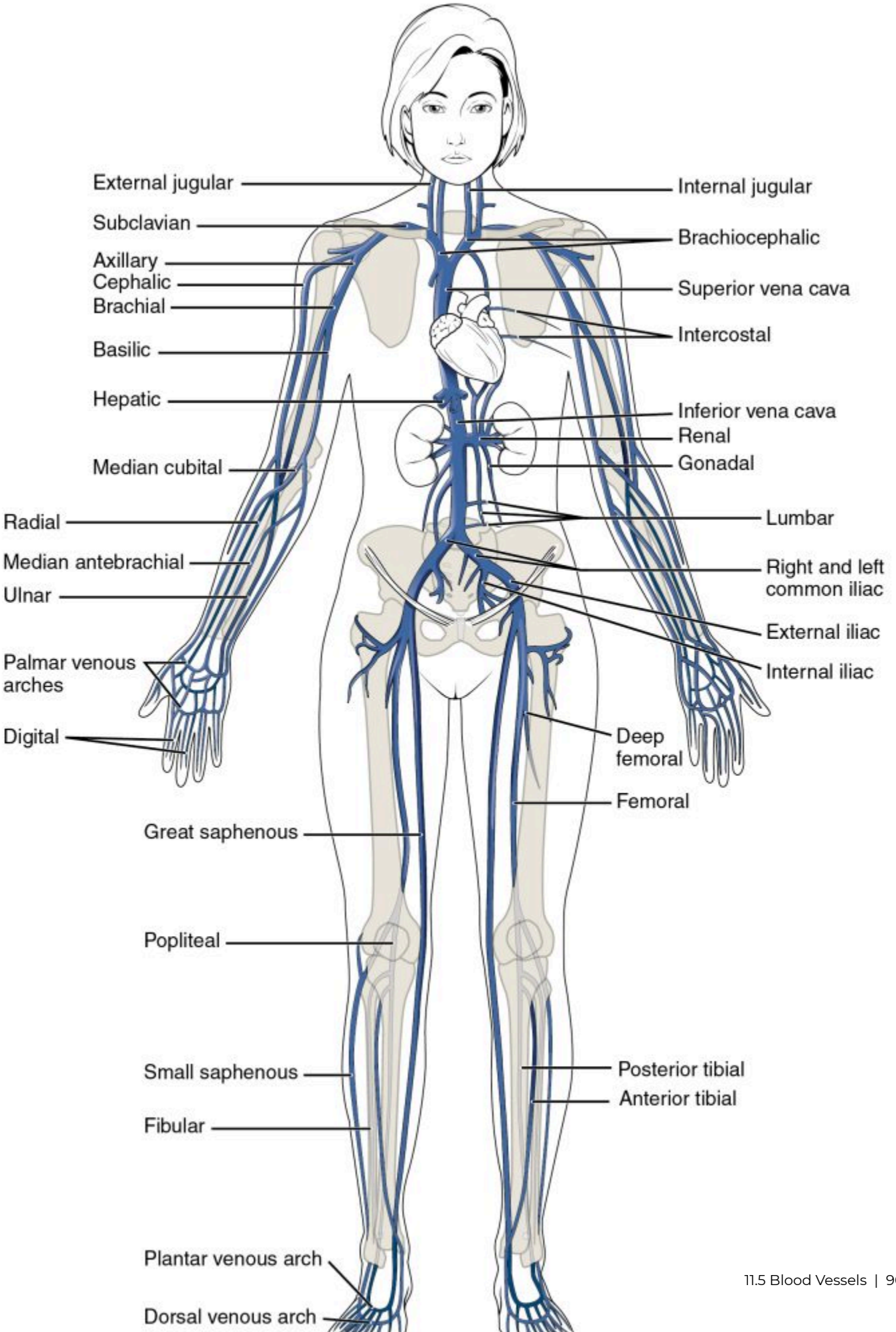

External jugular
Internal jugular
Subclavian
Brachiocephalic
Axillary
Cephalic
Brachial
Superior vena cava
Intercostal
Basilic
Hepatic
Inferior vena cava
Renal
Median cubital
Gonadal
Radial
Lumbar
Median antebrachial
Right and left common iliac
Ulnar
External iliac
Internal iliac
Palmar venous arches
Digital
Deep femoral
Femoral
Great saphenous
Popliteal
Small saphenous
Posterior tibial
Anterior tibial
Fibular
Plantar venous arch
Dorsal venous arch

Figure 11.45 Major Systemic Veins of the Body

The right atrium receives all the systemic venous return. Most of the blood flows into either the superior vena cava or the inferior vena cava. The superior vena cava receives blood from the head, neck, chest, shoulders, and upper limbs. The exception to this is that most venous blood flow from the coronary veins flows directly into the coronary sinus and from there directly into the right atrium. Inferior to the diaphragm, systemic venous blood from the abdominal and pelvic regions and the lower limbs enters the inferior vena cava to be returned to the right atrium.[45]

Major Veins That Flow Into the Superior Vena Cava

The **superior vena cava** drains most of the body superior to the diaphragm. On both the left and right sides, the **subclavian vein** forms when the axillary vein passes through the body wall from the axillary region. It fuses with the external and internal jugular veins from the head and neck to form the **brachiocephalic vein**. The superior vena cava then receives blood from the brachiocephalic veins.[46] See Figure 11.46[47] for an illustration of the veins that flow into the superior vena cava.

45. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

46. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

47. OpenStax College. (2013). *2132_Thoracic_Abdominal_Veins* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2132_Thoracic_Abdominal_Veins.jpg

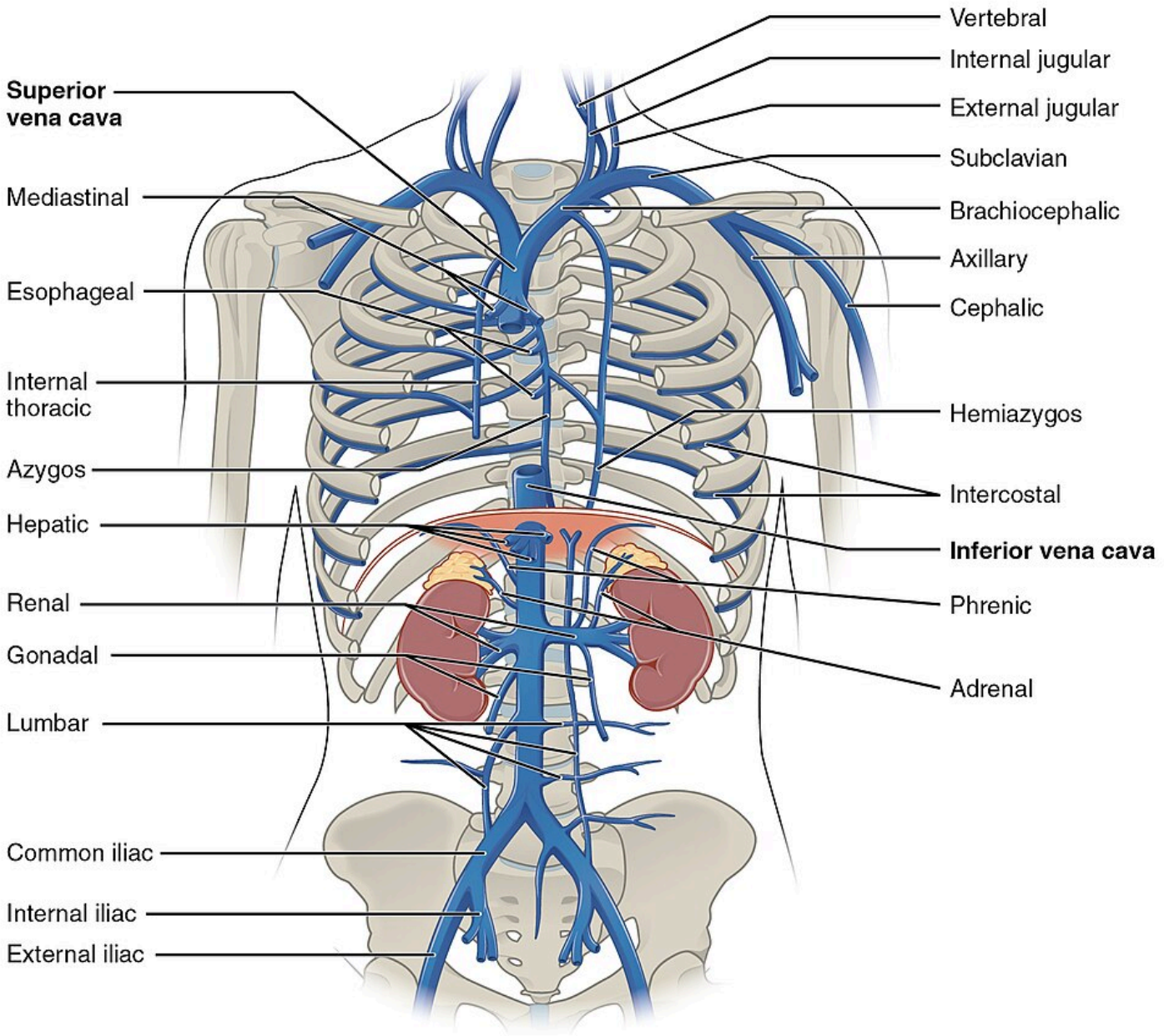


Figure 11.46 Veins That Flow Into the Superior Vena Cava

Table 11.5i summarizes the veins of the thoracic region that flow into the superior vena cava.

Table 11.5i. Major Veins of the Thoracic Region[48]

48. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Vessel	Description
Superior Vena Cava	Large systemic vein; drains blood from most areas superior to the diaphragm; empties into the right atrium
Subclavian Veins	Located deep in the thoracic cavity; formed by the axillary vein as it enters the thoracic cavity from the axillary region; drains the axillary and smaller local veins near the scapular region, and leads to the brachiocephalic vein
Brachiocephalic Veins	A pair of veins that form from a fusion of the external and internal jugular veins and the subclavian vein; subclavian, external and internal jugulars, vertebral, and internal thoracic veins flow into it; drain the upper thoracic region and lead to the superior vena cava

Major Veins of the Head and Neck

Blood from the brain and the superficial facial vein flow into each **internal jugular vein**. Blood from the more superficial portions of the head, scalp, and cranial regions, including the **temporal vein** and **maxillary vein**, flows into each **external jugular vein**. Although the external and internal jugular veins are separate vessels, there are anastomoses between them close to the thoracic region.[49] Blood from the external jugular vein empties into the subclavian vein. See Figure 11.47[50] for an illustration of the internal and external jugular veins.

49. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

50. OpenStax College. (2013). *2133_Head_and_Neck_Veins* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2133_Head_and_Neck_Veins.jpg

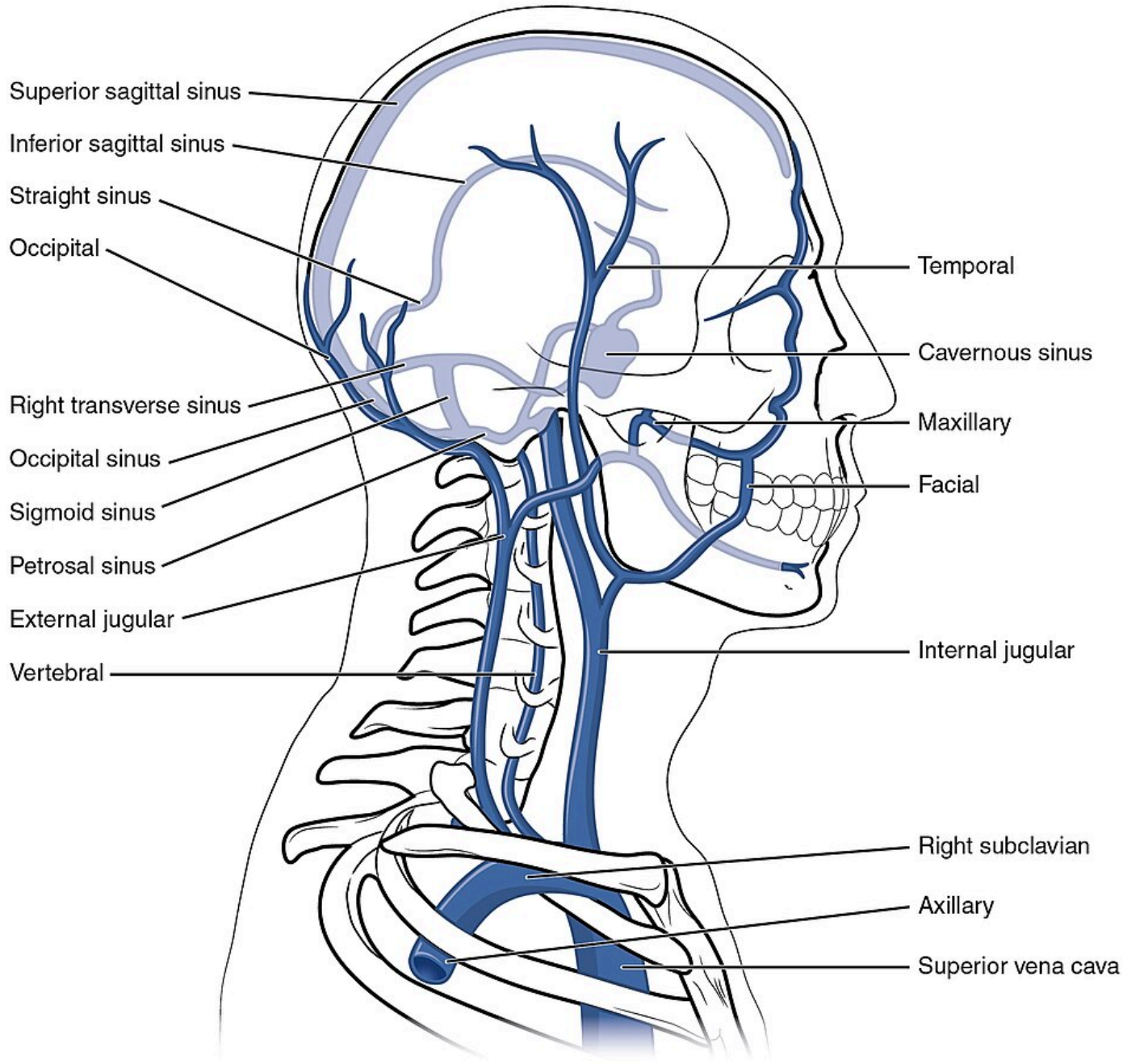


Figure 11.47 Veins of the Head and Neck

Table 11.5j. Major Veins of the Head and Neck[51]

51. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Vessel	Description
Internal Jugular Veins	Parallel to the common carotid artery, which is more or less its counterpart, and passes through the jugular foramen and canal; primarily drains blood from the brain, receives the superficial facial vein, and leads to the brachiocephalic vein
External Jugular Veins	Drains blood from the more superficial portions of the head, scalp, and cranial regions, and empties into the subclavian vein

Major Veins Draining the Upper Limbs

The **digital veins** in the fingers come together in the hand to form the **palmar venous arches**. From here, the veins come together to form the radial vein, the ulnar vein, and the median antebrachial vein. The **radial vein** and the **ulnar vein** parallel the bones of the forearm and join together at the antebrachium to form the **brachial vein**, a deep vein that flows into the axillary vein in the brachium.

The **median antebrachial vein** parallels the ulnar vein, is more medial in location, and joins the **basilic vein** in the forearm. As the basilic vein reaches the antecubital region, it gives off a branch called the **median cubital vein** that crosses at an angle to join the cephalic vein. The median cubital vein is the most common site for drawing venous blood in humans. The basilic vein continues through the arm medially and superficially to the axillary vein.

The **cephalic vein** begins in the antebrachium (between the elbow and wrist) and drains blood from the superficial surface of the arm into the axillary vein. It is extremely superficial and easily seen along the surface of the biceps brachii muscle in individuals with good muscle tone and in those without excessive adipose tissue in the arms.

The **subscapular vein** drains blood from the subscapular region and joins the cephalic vein to form the axillary vein. As it passes through the body wall and enters the thorax, the **axillary vein** becomes the subclavian vein.[52]

See Figure 11.48[53] for an illustration of the veins in the upper limb.

52. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

53. OpenStax College. (2013). *2134_Thoracic_Upper_Limb_Veins* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2134_Thoracic_Upper_Limb_Veins.jpg

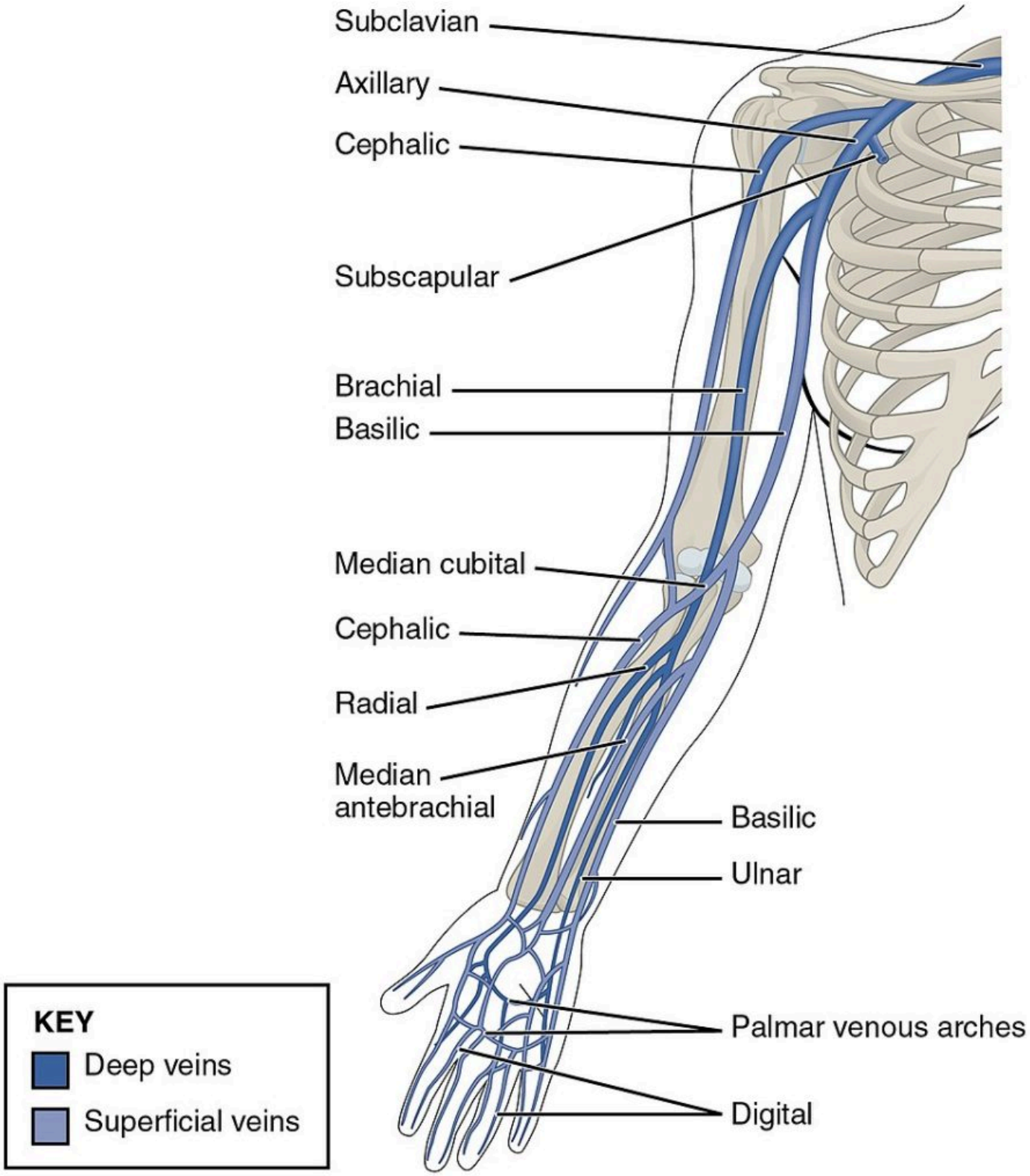


Figure 11.48 Veins of the Upper Limb

Many of the larger veins of the thoracic and abdominal region and upper limb are further represented in the flow chart in Figure 11.49.[54]

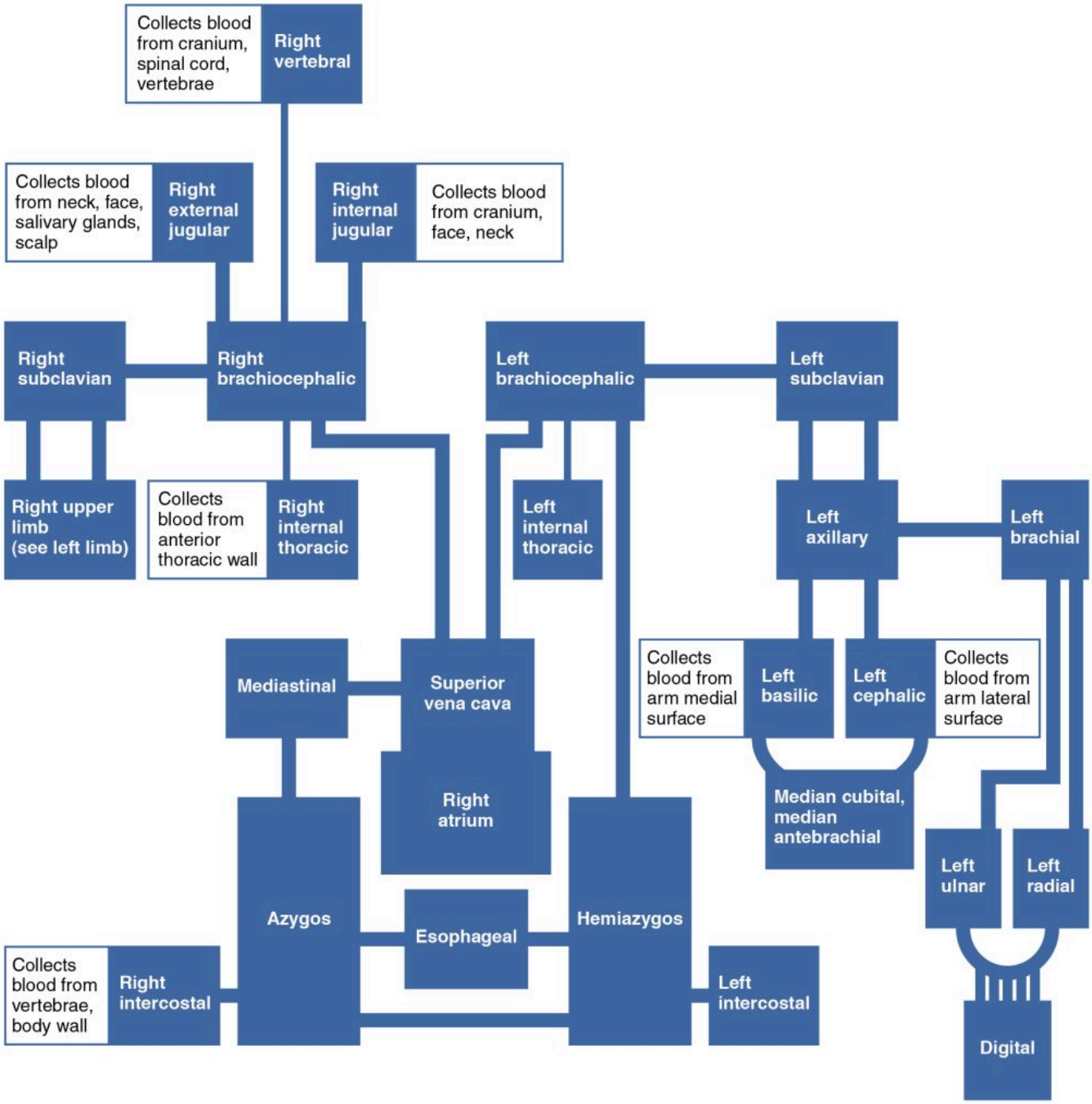


Figure 11.49 Veins Flowing Into the Superior Vena Cava

54. OpenStax College. (2013). *2135_Veins_Draining_into_Superior_Vena_Cava_Chart* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2135_Veins_Draining_into_Superior_Vena_Cava_Chart.jpg

Table 11.5k summarizes the veins of the upper limbs.

Table 11.5k. Major Veins of the Upper Limbs[55]

55. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Vessel	Description
Digital Veins	Drain the digits and lead to the palmar arches of the hand and dorsal venous arch of the foot
Palmar Venous Arches	Drain the hand and digits and lead to the radial vein, ulnar veins, and median antebrachial vein
Radial Veins	Vein that parallels the radius and radial artery; arises from the palmar venous arches and leads to the brachial vein
Ulnar Veins	Vein that parallels the ulna and ulnar artery; arises from the palmar venous arches and leads to the brachial vein
Brachial Veins	The deeper vein of the arm that forms from the radial and ulnar veins in the lower arm; leads to the axillary vein
Median Antebrachial Veins	Vein that parallels the ulnar vein but is more medial in location; intertwines with the palmar venous arches; leads to the basilic vein
Basilic Veins	Superficial, medial vein of the arm that arises from the median antebrachial vein, intersects with the median cubital vein, parallels the ulnar vein, and continues into the upper arm; along with the brachial vein, it leads to the axillary vein
Median Cubital Veins	Superficial vessel located in the antecubital region that links the cephalic vein to the basilic vein in the form of a “V”; a frequent site from which to draw blood
Cephalic Veins	Superficial, lateral vessel in the upper arm; leads to the axillary vein
Subscapular Veins	Drains blood from the subscapular region and leads to the axillary vein
Axillary Veins	Major vein in the axillary region; drains the upper limb and becomes the subclavian vein

Major Veins That Flow Into the Inferior Vena Cava

Most of the blood inferior to the diaphragm drains into the inferior vena cava before it is returned to the heart. The **inferior vena cava** parallels the abdominal aorta, where it can receive blood from abdominal veins.

Blood supply from the kidneys flows into each **renal vein**, the largest veins entering the inferior vena cava. A number of other smaller veins empty into the left renal vein. Each **adrenal vein** drains the adrenal or suprarenal glands located immediately superior to the kidneys. The right adrenal vein enters the inferior vena cava directly, whereas the left adrenal vein enters the left renal vein.

From the male reproductive organs, each **testicular vein** flows from the scrotum, forming a portion of the spermatic cord. Each **ovarian vein** drains an ovary in females. Each of these veins is generically called a **gonadal vein**. The right gonadal vein empties directly into the inferior vena cava, and the left gonadal vein empties into the left renal vein.

Blood supply from the liver drains into each **hepatic vein** and directly into the inferior vena cava. Because the inferior vena cava lies primarily to the right of the vertebral column and aorta, the left renal vein is longer, as are the left adrenal and gonadal veins. The longer length of the left renal vein makes the left kidney the primary target of surgeons removing this organ for donation.[56]

See Figure 11.50[57] for an illustration of the veins that flow into the inferior vena cava.

56. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

57. OpenStax College. (2013). *2132_Thoracic_Abdominal_Veins* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2132_Thoracic_Abdominal_Veins.jpg

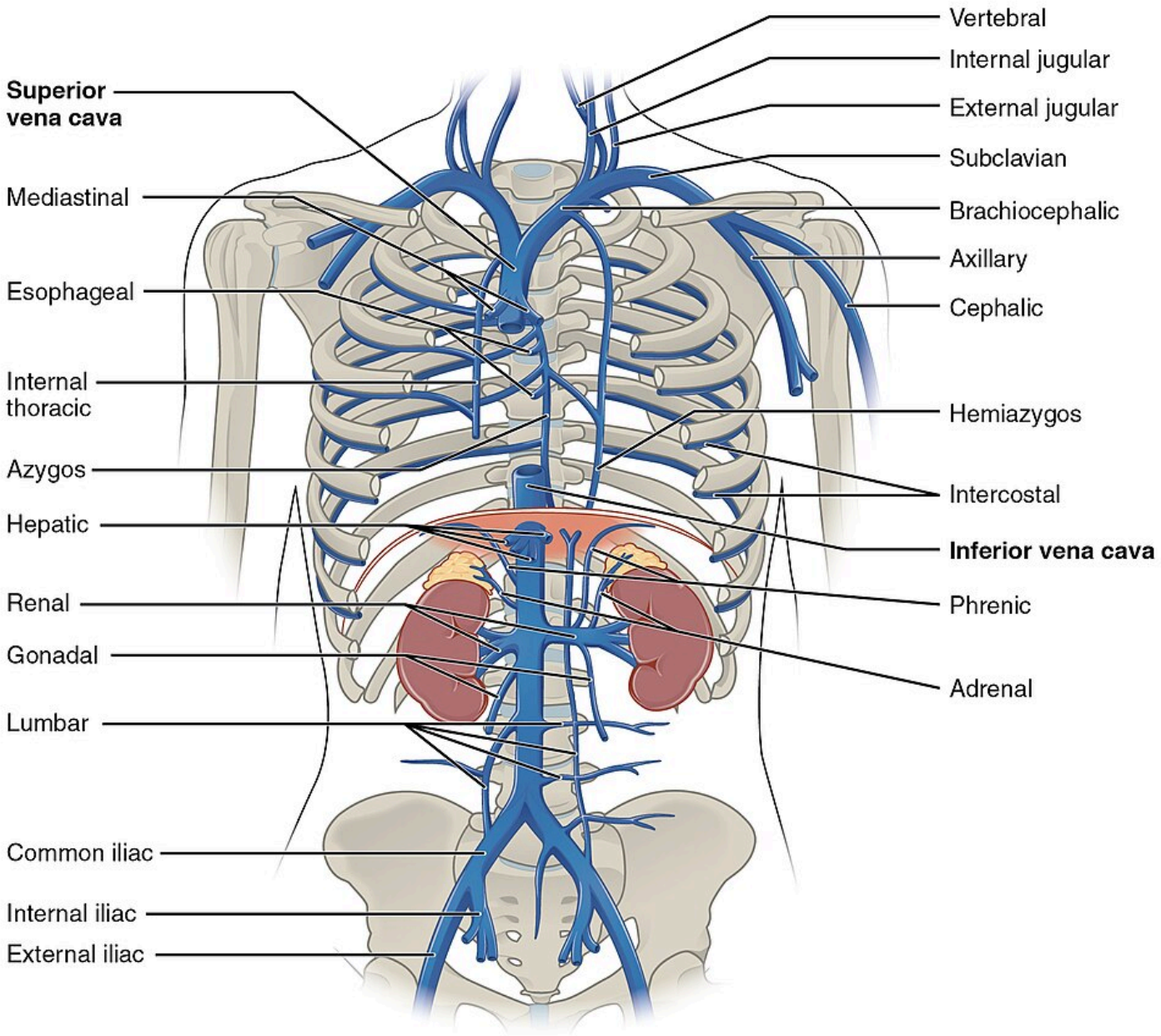


Figure 11.50 Veins That Flow into the Inferior Vena Cava

Figure 11.51[58] provides a flow chart of the veins flowing into the inferior vena cava.

58. OpenStax College. (2013). *2140_FlowChart_Veins_into_VenaCava* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2140_FlowChart_Veins_into_VenaCava.jpg

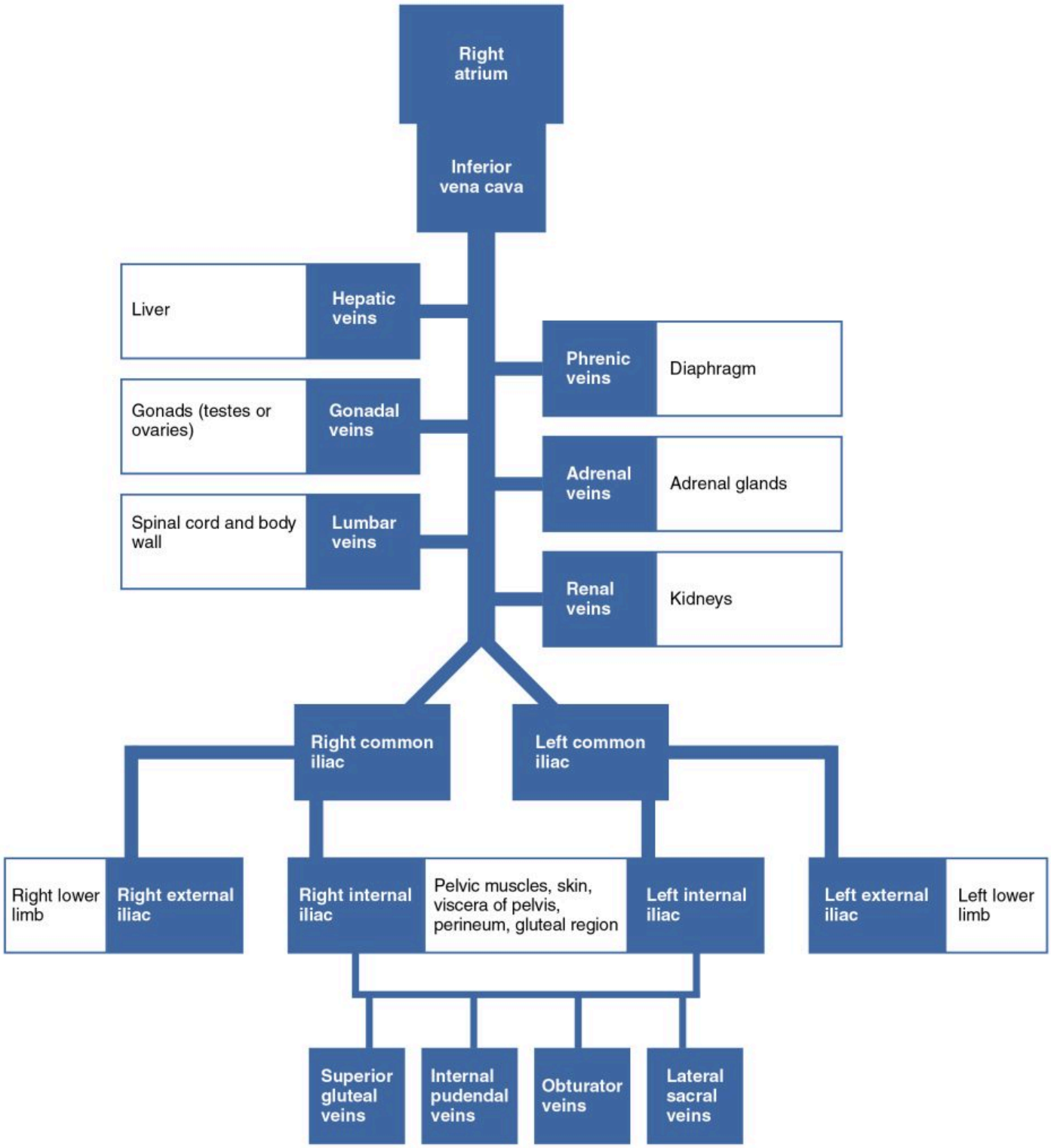


Figure 11.51 Venous Flow into Inferior Vena Cava

Table 11.5l summarizes the major veins of the abdominal region.

Table 11.5l. Major Veins of the Abdominal Region[59]

59. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Vessel	Description
Inferior Vena Cava	A large systemic vein that drains blood from areas largely inferior to the diaphragm; empties into the right atrium
Renal Veins	The largest vein entering the inferior vena cava; drains the kidneys and flows into the inferior vena cava
Adrenal Veins	Drains the adrenal or suprarenal glands; the right adrenal vein enters the inferior vena cava directly, and the left adrenal vein enters the left renal vein
Testicular Veins	Drains the testes and forms part of the spermatic cord; the right testicular vein empties directly into the inferior vena cava, and the left testicular vein empties into the left renal vein
Ovarian Veins	Drains the ovary; the right ovarian vein empties directly into the inferior vena cava, and the left ovarian vein empties into the left renal vein
Gonadal Veins	Generic term for a vein draining a reproductive organ; may be either an ovarian vein or a testicular vein, depending on the sex of the individual
Phrenic Veins	Drains the diaphragm; the right phrenic vein flows into the inferior vena cava, and the left phrenic vein empties into the left renal vein
Hepatic Veins	Drains systemic blood from the liver and flows into the inferior vena cava

Major Veins Draining the Lower Limbs

The superior surface of the foot drains into the digital veins, and the inferior surface drains into the **plantar veins**, which flow into a complex series of anastomoses in the feet and ankles, including the **dorsal venous arch** and the **plantar venous arch**.

From the dorsal venous arch, blood supply drains into the anterior and posterior tibial veins. The **anterior tibial vein** drains the area near the tibialis anterior muscle and combines with the posterior tibial vein and the fibular vein to form the popliteal vein. The **posterior tibial vein** drains the posterior surface of the tibia and joins the popliteal vein. The **fibular vein** drains the muscles and skin in proximity to the fibula and also joins the popliteal vein. The small **saphenous vein** located on the lateral surface of the leg drains blood from the superficial regions of the lower leg and foot and flows into the **popliteal vein**. As the popliteal vein passes behind the knee in the popliteal region, it becomes the femoral vein. It is palpable in patients without excessive adipose tissue.

The **great saphenous vein**, the deep femoral vein, and the femoral circumflex vein drain into the femoral vein. The great saphenous vein is a prominent surface vessel located on the medial surface of the leg and thigh and collects blood from the superficial portions of these areas. It runs from the ankle to the groin and is the longest vein in the body. The **deep femoral vein**, as the name suggests, drains blood from the deeper portions of the thigh. The **femoral circumflex vein** forms a loop around the femur just inferior to the trochanters and drains blood from the areas in proximity to the head and neck of the femur.

As the **femoral vein** penetrates the body wall from the femoral portion of the leg, it becomes the **external iliac vein**, a large vein that drains blood from the leg to the common iliac vein. The pelvic organs and skin drain into the **internal iliac vein**, which forms from several smaller veins in the region. The external and internal iliac veins combine near the inferior portion of the sacroiliac joint to form the common iliac vein. In addition to blood supply from the external and internal iliac veins, the **middle sacral vein** drains the sacral region into the **common iliac vein**. Similar to the common iliac arteries, the common iliac veins come together at the level of L5 to form the inferior vena cava.[60]

See Figure 11.52[61] for an illustration of the major veins flowing in the lower limbs.

60. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

61. OpenStax College. (2013). *2136ab_Lower_Limb_Veins_Anterior_Posterior* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2136ab_Lower_Limb_Veins_Anterior_Posterior.jpg

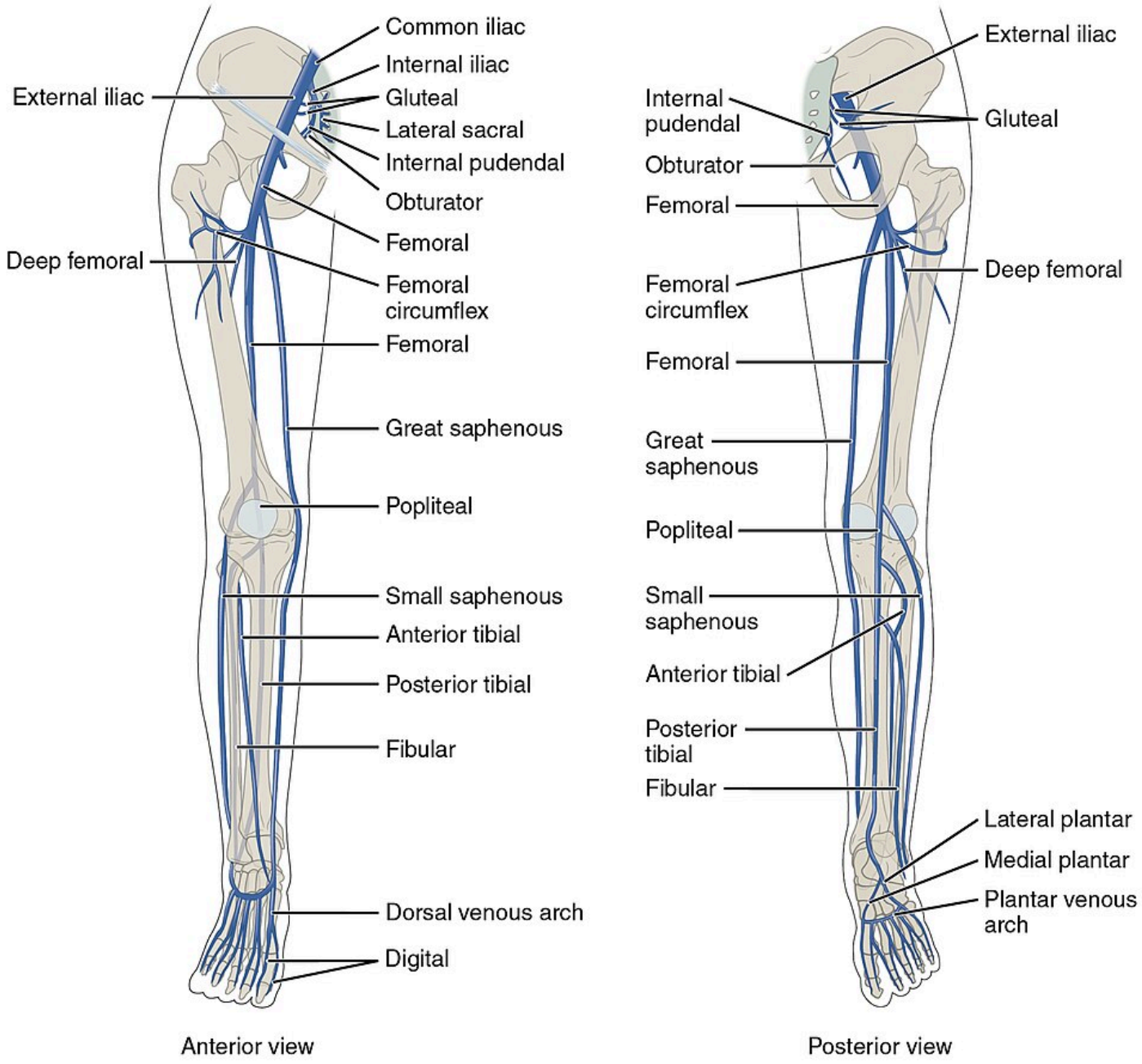


Figure 11.52 Major Veins Serving the Lower Limbs

See Figure 11.53[62] for a flow chart of veins flowing into the lower limb.

62. OpenStax College. (2013). *2137_Lower_Limb_Veins_Chart* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2137_Lower_Limb_Veins_Chart.jpg

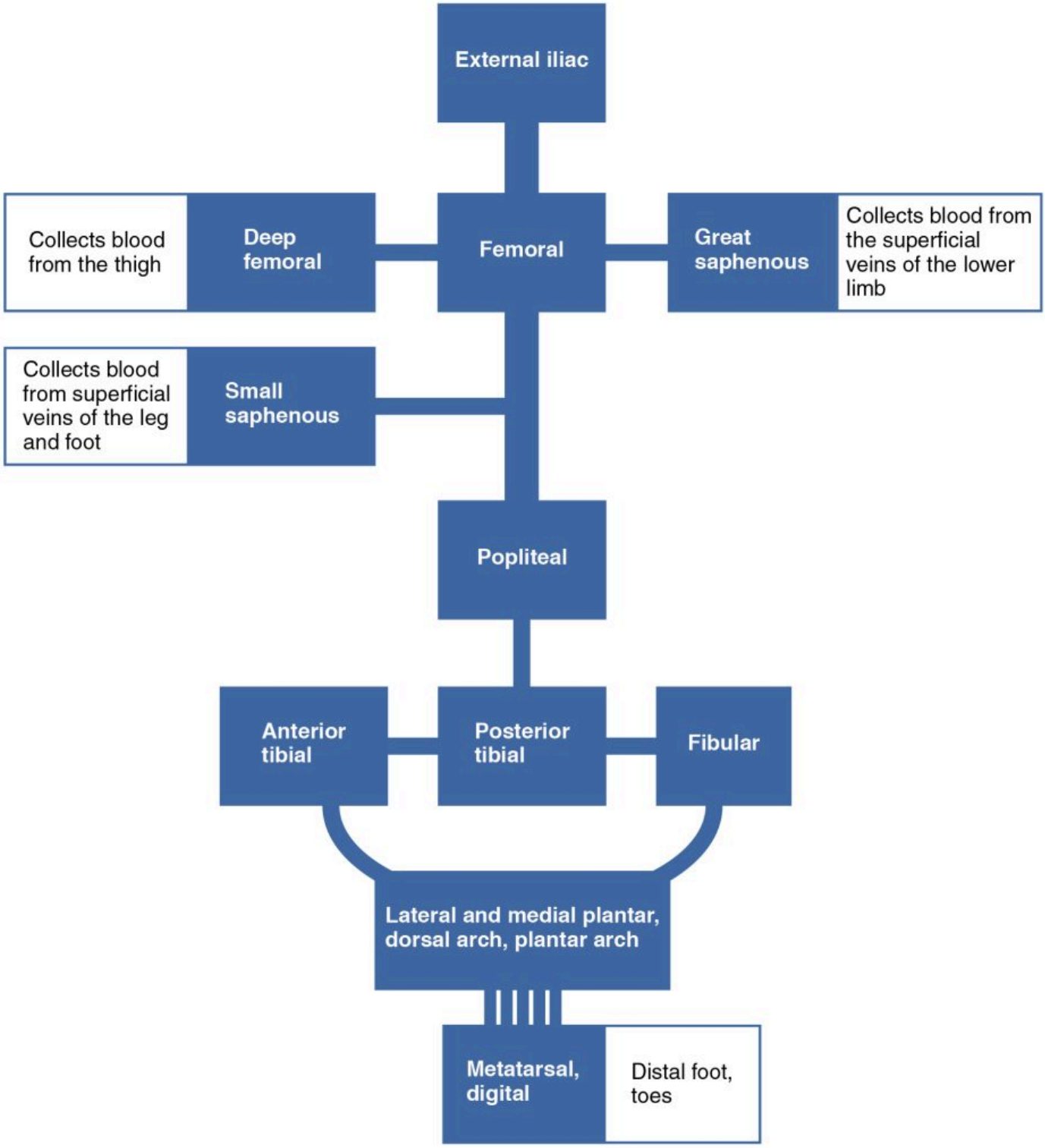


Figure 11.53 Major Veins of the Lower Limb

Table 11.5m summarizes the major veins of the lower limbs.

Table 11.5m. Major Veins of the Lower Limbs[63]

63. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Vessel	Description
Plantar Veins	Drain the foot and flow into the plantar venous arch
Dorsal Venous Arches	Drains blood from digital veins and vessels on the superior surface of the foot
Plantar Venous Arches	Formed from the plantar veins; flows into the anterior and posterior tibial veins through anastomoses
Anterior Tibial Veins	Formed from the dorsal venous arch; drains the area near the tibialis anterior muscle and flows into the popliteal vein
Posterior Tibial Veins	Formed from the dorsal venous arch; drains the area near the posterior surface of the tibia and flows into the popliteal vein
Fibular Veins	Drains the muscles and integument near the fibula and flows into the popliteal vein
Popliteal Veins	Drains the region behind the knee and forms from the fusion of the fibular, anterior, and posterior tibial veins; flows into the femoral vein
Great Saphenous Veins	Prominent surface vessel located on the medial surface of the leg and thigh; drains the superficial portions of these areas and flows into the femoral vein
Femoral Veins	Drains the upper leg; receives blood from the great saphenous vein, the deep femoral vein, and the femoral circumflex vein; becomes the external iliac vein when it enters the body wall

External Iliac Veins	Formed when the femoral vein passes into the body cavity, drains the legs, and flows into the common iliac vein
Internal Iliac Veins	Drains the pelvic organs and integument; formed from several smaller veins in the region; flows into the common iliac vein
Middle Sacral Vein	Drains the sacral region and flows into the left common iliac vein
Common Iliac Veins	Flows into the inferior vena cava at the level of L5; drains the sacral region; formed from the union of the external and internal iliac veins near the inferior portion of the sacroiliac joint

Hepatic Portal System

The liver is a complex biochemical processing plant. It processes nutrients absorbed by the digestive system; produces plasma proteins, clotting factors, and bile; and disposes of worn-out cell components and waste products. Instead of entering the circulation directly, absorbed nutrients and certain wastes (for example, materials produced by the spleen) travel to the liver for processing via the **hepatic portal system**. See Figure 11.54[64] for an illustration of the hepatic portal system.

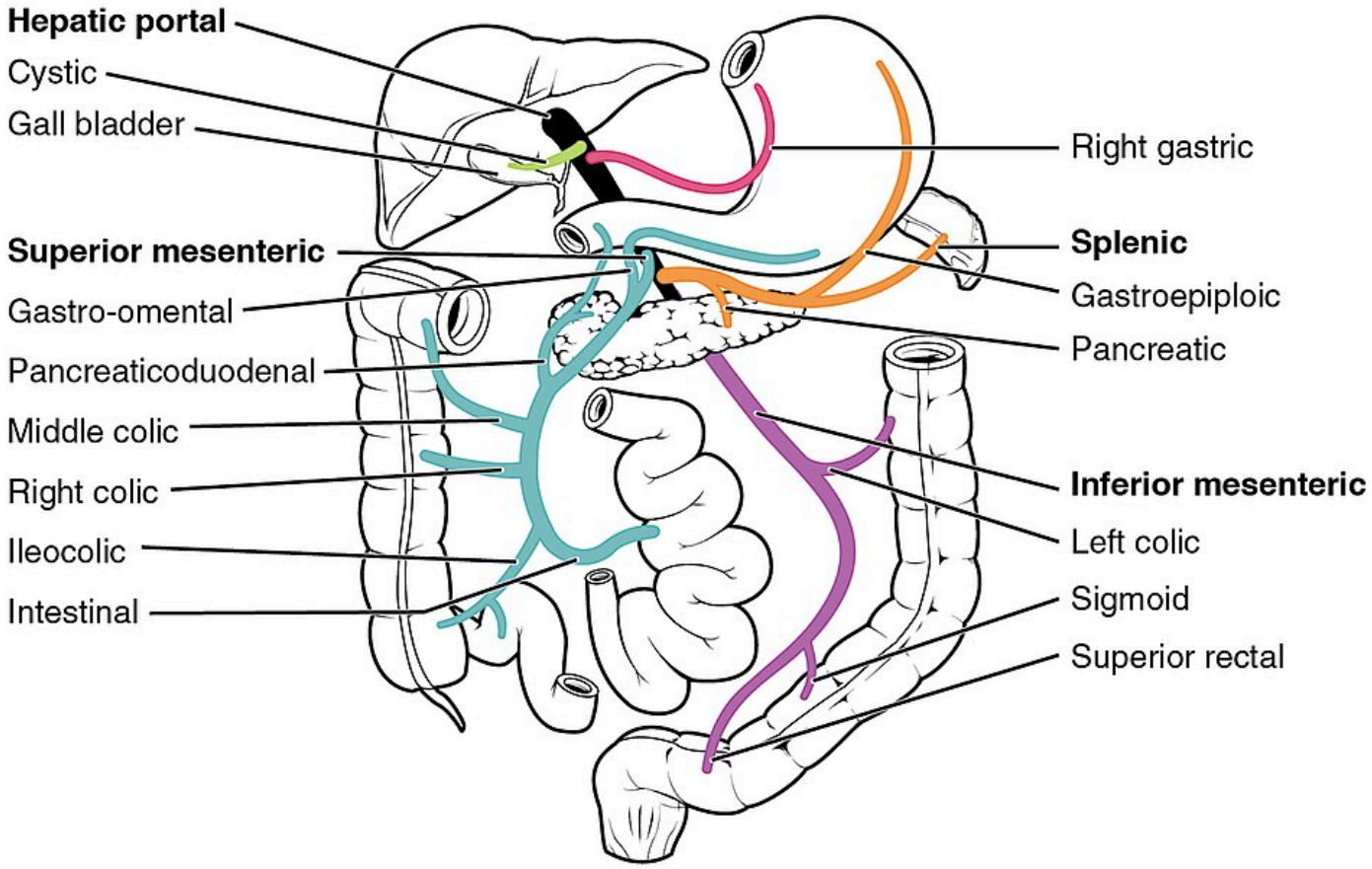


Figure 11.54 Hepatic Portal System

Portal systems begin and end in capillaries. In this case, the initial capillaries from the stomach, small intestine, large intestine, and spleen lead to the hepatic portal vein and end in specialized capillaries within the liver, the hepatic sinusoids. The hepatic portal

64. OpenStax College. (2013). *2138_Hepatic_Portal_Vein_System* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2138_Hepatic_Portal_Vein_System.jpg

vein delivers materials from these digestive and circulatory organs directly to the liver for processing.

Because of the hepatic portal system, the liver receives its blood supply from two different sources: from normal systemic circulation via the hepatic artery and from the hepatic portal vein. The liver processes the blood from the portal system to remove certain wastes and excess nutrients, which are stored for later use. This processed blood, as well as the systemic blood that comes from the hepatic artery, exits the liver via the right, left, and middle hepatic veins and flows into the inferior vena cava.[65]

Fetal Circulation

In a developing embryo, the heart develops enough by post-fertilization Day 21 to begin beating. Circulation patterns are clearly established by the fourth week of embryonic life. It is critical to the survival of the developing human that the circulatory system forms early to supply the growing tissue with nutrients and gases and to remove waste products. As the embryo grows within the mother's uterus, its requirements for nutrients and gas exchange also grow. The placenta (a circulatory organ unique to pregnancy) develops jointly from the embryo and uterine wall structures to fill this need. Emerging from the placenta is the **umbilical vein** that carries oxygen-rich blood from the mother to the fetus.

There are three major **shunts** (alternate paths for blood flow) found in the fetal circulatory system. The first two shunts are critical during fetal life when gas exchange is provided by the placenta, not the fetal lungs, which are compressed and filled with amniotic fluid. These shunts close shortly after birth when the newborn takes its first breaths. The third shunt persists a bit longer but becomes nonfunctional once the umbilical cord is severed. The three shunts are as follows:

- The **ductus venosus** is a temporary blood vessel that branches from the umbilical vein, allowing much of the freshly oxygenated blood from the mother and the placenta to bypass the immature fetal liver to flow directly to the fetal inferior vena cava and into the heart, where it is pumped into fetal circulation. The ductus venosus closes slowly during the first weeks of infancy and degenerates to become the **ligamentum venosum**.

65. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

- The **foramen ovale** is an opening in the interatrial septum that allows blood to flow from the right atrium to the left atrium and bypass the lungs because they are not required for oxygenation. A valve associated with this opening prevents backflow of blood during the fetal period. After childbirth, when the newborn begins to breathe, blood pressure in the atria increases, and this shunt closes. The **fossa ovalis** remains in the interatrial septum after birth, marking the location of the former foramen ovale.
- The **ductus arteriosus** is a short, muscular vessel that connects the pulmonary trunk to the aorta, diverting most of the blood pumped from the right ventricle into the aorta. A small amount of blood reaches the fetal lungs to supply the developing lung tissue. When a newborn takes their first breath, the lungs expand, and the pressure within the lungs drops dramatically, causing the pulmonary vessels to expand. As the amount of oxygen increases, the smooth muscles in the wall of the ductus arteriosus constrict, sealing off the passage. Eventually, the muscular and endothelial components of the ductus arteriosus degenerate, leaving only the connective tissue component of the **ligamentum arteriosum**.

Two **umbilical arteries** carry oxygen-depleted fetal blood, including wastes and carbon dioxide, to the placenta. Remnants of the umbilical arteries remain in the adult.[66]

See Figure 11.55[67] for an illustration of fetal circulation with oxygen-rich blood received from the placenta.

66. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

67. OpenStax College. (2013). *2139_Fetal_Circulation* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2139_Fetal_Circulation.jpg

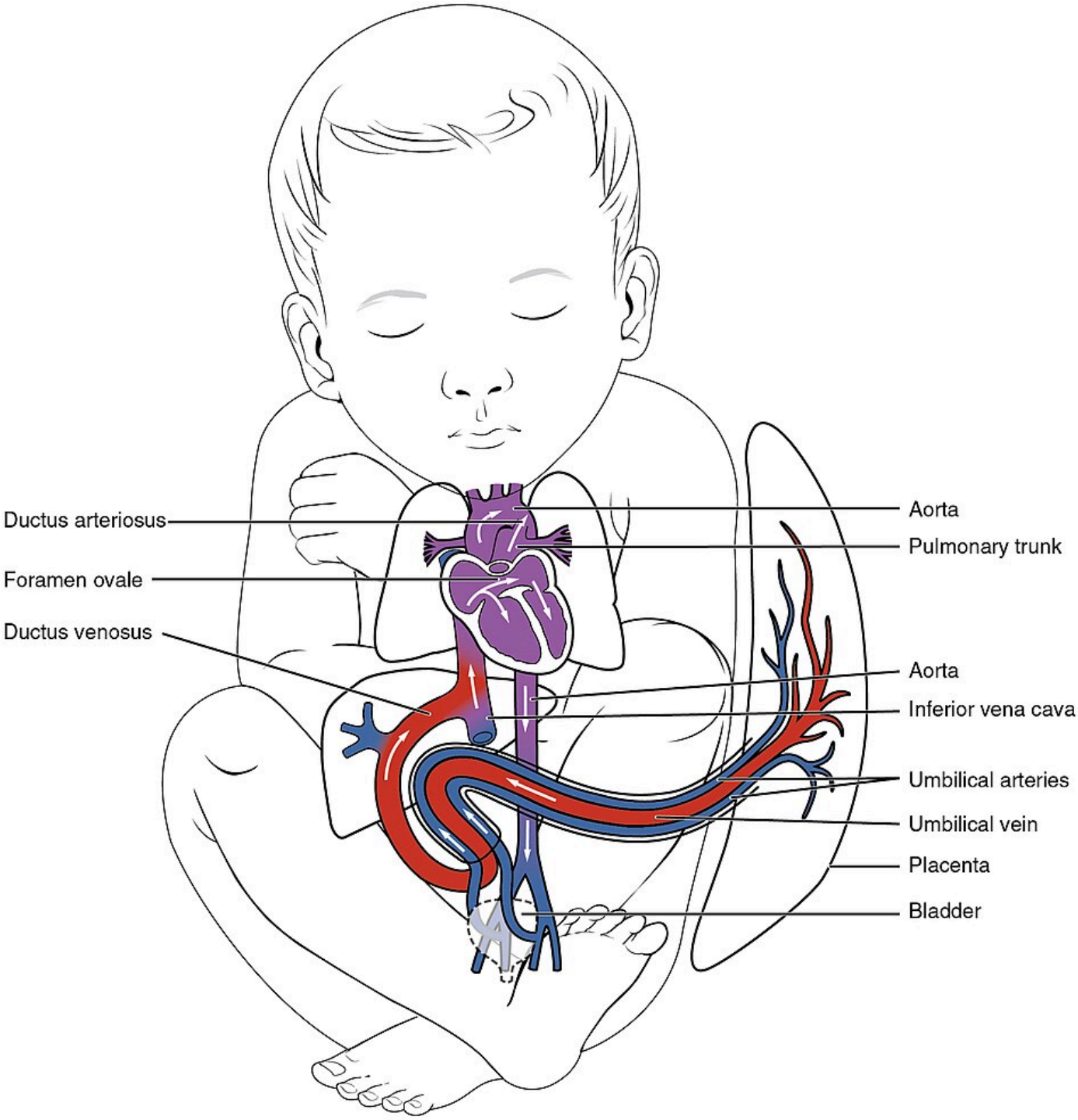


Figure 11.55 Fetal Circulation

Video

Watch the video “Blood Vessels and Circulation Explained” below to learn more about blood vessels and circulation throughout the body.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.



11.6 Cardiovascular Disorders

Aneurysm

An **aneurysm** is a weakened blood vessel wall that bulges or balloons. An aneurysm can break open, which is called a rupture. A ruptured aneurysm causes severe internal bleeding and be life-threatening. Some aneurysms cause no symptoms. Aneurysms can form in several parts of the body, including the following:[1]

- The body's main artery, called the aorta (aortic aneurysm).
- The part of the aorta that passes through the abdominal area (abdominal aortic aneurysm).
- The part of the aorta that passes through the chest (thoracic aortic aneurysm).
- Blood vessels that send blood to the brain (brain aneurysm).
- Blood vessels in other parts of the body, such as the legs, groin, or neck (peripheral aneurysm).

Depending on the location, small aneurysms with low risk of rupture may be monitored with regular health checkups and imaging tests. Treatment of aneurysms may involve open surgery or a less invasive treatment called endovascular surgery. However, if an aneurysm ruptures, a life-threatening hemorrhage can occur, requiring emergency surgery for survival.[2]

Arrhythmias

An **arrhythmia** is an abnormal heart rhythm due to disrupted electrical activity of the conduction system. Arrhythmias can be diagnosed by an electrocardiogram or the use of a Holter monitor. Examples of common arrhythmias are atrial fibrillation, heart block, ventricular tachycardia, and ventricular fibrillation.

1. Ernstmeyer, K., & Christman, E. (Eds.). (2025). *Nursing health promotion*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthpromo/
2. Mayo Clinic. (2025). *Aneurysms*. https://www.mayoclinic.org/diseases-conditions/aneurysms/symptoms-causes/syc-20354633

- **Atrial fibrillation (A-Fib)** is characterized by atrial quivering instead of contracting. Atrial fibrillation can cause a decrease in the volume of blood leaving the heart with each heartbeat because the ventricles do not completely fill with blood before contracting. Individuals with atrial fibrillation may be asymptomatic or have palpitations, decreased blood pressure, or shortness of breath. Atrial fibrillation also increases the risk of a cerebrovascular accident (stroke).
- **Heart block** refers to a disruption in the normal conduction pathway of electrical signals through the atria and ventricles. Heart block can vary in severity from first-degree heart block, which is the least severe and often has no symptoms, to third-degree heart block, which can be life-threatening. Symptoms of heart block may include bradycardia, missed heartbeats, fatigue, dizziness, chest pain, and shortness of breath.
- **Ventricular tachycardia (V Tach)** refers to a very rapid heartbeat that originates in the ventricles.
- **Ventricular fibrillation (V Fib)** is a disorganized heart rhythm that causes the ventricles to quiver instead of contract. Ventricular tachycardia and ventricular fibrillation are life-threatening arrhythmias that require rapid emergency response and the use of a defibrillator to resolve the abnormal rhythm.[3,4]

  See Figure 11.56[5] for EKG tracings of common arrhythmias.

3. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical Terminology 2e.* Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/

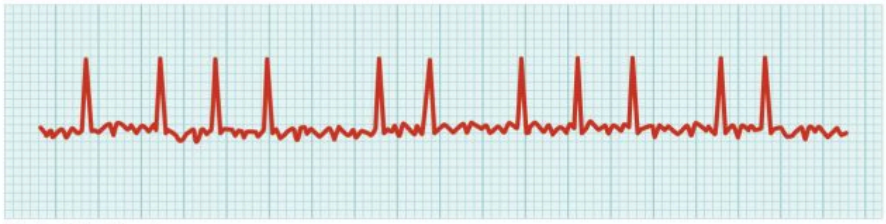
4. Desai, D. S., & Hajouli, S. (2023). *Arrhythmias*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK558923/

5. OpenStax College. (2013). *2024_Cardiac_Arrhythmias* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2024_Cardiac_Arrhythmias.jpg



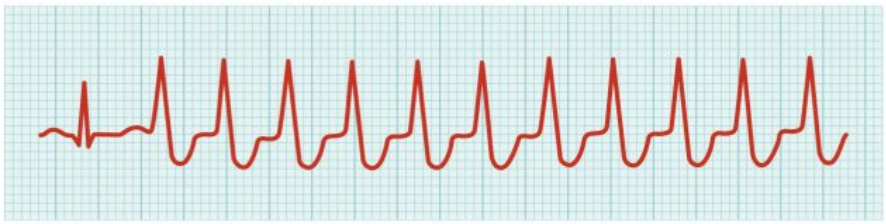
(a) Second-degree (partial) block

Note how half of the P waves are not followed by the QRS complex and T waves while the other half are.
Question: What would you expect to happen to heart rate (pulse)?



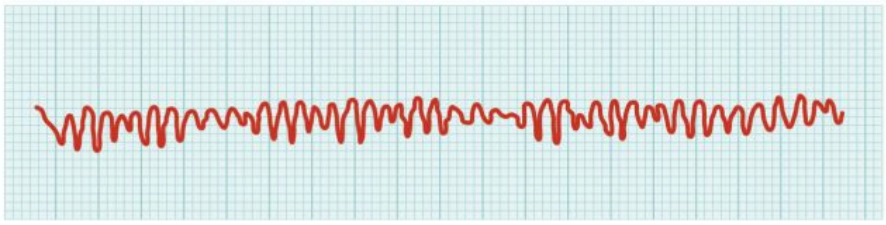
(b) Atrial fibrillation

Note the abnormal electrical pattern prior to the QRS complexes. Also note how the frequency between the QRS complexes has increased.
Question: What would you expect to happen to heart rate (pulse)?



(c) Ventricular tachycardia

Note the unusual shape of the QRS complex, focusing on the "S" component.
Question: What would you expect to happen to heart rate (pulse)?



(d) Ventricular fibrillation

Note the total lack of normal electrical activity.
Question: What would you expect to happen to heart rate (pulse)?



(e) Third-degree block

Note that in a third-degree block some of the impulses initiated by the SA node do not reach the AV node while others do. Also note that the P waves are not followed by the QRS complex.
Question: What would you expect to happen to heart rate (pulse)?

Figure 11.56 EKG Tracings of Common Arrhythmias

Arteriosclerosis and Atherosclerosis

Arteriosclerosis and atherosclerosis are interrelated cardiovascular conditions that can significantly impact a person's cardiovascular health. **Arteriosclerosis** refers to the

thickening and stiffening of arterial walls that is commonly associated with normal aging. The subsequent loss of elasticity of blood vessels makes them less responsive to changes in blood flow and can reduce blood flow to organs and tissues within the body.[6]

Atherosclerosis is a condition where cholesterol, low-density lipoprotein (LDL) deposits, and wastes build up within the lining of the arteries. It begins after injury to the endothelium (inner lining) of an artery, often caused by tobacco use, hypertension, high blood glucose levels, infection, excessive blood lipids, or other factors. Artery walls that are constantly stressed by blood flowing at high pressure are more likely to be injured. This buildup of substances within the vessel walls, called plaque, creates inflammation and can cause blockage of the artery[7]

Atherosclerosis of the coronary arteries leads to coronary artery disease. See Figure 11.57[8] for an illustration of atherosclerosis.

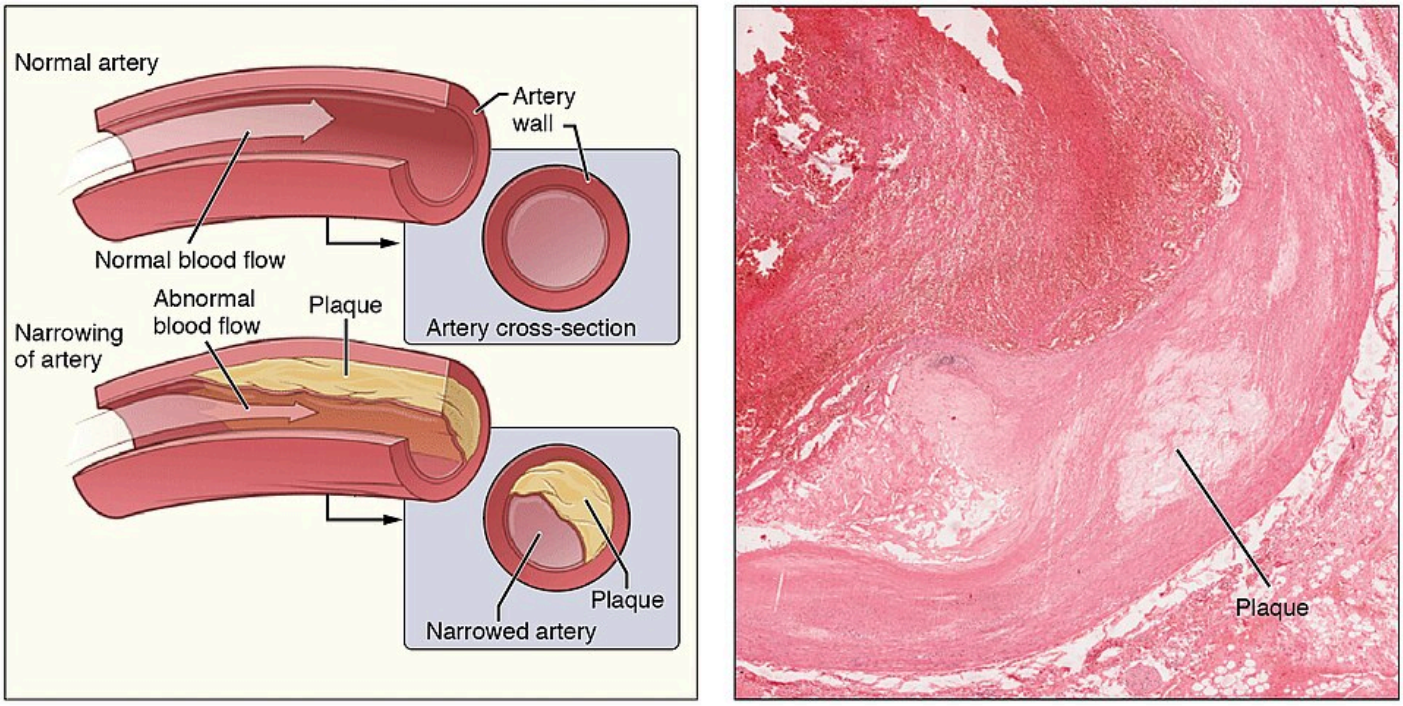


Figure 11.57 Atherosclerosis

6. Ernstmeyer, K., & Christman, E. (Eds.). (2025). *Nursing health promotion*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthpromo/
7. Ernstmeyer, K., & Christman, E. (Eds.). (2025). *Nursing health promotion*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthpromo/
8. OpenStax College. (2013). *2113ab_Atherosclerosis* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2113ab_Atherosclerosis.jpg

While the two conditions are interrelated, one can occur without the other. For instance, someone may have arteriosclerosis but not have atherosclerosis. However, atherosclerosis is a specific type of arteriosclerosis, meaning that if atherosclerosis is present, there is also thickening and stiffening of arterial walls in addition to the build-up of plaque.[9]

Broken Heart Syndrome

Extreme stress from life events such as the death of a loved one, break up of a relationship, loss of a job, or foreclosure of a home can lead to a condition commonly referred to as **broken heart syndrome**, also known as Takotsubo cardiomyopathy, transient apical ballooning syndrome, apical ballooning cardiomyopathy, stress-induced cardiomyopathy, and Gebrochenes-Herz syndrome.

The effects on the heart include profound weakening of the myocardium that can lead to lethal arrhythmias, acute heart failure, or rupture of a ventricle. The exact cause of this syndrome is not known, but several factors have been suggested, including transient vasospasm, dysfunction of the cardiac capillaries, or thickening of the myocardium—particularly in the left ventricle—that may lead to a lack of critical circulation of blood to this region.

With treatment to restore normal function, many patients survive the initial acute event, but there is a strong correlation with death. Research revealed that within one year of the death of a loved one, women are more than twice as likely to die, and men are six times as likely to die than would otherwise be expected. The same study indicated that long-term relationships had a greater incidence of a person dying soon after the death of their spouse.[10]

Cardiac Tamponade

If excess fluid builds up within the pericardial space, it can lead to a condition called

9. Mayo Clinic. (n.d.). *Arteriosclerosis/Atherosclerosis*. https://www.mayoclinic.org/diseases-conditions/arteriosclerosis-atherosclerosis/symptoms-causes/syc-20350569

10. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

cardiac tamponade, also called pericardial tamponade. With each contraction of the heart, more fluid accumulates within the pericardial cavity. To fill with blood for the next contraction, the heart must relax. However, the excess fluid in the pericardial cavity puts pressure on the heart and prevents full relaxation, so the chambers within the heart contain less blood as they begin each heart cycle. Over time, less and less blood is ejected from the heart.

If the fluid builds up slowly, the pericardial cavity may be able to expand gradually to accommodate this extra volume. However, rapid accumulation of as little as 100 mL of fluid following trauma may trigger cardiac tamponade. Common causes of cardiac tamponade include pericarditis, cancer, and cardiac surgery. Usually, a needle is inserted into the pericardial cavity to remove the excess fluid. If left untreated, cardiac tamponade can be fatal.[11]

Congenital Heart Defects

Congenital heart defects are structural abnormalities in the heart or blood vessels that are present at birth and affect how blood flows through the heart and out to the rest of the body. Heart defects can vary from mild (such as a small hole in the heart) to severe (such as missing parts of the heart). In the United States, heart defects affect 1% of births annually, or about 40,000 infants. Of those infants born with a heart defect, about 25% have a severe heart defect requiring surgery or other procedures in the first year of life.[12] Common congenital heart defects are illustrated in Figure 11.58.[13] These conditions are further described in the following subsections.

11. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

12. Medstar Health. (2025). *Patent foramen ovales and atrial septal defects.* https://www.medstarhealth.org/services/patent-foramen-ovale-atrial-septal-defects-treatments

13. OpenStax College. (2013). *2009_Congenital_Heart_Defects* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2009_Congenital_Heart_Defects.jpg

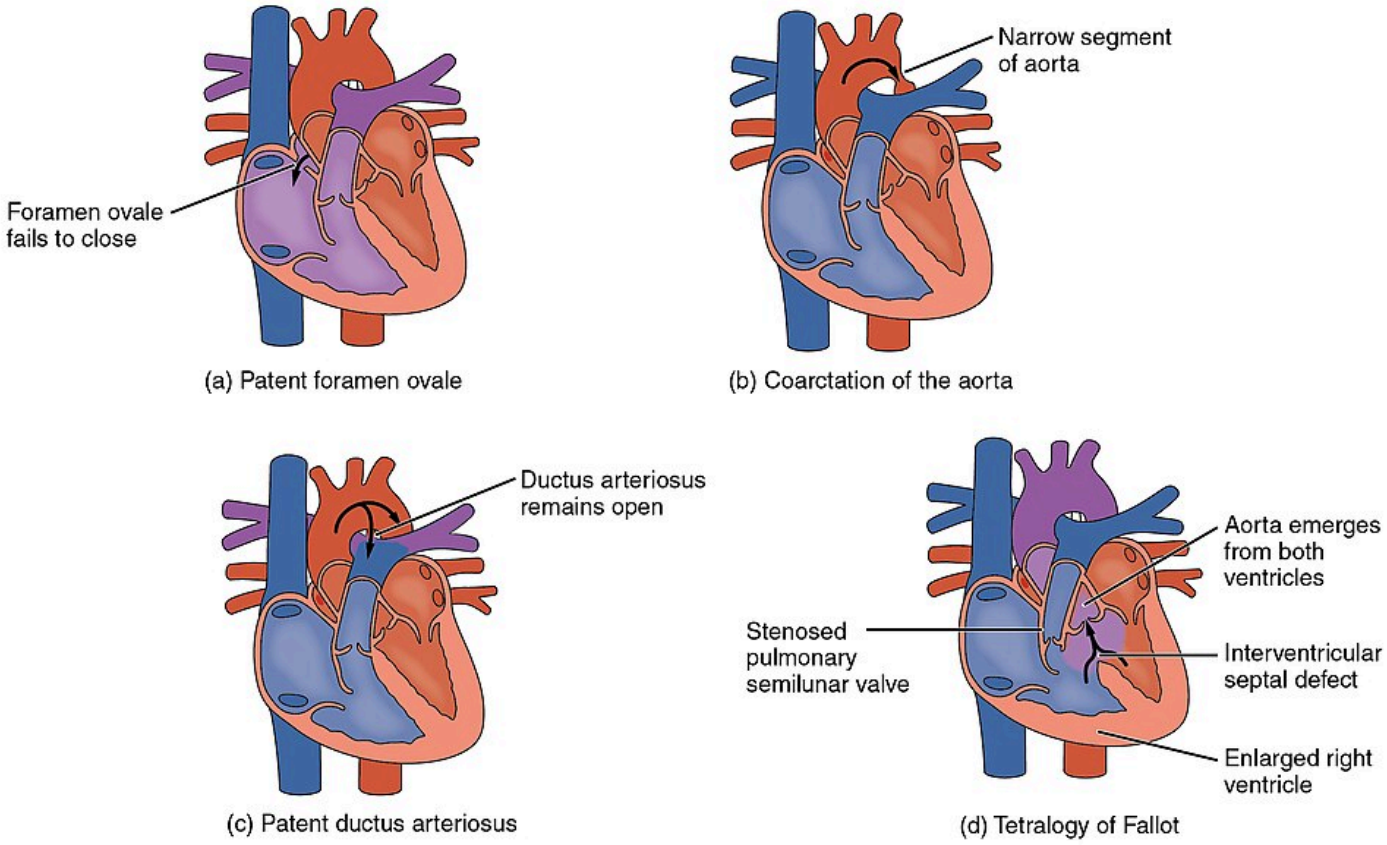


Figure 11.58 Congenital Heart Defects: (a) Patent Foramen Ovale, (b) Coarctation of the Aorta, (c) Patent Ductus Arteriosus, and (d) Tetralogy of Fallot

Patent Foramen Ovale and Atrial Septal Defect

Patent foramen ovale (PFO) is a common congenital heart defect that occurs when the fossa ovalis in the interatrial septum, which is present during fetal circulation, does not fuse after birth. The word *patent* is from the Latin root *patens*, meaning "open." PFO allows oxygenated blood to flow backwards from the left atrium into the right atrium. Small PFOs are typically asymptomatic. As many as 15-25% adults have PFOs that are found incidentally on diagnostic tests for other conditions or on autopsy.[14]

An atrial septal defect (ASD) is an abnormal opening between the atria. ASDs and PFOs are typically detected by auscultation of a heart murmur (a blowing or whooshing sound that signifies turbulent blood flow). The diagnosis is confirmed through diagnostic imaging with an echocardiogram. Benign (asymptomatic) defects are

14. Medstar Health. (2025). *Patent foramen ovales and atrial septal defects*. https://www.medstarhealth.org/services/patent-foramen-ovale-atrial-septal-defects-treatments

generally monitored, while symptomatic defects affecting oxygenation status typically require surgical repair.[15]

Coarctation of the Aorta

Coarctation of the aorta is a congenital abnormal narrowing of the aorta that is normally located at the insertion of the ligamentum arteriosum, the remnant of the fetal shunt called the ductus arteriosus. If severe, this condition drastically restricts blood flow through the aorta and is life-threatening. In some individuals, the condition may be fairly benign and not detected until later in life. Detectable symptoms in an infant include difficulty breathing, poor appetite, trouble feeding, and poor weight gain. In older individuals, symptoms include dizziness, fainting, shortness of breath, chest pain, fatigue, headache, and nosebleeds. Treatment involves surgery to resect (remove) the narrowed region or angioplasty to open the abnormally narrow passageway. Studies have shown that the earlier the surgery is performed, the better the chance of survival.[16]

Patent Ductus Arteriosus

Patent ductus arteriosus (PDA) is a congenital condition in which the ductus arteriosus fails to close at birth. Recall that the ductus arteriosus is a normal shunt in fetal circulation to connect the pulmonary trunk to the aorta, causing most of the circulating oxygenated blood to bypass the fetal lungs. As the newborn takes its first breaths and the lungs expand, the vascular resistance and lung pressure abruptly decrease, normally causing the ductus arteriosus to constrict and close. However, when a PDA is present, the opening continues to exist between the aorta and the pulmonary trunk, causing oxygen-rich blood from the aorta to flow backwards into the pulmonary trunk. This additional fluid moving toward the lungs increases pulmonary pressure and can impact respiration. Small PDAs often close on their own and are asymptomatic. Larger PDAs are often symptomatic and require treatment. Symptoms may include dyspnea (shortness of breath), tachycardia (fast heart rate), enlarged heart, and poor weight gain in infants. Treatments include surgical closure (ligation), manual closure using

15. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

16. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

platinum coils or specialized mesh inserted via the femoral artery or vein, or nonsteroidal anti-inflammatory drugs to block the synthesis of prostaglandin E2, which maintains the vessel in an open position. If untreated, the condition can result in pulmonary congestion and heart failure.[17,18]

Tetralogy of Fallot

Tetralogy of Fallot (ToF) is a complex set of congenital heart defects that occurs in approximately 400 out of one million live births. The term *tetralogy* is derived from the four components associated with the condition, although only three may be present to be diagnosed with the disorder. The four components include pulmonary stenosis (rigidity or stenosis of the pulmonary valve), a large ventricular septal defect (opening between the ventricles), an overriding aorta (the aorta is shifted above both ventricles and centered over the ventricular septal defect), and right ventricular hypertrophy (enlargement of the right ventricle). The components of ToF cause multiple effects. Pulmonary stenosis makes it difficult for blood to flow from the right ventricle into the lungs, causing increased pressure inside the right ventricle. This causes the right ventricle to work harder to pump blood, causing right ventricular hypertrophy that can lead to heart failure. It also causes deoxygenated blood from the right ventricle to move through the ventricular septal defect into the left ventricle. Because the aorta is located between the ventricles and over the ventricular septal defect, oxygenated blood from the left atrium mixes with deoxygenated blood from the right ventricle, and this partially oxygenated blood moves through the aorta and to the rest of the body, causing hypoxia and cyanosis.[19,20]

Symptoms include a distinct heart murmur; low blood oxygen saturation; dyspnea or difficulty in breathing; polycythemia; broadening (clubbing) of the fingers and toes; and, in children, difficulty in feeding or failure to grow and develop. It is the most common cause of cyanosis following birth. A pulse oximetry screening tool is routinely used in hospitals after birth to detect signs of critical congenital heart defects (CCHD) such as

17. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

18. Centers for Disease Control and Prevention. (n.d.). *About congenital heart defects.* https://www.cdc.gov/heart-defects/about/index.html

19. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

20. Doyle, T., & Kavanaugh-McHugh, A. (2023). Tetralogy of Fallot (TOF): Management and outcome. *UpToDate*. https://www.uptodate.com/contents/tetralogy-of-fallot-tof-management-and-outcome

ToF. During this screening test, pulse oximetry is performed at 24 hours of age on the right hand (preductal) and either foot (postductal). If both readings are greater than or equal to 95% and there is no more than a 3% difference between the two readings, the infant is at less risk for ToF. ToF is diagnosed by echocardiography (ultrasound of the heart).[21,22]

Treatment involves extensive surgical repair, including the use of stents to redirect blood flow, replacement of valves, and patches to repair the septal defect. Surgical repair results in excellent long-term survival in the United States, with over 90% survival rates for individuals 25 years after repair. However, heart failure and arrhythmias are common long-term consequences that can lead to death.[23]

Blue Baby

Cyanotic heart defects such as Tetralogy of Fallot involve right-to-left shunting of blood through the heart, which causes deoxygenated blood from the venous system to bypass transport to the lungs and is pumped through the aorta to the arterial system. Recall that in a normal heart, blood flows from the right ventricle to the lungs, where it is oxygenated and then returns to the left atrium and left ventricle, where it is pumped through the aorta to the rest of the body. When a cyanotic defect is present, poorly oxygenated blood is pumped to the body, causing decreased blood oxygen saturation levels, organ and tissue hypoxia, and cyanosis. Because the blood bypasses the lungs, oxygen administration does little to improve oxygen saturation levels. Cyanosis manifests as a bluish color to the lips, fingers, and toes of an infant or child and may occur at rest or with activity, depending on the severity of the heart defect. As such, the term “blue baby” has been used to describe children with cyanotic heart defects.[24,25]

21. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

22. Centers for Disease Control and Prevention. (n.d.). *About congenital heart defects.* https://www.cdc.gov/heart-defects/about/index.html

23. Doyle, T., & Kavanaugh-McHugh, A. (2023). Tetralogy of fallot (TOF): Management and outcome. *UpToDate*. https://www.uptodate.com/contents/tetralogy-of-fallot-tof-management-and-outcome

24. Centers for Disease Control and Prevention. (n.d.). *About congenital heart defects.* https://www.cdc.gov/heart-defects/about/index.html

25. U.S. National Library of Medicine. (2023). *Cyanotic heart disease*. MedlinePlus. https://medlineplus.gov/ency/article/001104.htm

Coronary Artery Disease

Coronary artery disease (CAD) is the leading cause of death worldwide. It occurs when the buildup of **plaque**, a fatty material including cholesterol, connective tissue, white blood cells, and smooth muscle cells, obstructs blood flow within coronary arteries and decreases compliance of the vessels. This condition is called atherosclerosis. As the coronary blood vessels become occluded, the flow of oxygenated blood is restricted, resulting in the cardiac muscle cells receiving insufficient oxygen, a condition called ischemia. Some individuals with coronary artery disease report the development of chest pain on exertion called angina pectoris. If left untreated, coronary artery disease can cause a myocardial infarction (heart attack), resulting in the death of cardiac cells that can seriously impair heart function. See Figure 11.59[26] for an image of blockages of coronary arteries highlighted by the injection of dye.

26. OpenStax College. (2013). *2016_Occluded_Coronary_Arteries* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2016_Occluded_Coronay_Arteries.jpg

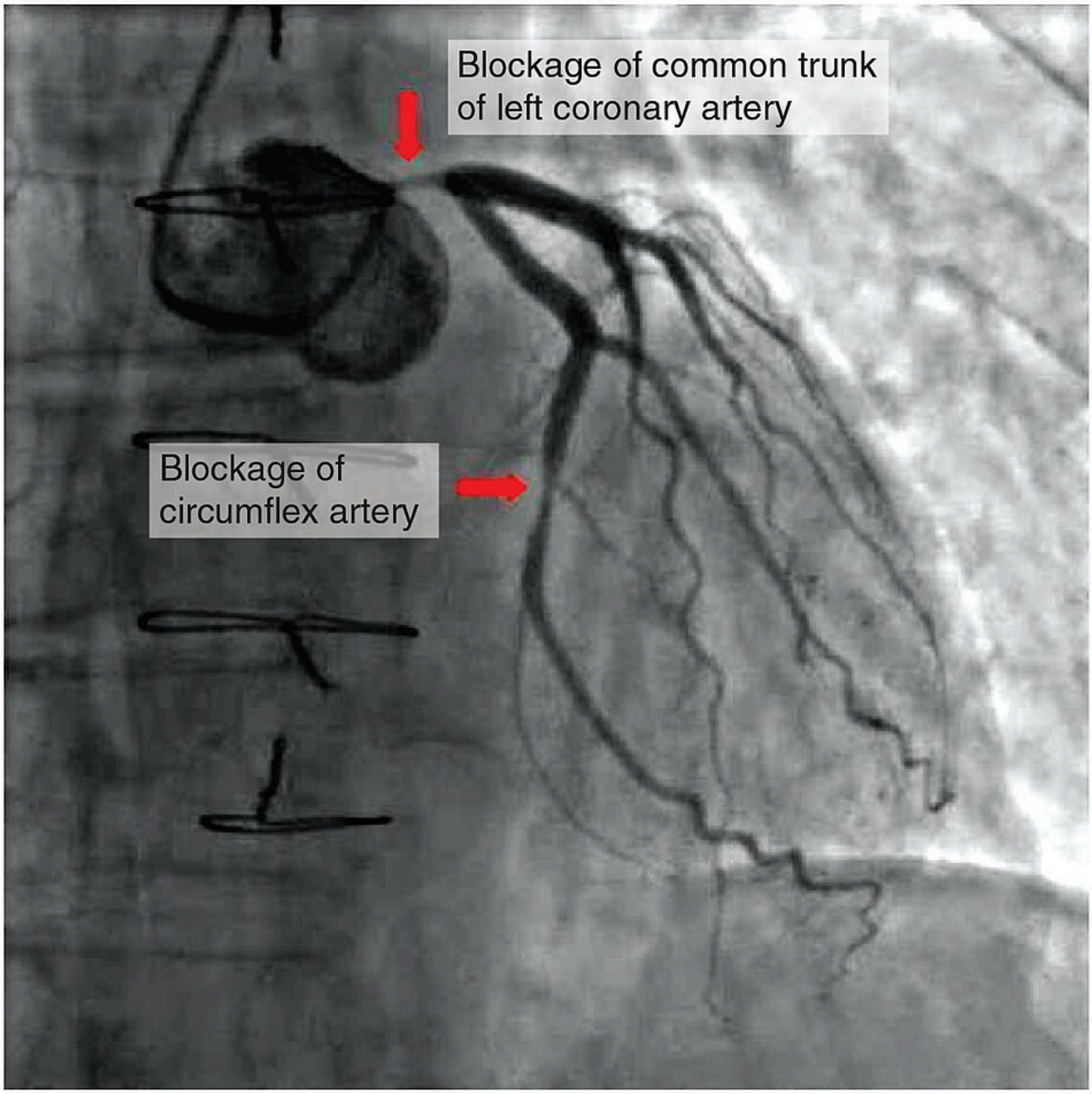


Figure 11.59 Atherosclerotic Coronary Arteries

Coronary artery disease develops slowly as fatty “streaks” in the vessels gradually progress throughout life. Risk factors include family history, smoking, hypertension, obesity, diabetes, alcohol consumption, lack of exercise, stress, and hyperlipidemia (high circulating levels of lipids in the blood). Early treatment often begins with lifestyle changes such as making healthy diet choices, stopping smoking, engaging in regular

exercise, and taking medications to reduce blood pressure, blood glucose, and lipid levels.[27]

Surgical treatment of coronary artery disease includes angioplasty and insertion of a stent, or coronary artery bypass graft surgery. **Angioplasty** is a procedure in which the occlusion caused by plaque is mechanically widened with a balloon. A specialized catheter with an expandable tip is inserted into a vessel, in the leg or arm, and then directed to the site of the occlusion, where the balloon is inflated to compress the plaque and open the vessel to increase blood flow. A stent consisting of a specialized mesh is typically inserted at the site of occlusion to reinforce the weakened and damaged walls. Coronary artery bypass graft (CABG) surgery uses a replacement vessel to bypass the occluded area.[28]

Edema

Despite the presence of valves in veins, some blood will inevitably pool in the lower limbs over the course of a day due to the pull of gravity. Blood that accumulates in a vein will increase the pressure within it, which is reflected into the smaller veins, venules, and eventually even the capillaries. Increased pressure promotes the flow of fluids out of the capillaries and into the interstitial fluid. The presence of excess tissue fluid around the cells leads to a condition called **edema**.[29]

Most people experience a daily accumulation of tissue fluid, especially if they spend much of their work life on their feet (such as health professionals). However, edema goes beyond normal swelling and requires medical treatment. Edema has many potential causes, such as heart failure, kidney failure, and severe protein deficiency. Edema is commonly managed with compression stockings and medications called diuretics that cause the kidneys to excrete additional salt and fluid.[30]

27. Ernstmeyer, K., & Christman, E. (Eds.). (2025). *Nursing health promotion*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthpromo/

28. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

29. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

30. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Heart Failure

Heart failure (HF) occurs when the heart loses its effectiveness in pumping blood and is referred to as decreased cardiac output. When the heart is not pumping effectively, classic symptoms of fatigue, shortness of breath, edema, or lung congestion can occur. Signs and symptoms can also vary based on whether the right or left side of the heart is affected.

There are many common causes of HF, including coronary artery disease, myocardial infarction (MI), hypertension, valve disorders, and cardiomyopathy. Common tests used to diagnose heart failure include brain natriuretic peptide (BNP), chest X-ray (CXR), echocardiogram, and electrocardiogram (ECG).

Common medical interventions used to treat HF include medication therapy, lifestyle modifications, cardiac rehabilitation, and surgical interventions.[31]

Hypertension

Normal blood pressure in an adult is defined as less than 120/80 mm Hg. **Hypertension** refers to chronically elevated blood pressure greater than 120/80 mm Hg. Hypertension is very common, affecting millions of individuals worldwide. There are several classifications of blood pressure based on the systolic and diastolic readings. See Table 11.6 for current classifications of hypertension according to the American Heart Association.[32,33]

Table 11.6. Classifications of Hypertension

31. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Nursing health alterations*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthalts/

32. Ernstmeyer, K., & Christman, E. (Eds.). (2025). *Nursing health promotion*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthpromo/

33. Basile, J., & Bloch, M. J. (2023). Overview of hypertension in adults. *UpToDate*. https://www.uptodate.com/contents/overview-of-hypertension-in-adults

Blood Pressure Classification	Systolic (mm Hg)	Diastolic (mm Hg)
Normal	Less than 120	Less than 80
Elevated (Prehypertension)	120–129	Less than 80
Hypertension Stage 1	130–139	80–89
Hypertension Stage 2	140 or higher	90 or higher
Hypertension Stage 3	Higher than 180	Higher than 120

Primary hypertension is the most common type of hypertension and has no identifiable cause. It typically develops gradually over time and is influenced by various risk factors such as genetics, age, race, diet, lifestyle, and stress. Hypertension is typically a silent disorder, meaning many individuals with hypertension have no symptoms and are unaware of the condition until they have an elevated blood pressure reading. Untreated hypertension can lead to significant health complications such as myocardial infarction (heart attack), heart failure, cerebrovascular accident (stroke), vision loss, and kidney damage.[34]

Lifestyle changes are often the first step in hypertension management and can be effective in lowering blood pressure. Recommendations include a heart-healthy, low-salt diet; regular physical activity; weight loss; and smoking cessation. Antihypertensive medications are prescribed to control blood pressure if lifestyle modifications alone are insufficient.[35,36]

Heart Valve Disorders

If heart valves do not function properly, they can result in valvular heart disease that can range from asymptomatic to life-threatening. Valvular heart disease can be **congenital**, meaning the individual was born with the defect, whereas others may be attributed to disease processes or trauma. Valvular disorders are often caused by carditis (inflammation of the heart) that is commonly triggered by rheumatic fever. Rheumatic fever is an autoimmune response to an untreated bacterial infection with *Streptococcus pyogenes,* the organism that causes a condition commonly called "strep throat."

When a valve malfunctions, the flow of blood is disrupted and is often described as insufficiency. The specific type of insufficiency is named for the valve involved: aortic insufficiency, mitral insufficiency, tricuspid insufficiency, or pulmonary insufficiency.

If one of the cusps of the valve is forced backward by the force of the blood, the condition is referred to as a prolapsed valve. Prolapse may occur if the chordae tendineae are damaged or broken, causing the closure mechanism to fail.

34. Ernstmeyer, K., & Christman, E. (Eds.). (2025). *Nursing health promotion*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthpromo/

35. Ernstmeyer, K., & Christman, E. (Eds.). (2025). *Nursing health promotion*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthpromo/

36. Basile, J., & Bloch, M. J. (2023). Overview of hypertension in adults. *UpToDate*. https://www.uptodate.com/contents/overview-of-hypertension-in-adults

The failure of the valve to close properly disrupts the normal one-way flow of blood and results in regurgitation, when the blood flows backward from its normal path. The disrupted flow of blood produces a heart murmur that can be heard on auscultation with a stethoscope. **Mitral regurgitation** is the most common valve disorder, detected in approximately 2% of the population.

Valvular stenosis is a condition in which the heart valves become rigid and may calcify over time. The loss of flexibility of the valve interferes with normal function and may cause the heart to work harder to propel blood through the valve, which eventually weakens the heart. Aortic stenosis affects approximately 2% of the population over 65 years of age, and the percentage increases to approximately 4% in individuals over 85 years.

If a heart valve disorder is suspected, an echocardiogram is performed for diagnosis of the disorder. Treatment for heart valve disorders can range from lifestyle changes and medications to surgical repair or replacement, depending on the severity and type of valve disease.[37]

Myocardial Infarction

Myocardial infarction (MI) is the medical term for what is commonly known as a heart attack. An MI results from a lack of oxygenated blood flow (ischemia) to a region of the heart's myocardium, resulting in death of the cardiac muscle cells. An MI often occurs when a coronary artery is blocked by the buildup of atherosclerotic plaque that consists of lipids, cholesterol, fatty acids, and white blood cells. An MI can also occur when a piece of an unstable atherosclerotic plaque travels through the coronary arterial system and lodges in one of the smaller vessels. The resulting blockage restricts the flow of blood and oxygen to the myocardium and causes death of the tissue.[38]

Modifiable risk factors for MI include high blood pressure, high cholesterol, smoking, obesity, physical inactivity, and diets high in saturated fats, trans fats, sodium, and refined sugars. Chronic stress and excessive alcohol consumption can also play a role in the development of coronary artery disease. There are also numerous nonmodifiable

37. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

38. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

risk factors for coronary artery disease. The risk of coronary artery disease increases with age; men over the age of 45 and women over the age of 55 are at higher risk. Family history and genetics are also nonmodifiable risk factors, especially if a patient has a first-degree relative who has been diagnosed with coronary artery disease or had a myocardial infarction at a young age. Specific ethnic groups, such as African Americans, are also at higher risk for the development of cardiovascular disease.[39,40]

During an MI, the individual may experience sudden pain deep to the sternum (retrosternal pain) called angina pectoris, often radiating down the left arm or into the jaw. Additional symptoms of MI may include dyspnea (shortness of breath), palpitations (irregular heartbeat), diaphoresis (sweating), nausea and vomiting, anxiety, and fainting (syncope). However, females may not have these classic symptoms but simply experience vague symptoms of fatigue, indigestion, and anxiety. Until this anomaly between the sexes was discovered, many female patients suffering MIs were misdiagnosed with indigestion and sent home from the emergency room without treatment.[41] See Figure 11.60[42] for an illustration of the symptoms of an MI.

39. Ernstmeyer, K., & Christman, E. (Eds.). (2025). *Nursing health promotion*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthpromo/

40. Ojha, N., & Dhamoon, A. S. (2023). *Myocardial infarction*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK537076/

41. Ernstmeyer, K., & Christman, E. (Eds.). (2025). *Nursing health promotion*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthpromo/

42. Myupchar.com. (2019). *Depiction of a person suffering from a heart attack(Myocardial Infarction)* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Depiction_of_a_person_suffering_from_a_heart_attack_(Myocardial_Infarction).png

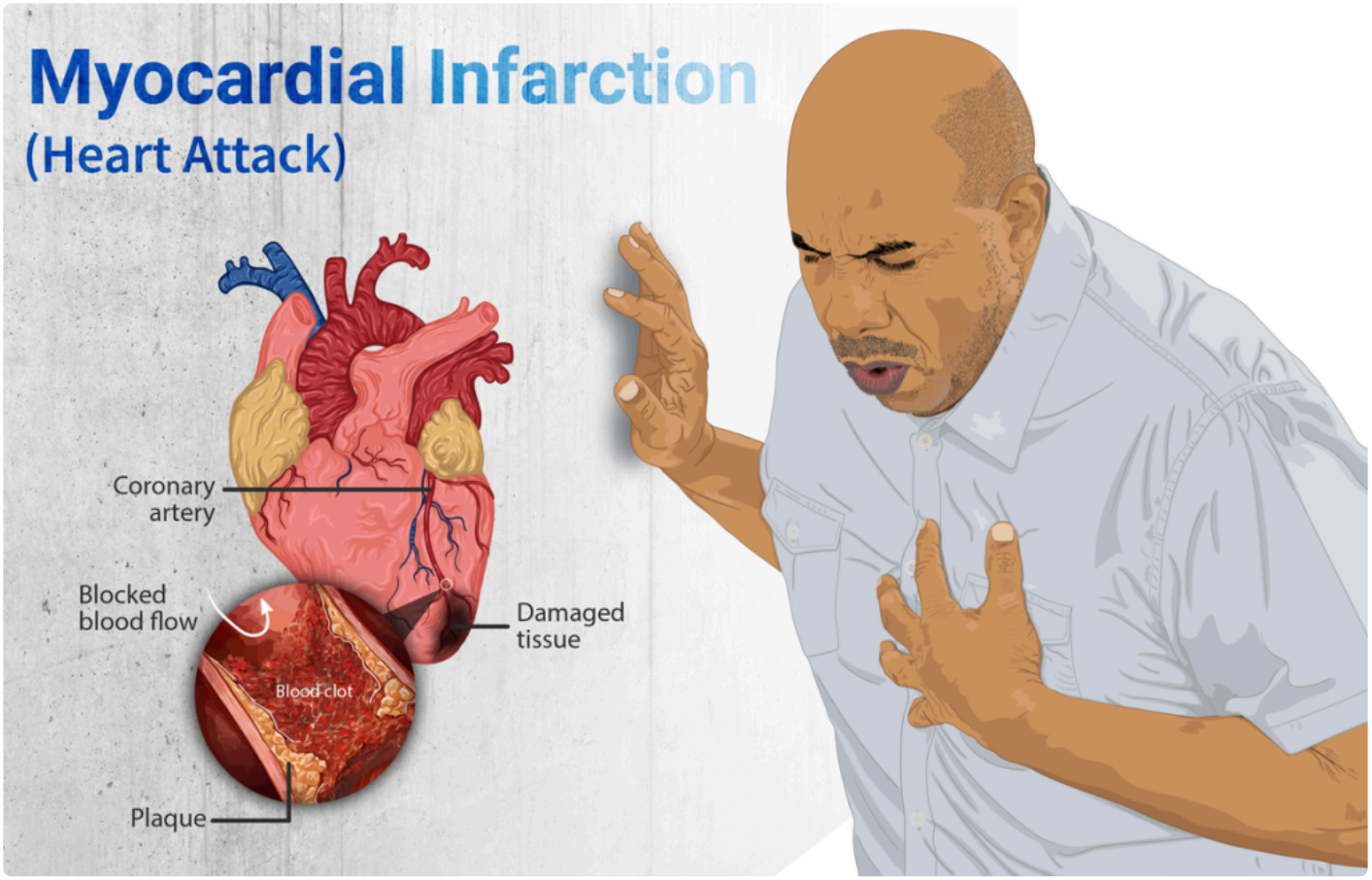


Figure 11.60 Symptoms of a Myocardial Infarction

Immediate emergency treatment for MI is essential and includes aspirin to reduce clot formation, nitroglycerin to dilate the coronary arteries and improve blood flow to the heart tissue, and administration of supplementary oxygen as indicated. Intravenous heparin is typically administered to prevent the clot from enlarging. Emergent revascularization procedures, such as angioplasty, stenting, or coronary artery bypass graft (CABG) surgery, are typically performed if vessel occlusion is significant. If revascularization procedures cannot be performed within a few hours, thrombolytic agents may be administered to dissolve the clot.[43,44] Read more about these procedures under the "Coronary Artery Disease" subsection.

43. Ernstmeyer, K., & Christman, E. (Eds.). (2025). *Nursing health promotion*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthpromo/

44. Ojha, N., & Dhamoon, A. S. (2023). *Myocardial Infarction*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK537076/

Pericarditis

Pericarditis is swelling and irritation of the pericardium, the thin, saclike tissue surrounding the heart. Pericarditis often causes sharp, stabbing chest pain when the irritated layers of the pericardium rub against each other. The pain often worsens when breathing deeply or lying down, but improves when sitting up or leaning forward. Pericarditis is typically caused by a viral infection, but is also associated with autoimmune disorders such as rheumatoid arthritis or lupus. Pericarditis often resolves on its own with rest, but treatment may be required for severe cases to prevent complications such as pericardial effusion that can lead to cardiac tamponade.[45]

Peripheral Artery Disease

Peripheral artery disease (PAD) is caused by atherosclerosis, with narrowed or blocked arteries, causing reduced oxygenated blood flow to the lower extremities. Risk factors for peripheral artery disease are similar to those for atherosclerosis and include smoking, hypertension, high cholesterol, and inflammation. Additional risk factors include age and a history of diabetes or previous injuries or trauma to arterial vessels.

See Figure 11.61[46] for an illustration of PAD.

45. Mayo Clinic. (2024). *Pericarditis*. https://www.mayoclinic.org/diseases-conditions/pericarditis/symptoms-causes/syc-20352510

46. National Heart, Lung, and Blood Institute. (2013). *Peripheral_Arterial_Disease* [Diagram]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Peripheral_Arterial_Disease.gif

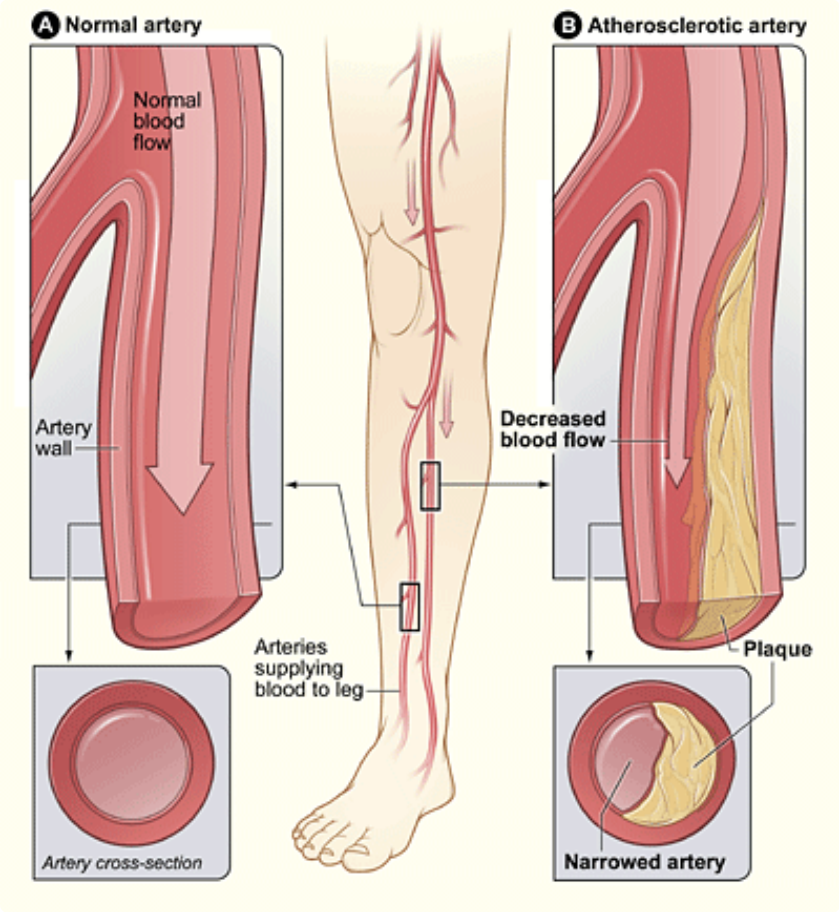


Figure 11.61 Peripheral Arterial Disease

Peripheral artery disease can cause non-healing wounds in the lower extremities, which can become infected and lead to foot or leg amputation. Peripheral artery disease also increases the risk for myocardial infarction and stroke.

The most common symptom of peripheral artery disease is painful muscle cramping in the hips, thighs, or calves when walking, climbing stairs, or exercising, called intermittent claudication. This pain typically resolves when the activity is stopped, although it may take a few minutes. Other symptoms may include muscle wasting or atrophy, reduced or absent pulses, prolonged capillary refill time, changes in skin color, hair loss, and sensations of numbness or tingling.

Health care providers may use a combination of noninvasive and invasive tests to evaluate blood flow and identify blockages in the arteries of the limbs. Treatment of

peripheral artery disease consists of lifestyle modifications, medication therapy, and surgical management[47]

Shock

Shock is a life-threatening condition where the body's tissues and organs don't receive enough blood and oxygen. This inadequate blood flow leads to cellular dysfunction and can result in organ damage and failure if not treated promptly. It should not be confused with emotional or psychological shock.[48]

Shock is generally classified into four categories called hypovolemic, cardiogenic, distributive, and obstructive[49]:

- **Hypovolemic shock** can be caused by hemorrhage or significant fluid losses, often related to severe vomiting or diarrhea or extensive burns. Typically, patients with hypovolemic shock have decreased blood pressure; a rapid heart rate; a weak pulse often described as "thready"; cool, clammy skin in the extremities due to restricted peripheral blood flow; rapid, shallow breathing; thirst; and dry mouth. Treatments involve treating the cause and providing intravenous fluids.[50]
- **Cardiogenic shock** results from the inability of the heart to adequately pump and maintain cardiac output. It is often caused by myocardial infarction (heart attack), but may also be caused by arrhythmias, valve disorders, cardiomyopathies, and heart failure. Treatment focuses on restoring the heart's pumping ability and supporting blood flow until the underlying cause can be resolved. This often involves medications, mechanical circulatory support devices, and potentially surgery.[51]
- **Distributive shock** characterized by peripheral vasodilation and includes conditions such as septic shock, anaphylactic shock, neurogenic shock (caused by trauma to the cranium or spinal cord that damages the cardiovascular centers in the medulla oblongata or the nerve fibers originating from this region), and endocrine and metabolic shock (caused by adrenal failure, severe hypothyroidism called

47. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Nursing health alterations*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthalts/
48. Haseer Koya, H., & Paul, M. (2023). *Shock*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK531492/
49. Haseer Koya, H., & Paul, M. (2023). *Shock*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK531492/
50. Taghavi, S., Nassar, A. K., & Askari, R. (2023). *Hypovolemic shock*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK513297/
51. UCSF Health. (n.d.). *Cardiogenic shock*. https://www.ucsfhealth.org/conditions/cardiogenic-shock

myxedema, diabetic ketoacidosis, other severe acid-base imbalances, and severe electrolyte imbalances). Treatment includes the administration of intravenous fluids and medications to maintain adequate blood pressure to the organs.

- **Obstructive shock** is caused by extracardiac conditions leading to a decrease in the left ventricular cardiac output and decreased delivery of oxygen to tissues. Causes include conditions such as pulmonary embolism (a blood clot lodged in the pulmonary circuit), tension pneumothorax (a collapsed lung with excessive air present in the thoracic cavity), constrictive pericarditis, or cardiac tamponade. Treatments are based on the underlying cause and, in addition to administering fluids intravenously, may include administration of anticoagulant medications, removal of air from the thoracic cavity, removal of fluid from the pericardial cavity, or other types of surgery as required.

Varicose Veins

Varicose veins occur in the superficial veins of the legs when defective valves allow blood to accumulate, causing them to distend, twist, and become visible on the surface of the skin. Varicose veins can occur in anyone, but they are more common in females and often related to pregnancy. Without treatment, varicose veins tend to grow worse over time. Individuals often wear compression socks or support hose and elevate their legs whenever possible to minimize blood pooling. Laser surgery and interventional radiologic procedures can reduce the size and severity of varicose veins. Severe cases may require surgery to remove the damaged vessels. Due to the presence of anastomoses for smaller veins, removal does not typically impair the individual's circulation.[52] See Figure 11.62[53] for an image of varicose veins.

52. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

53. OpenStax College. (2013). *2107_Varicose_Vein* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2107_Varicose_Vein.jpg



Figure 11.62 Varicose Veins

11.7 Career Connections Related to the Cardiovascular System

The cardiovascular system includes the heart, blood, and blood vessels. It moves oxygen, nutrients, hormones, and waste products throughout the body and helps maintain blood pressure, circulation, and body temperature. When the heart or blood vessels are affected by disease or injury, many professionals may help with testing, monitoring, treatment, rehabilitation, and patient care. Careers related to the cardiovascular system can include cardiac care nurses, cardiovascular technologists, cardiac sonographers, vascular sonographers, medical assistants, and phlebotomists.

Cardiac Care Nurse

Cardiac care nurses are registered nurses who care for patients with heart diseases or conditions. They may work in hospitals, clinics, cardiac care units, intensive care units, rehabilitation settings, or outpatient cardiology offices. Cardiac care nurses may monitor heart rhythms, administer medications, provide patient education, help patients recover from procedures or surgery, and respond to cardiac emergencies.

Cardiovascular Technologist

Cardiovascular technologists help perform diagnostic tests and procedures used to evaluate the heart and blood vessels. They may assist with electrocardiograms, stress testing, Holter monitor testing, blood pressure monitoring, pacemaker checks, or procedures in cardiac catheterization labs. Their work helps health care providers identify heart rhythm problems, blocked vessels, valve disorders, and other cardiovascular conditions.

Cardiac Sonographer

Cardiac sonographers, also called echocardiography technologists, use ultrasound

equipment to create images of the heart. These images help providers evaluate the heart's chambers, valves, blood flow, and overall function. Cardiac sonographers may work in hospitals, clinics, and outpatient imaging centers, and they use knowledge of anatomy, physiology, imaging equipment, patient care, and safety practices.

Vascular Sonographer

Vascular sonographers use ultrasound equipment to create images of arteries and veins. These images help providers evaluate blood flow and diagnose conditions such as blood clots, narrowed vessels, aneurysms, and circulation problems. Vascular sonographers may examine blood vessels in the neck, abdomen, arms, legs, or other areas of the body.

Medical Assistant

Medical assistants work in clinics and other health care settings where they support patient care and office procedures. In cardiology or primary care settings, medical assistants may help room patients, collect health information, check vital signs, prepare patients for examinations, assist with basic procedures, support documentation, and communicate follow-up instructions.

Phlebotomist

Phlebotomists are health care professionals who collect blood samples for testing, donation, or research. In cardiovascular care, blood tests may help providers monitor cholesterol levels, blood clotting, medication effects, or signs of heart damage. Phlebotomists use knowledge of anatomy, infection prevention, patient identification, specimen labeling, and safety procedures to help ensure accurate test results and patient safety.

Take a Closer Look

Explore careers related to the human body's cardiovascular system on these websites.

- Cardiac care nurse from the American Association of Critical-Care Nurses
- Cardiac-vascular nurse from the American Nurses Association
- Cardiovascular technologists and technicians from the U.S. Bureau of Labor Statistics
- Cardiac sonographer from Mayo Clinic College of Medicine and Science
- Echocardiography careers from the American Society of Echocardiography
- Vascular ultrasound careers from the Society for Vascular Ultrasound
- Medical assistant from the American Association of Medical Assistants
- Phlebotomists from the U.S. Bureau of Labor Statistics

11.8 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

11.9 Glossary

Abdominal aorta: The part of the descending aorta that passes through the abdominal cavity, supplying oxygenated blood to the abdominal organs, pelvis, and lower limbs. (**Chapter 11.5**)

Adrenal artery: Supplies blood to the adrenal glands and arises near the superior mesenteric artery. (**Chapter 11.5**)

Adrenal vein: The vein that drains blood from the adrenal (suprarenal) glands and empties into the inferior vena cava or the renal vein. (**Chapter 11.5**)

Anastomosis: A connection between two blood vessels that supply the same area, providing an alternate pathway for blood flow. (**Chapter 11.2**)

Aneurysm: An aneurysm is a weakened blood vessel wall that bulges or balloons. An aneurysm can break open, which is called a rupture. A ruptured aneurysm causes severe internal bleeding and can be life-threatening. (**Chapter 11.6**)

Angioplasty: A procedure in which the occlusion caused by plaque is mechanically widened with a balloon. (**Chapter 11.6**)

Anterior interventricular sulcus: A groove on the front (anterior) surface of the heart that marks the boundary between the left and right ventricles. (**Chapter 11.2**)

Anterior tibial artery: Located between the tibia and fibula and supplies blood to the muscles and skin of the anterior tibial region. (**Chapter 11.5**)

Anterior tibial vein: A vein that drains blood from the front (anterior) part of the lower leg (shin area) and carries it upward toward the heart, eventually joining larger veins in the leg. (**Chapter 11.5**)

Aorta: The largest artery in the body. (**Chapter 11.5**)

Aortic arch: The curved portion of the aorta, the largest artery in the body, which gives rise to major arteries that supply blood to the head, neck, and upper limbs. (**Chapter 11.5**)

Aortic hiatus: An opening in the diaphragm through which the descending aorta passes from the chest into the abdomen. (**Chapter 11.5**)

Apex: The pointed, inferior tip of the heart located just left of the sternum. (**Chapter 11.2**)

Arrhythmia: An abnormal heart rhythm due to disrupted electrical activity of the conduction system. (**Chapter 11.6**)

Arterial circle (circle of Willis): A circular network of arteries located at the base of the brain that provides collateral blood flow between the anterior and posterior cerebral circulations, helping ensure a consistent blood supply to the brain. (**Chapter 11.5**)

Arteries: Blood vessels that carry blood away from the heart to the body's tissues. Most arteries carry oxygenated blood, except for the pulmonary arteries, which carry deoxygenated blood to the lungs. (**Chapter 11.2**, **Chapter 11.5**)

Arteriole: A very small artery that leads to a capillary. (**Chapter 11.5**)

Arteriosclerosis: The thickening and stiffening of arterial walls that is commonly associated with normal aging. (**Chapter 11.6**)

Ascending aorta: Moves in an upward direction. (**Chapter 11.5**)

Atherosclerosis: A condition where cholesterol, low-density lipoprotein (LDL) deposits, and wastes build up within the lining of the arteries. (**Chapter 11.6**)

Atria: The two upper chambers of the heart that receive blood returning to the heart and pump it into the ventricles. (**Chapter 11.2**)

Atrial fibrillation (A-Fib): A common type of arrhythmia (irregular heartbeat) in which the atria (upper chambers of the heart) beat rapidly and irregularly, reducing the heart's efficiency and increasing the risk of stroke. (**Chapter 11.6**)

Atrioventricular (AV): Relating to the connection between the atria and ventricles of the heart. (**Chapter 11.3**)

Atrioventricular (AV) bundle: A group of specialized heart muscle fibers that transmit electrical impulses from the AV node down to the ventricles. (**Chapter 11.3**)

Atrioventricular septum: The wall or partition that separates the atria (upper heart chambers) from the ventricles (lower heart chambers). (**Chapter 11.2**)

Atrioventricular valves: Valves located between the atria and ventricles (the tricuspid valve on the right and the mitral/bicuspid valve on the left) that prevent backflow of blood into the atria during ventricular contraction. (**Chapter 11.2**)

Auricles: Flaplike, thin-walled structures that can slightly expand to increase the volume of the atria, the upper chambers of the heart. (**Chapter 11.2**)

Autorhythmicity: The heart's ability to generate its own electrical impulses without input from the nervous system, allowing it to contract in a regular, rhythmic pattern. (**Chapter 11.2**)

Axillary artery: A major artery that carries blood from the subclavian artery through the armpit (axilla) region to the upper limb. (**Chapter 11.5**)

Axillary vein: A large vein that drains blood from the upper limb and shoulder, running through the armpit (axilla) and continuing as the subclavian vein. (**Chapter 11.5**)

Basilic vein: A large superficial vein on the inner side of the arm that helps drain blood from the hand and forearm and eventually joins the brachial vein to form the axillary vein. (**Chapter 11.5**)

Blood flow: Initiated by the contraction of the ventricles of the heart and refers to the movement of blood through a vessel, tissue, or organ. (**Chapter 11.5**)

Blood pressure: The force exerted by blood on the walls of the blood vessels or the chambers of the heart. (**Chapter 11.5**)

Brachial artery: Supplies blood to much of the brachial region and divides at the elbow into several smaller branches, including the deep brachial arteries, which provide blood to the posterior surface of the arm, and the ulnar collateral arteries, which supply blood to the region of the elbow. (**Chapter 11.5**)

Brachial vein: A deep vein of the upper arm that drains blood from the arm and joins with the basilic vein to form the axillary vein. (**Chapter 11.5**)

Brachiocephalic artery: The first major branch of the aortic arch that supplies blood to the right arm, head, and neck. (**Chapter 11.5**)

Brachiocephalic vein: A large vein formed by the union of the subclavian and internal jugular veins; it drains blood from the head, neck, and upper limbs into the superior vena cava. (Chapter 11.5)

Bradycardia: A condition in which the resting heart rate for an adult drops below 60 bpm. (**Chapter 11.4**)

Broken heart syndrome: Also known as Takotsubo cardiomyopathy, stress-induced cardiomyopathy, or apical ballooning syndrome, it is a temporary heart condition triggered by intense emotional or physical stress. It mimics a heart attack but usually resolves within days or weeks. (**Chapter 11.6**)

Bundle branches: Pathways that split from the AV bundle and carry impulses down the left and right sides of the interventricular septum to the ventricles. (**Chapter 11.3**)

Bundle of His: A group of specialized heart muscle fibers that transmit electrical impulses from the AV node down to the ventricles. (**Chapter 11.3**)

Capillaries: The smallest blood vessels in the body, where the exchange of oxygen,

nutrients, waste products, and other substances occurs between the blood and surrounding tissues. (Chapter 11.5)

Cardiac conduction system: A network of specialized heart cells that generate and transmit electrical impulses, controlling the heart's rhythmic contractions. (Chapter 11.3)

Cardiac cycle: The period of time that begins with the contraction of the atria and ends with ventricular relaxation. (Chapter 11.4)

Cardiac output (CO): The amount of blood pumped by each ventricle in one minute. (Chapter 11.4)

Cardiac tamponade: A medical emergency in which fluid builds up in the pericardial sac (the lining around the heart), putting pressure on the heart and preventing it from filling and pumping properly. (Chapter 11.6)

Cardiogenic shock: Results from the inability of the heart to adequately pump and maintain cardiac output. (Chapter 11.6)

Cardiologist: A physician who specializes in the diagnosis and treatment of heart disease. (Chapter 11.7)

Cardiology: The study of the heart. (Chapter 11.1)

Celiac trunk: A major branch of the abdominal aorta that quickly divides into the left gastric, splenic, and common hepatic arteries to supply blood to the stomach, spleen, liver, and other abdominal organs. (Chapter 11.5)

Cephalic vein: Begins in the antebrachium (between the elbow and wrist) and drains blood from the superficial surface of the arm into the axillary vein. (Chapter 11.5)

Chordae tendineae: Tough, fibrous cords that connect the valve flaps (cusps) of the tricuspid and mitral valves to papillary muscles in the ventricles. (Chapter 11.2)

Coarctation of the aorta: A congenital abnormal narrowing of the aorta that is normally located at the insertion of the ligamentum arteriosum, the remnant of the fetal shunt called the ductus arteriosus. (Chapter 11.6)

Common carotid arteries: Divide into internal and external carotid arteries. (Chapter 11.5)

Common hepatic artery: A branch of the celiac trunk that supplies oxygenated blood to the liver, stomach, duodenum, and pancreas. (Chapter 11.5)

Common iliac artery: One of the two large arteries that branch off from the abdominal aorta, supplying blood to the pelvis and lower limbs. (Chapter 11.5)

Common iliac vein: A large vein formed by the union of the internal and external iliac veins, which drains blood from the pelvis and lower limbs into the inferior vena cava. (**Chapter 11.5**)

Compliance: The ability to expand or stretch. (**Chapter 11.5**)

Congenital: Meaning the individual was born with the defect. (**Chapter 11.6**)

Congenital heart defects: Structural abnormalities in the heart or blood vessels that are present at birth and affect how blood flows through the heart and out to the rest of the body. (**Chapter 11.6**)

Coronary artery disease (CAD): The leading cause of death worldwide. It occurs when the buildup of plaque obstructs blood flow within the coronary arteries and decreases the compliance of the vessels. (**Chapter 11.6**)

Coronary sinus: A thin-walled vessel on the posterior surface of the right atrium that receives deoxygenated blood from the heart muscle and empties it into the right atrium. (**Chapter 11.2**)

Coronary sulcus: A deep groove located between the atria and ventricles of the heart. (**Chapter 11.2**)

Coronary veins: Systemic veins that collect deoxygenated blood from the heart muscle and drain it into the coronary sinus. (**Chapter 11.2**)

Deep femoral artery: A major branch of the femoral artery that supplies blood to the deeper muscles of the thigh. (**Chapter 11.5**)

Deep femoral vein: Drains blood from the deeper portions of the thigh. (**Chapter 11.5**)

Depolarization: The electrical activation of atrial muscle cells that triggers their contraction, increasing atrial pressure and pumping blood into the ventricles through open atrioventricular valves. (**Chapter 11.4**)

Descending aorta: The part of the aorta that extends downward from the aortic arch, carrying oxygenated blood to the chest, abdomen, and lower parts of the body. (**Chapter 11.5**)

Diastole: The period of relaxation that occurs as the chambers fill with blood. (**Chapter 11.4**)

Diastolic pressure: The lower number in a blood pressure reading; it measures the pressure in the arteries when the heart is resting between beats. (**Chapter 11.5**)

Digital arteries: Supply blood to the digits. (**Chapter 11.5**)

Digital veins: Veins that drain blood from the fingers and toes, returning it toward the heart. (Chapter 11.5)

Distributive shock: Characterized by peripheral vasodilation and includes conditions such as septic shock, anaphylactic shock, neurogenic shock, or others. (Chapter 11.6)

Dorsal arch: An arterial network on the back (dorsal) side of the foot formed mainly by the dorsalis pedis artery, which supplies blood to the foot and toes. (Chapter 11.5)

Dorsalis pedis artery: An artery on the top of the foot that supplies blood to the foot and toes. (Chapter 11.5)

Dorsal venous arch: A complex series of anastomoses in the feet and ankles that the plantar veins flow into. (Chapter 11.5)

Ductus arteriosus: A fetal blood vessel that connects the pulmonary artery to the aorta, allowing blood to bypass the lungs before birth. It normally closes soon after birth. (Chapter 11.5)

Ductus venosus: A fetal blood vessel that shunts oxygen-rich blood from the umbilical vein directly to the inferior vena cava, bypassing the liver. (Chapter 11.5)

Edema: Swelling caused by excess fluid trapped in the body's tissues, often occurring in the hands, feet, ankles, or legs. (Chapter 11.6)

Elastic artery: Arteries closest to the heart have the thickest walls, containing a high percentage of elastic fibers in all three of their tunics. (Chapter 11.5)

Electrocardiogram (ECG): A test that records the electrical activity of the heart over time using electrodes placed on the skin, producing a waveform that helps diagnose heart conditions. (Chapter 11.3)

End diastolic volume (EDV): The volume of blood in the ventricles at the end of ventricular filling (diastole), just before the heart contracts. (Chapter 11.4)

Endocardium: The innermost layer of the heart wall, connected to the myocardium by a thin layer of connective tissue. (Chapter 11.2)

Endothelium: A simple squamous epithelial tissue that makes up the endocardium, lining the inside of the heart. (Chapter 11.2)

End systolic volume (ESV): The amount of blood remaining in each ventricle after ventricular systole (contraction) and ejection of blood. (Chapter 11.4)

Epicardium: Also known as the visceral pericardium, it is the inner layer of the serous pericardium that is fused to the surface of the heart and forms part of the heart wall. (Chapter 11.2)

External carotid artery: Supplies blood to numerous structures within the face, lower jaw, neck, esophagus, and larynx. (**Chapter 11.5**)

External iliac artery: A continuation of the common iliac artery that supplies blood to the lower limbs; it becomes the femoral artery as it passes under the inguinal ligament. (**Chapter 11.5**)

External iliac vein: A large vein that drains blood from the leg to the common iliac vein. (**Chapter 11.5**)

External jugular vein: A vein that drains blood from the superficial areas of the head and neck and empties into the subclavian vein. (**Chapter 11.5**)

Femoral artery: A large artery in the thigh that supplies oxygenated blood to the lower limb. (**Chapter 11.5**)

Femoral circumflex vein: Forms a loop around the femur just inferior to the trochanters and drains blood from the areas in proximity to the head and neck of the femur. (**Chapter 11.5**)

Femoral vein: A large deep vein in the thigh that collects blood from the popliteal vein and the great saphenous vein, transporting it upward toward the external iliac vein and eventually back to the heart. (**Chapter 11.5**)

Fibrous pericardium: The tough outer layer of the pericardium made of dense connective tissue that protects the heart and anchors it in the chest. (**Chapter 11.2**)

Fibrous skeleton of the heart: Dense connective tissue that reinforces the heart muscle. It includes four rings surrounding the openings between the atria and ventricles, and the openings to the pulmonary trunk and aorta. (**Chapter 11.2**)

Fibular vein: A vein that drains blood from the lateral (outer) side of the lower leg and foot, returning it toward the heart. (**Chapter 11.5**)

Foramen ovale: An opening in the fetal heart that allowed blood to flow directly from the right atrium to the left atrium, bypassing the lungs before birth. (**Chapter 11.2**)

Fossa ovalis: A small oval-shaped depression on the interatrial septum, marking the spot of a fetal opening called the foramen ovale. (**Chapter 11.2**, **Chapter 11.5**)

Genicular artery: An artery that supplies blood to the knee joint and surrounding structures. (**Chapter 11.5**)

Gonadal artery: Supplies blood to the gonads, or reproductive organs, and is also described as either an ovarian artery or a testicular artery, depending upon the sex of the individual. (**Chapter 11.5**)

Gonadal vein: The vein that drains blood from the gonads (ovaries in females, testes in males) and returns it to the inferior vena cava or the left renal vein. (**Chapter 11.5**)

Great saphenous vein: The longest vein in the body, running along the inner leg from the foot to the groin, where it drains into the femoral vein; it is a superficial vein used often in vein grafts for surgeries. (**Chapter 11.5**)

Heart block: Refers to a disruption in the normal conduction pathway of electrical signals through the atria and ventricles. (**Chapter 11.6**)

Heart failure (HF): Occurs when the heart loses its effectiveness in pumping blood and is referred to as decreased cardiac output. (**Chapter 11.6**)

Heart rate (HR): The number of heartbeats per minute, typically measured in beats per minute (bpm). (**Chapter 11.4**)

Heart sounds: Noises generated by the beating heart and the flow of blood, typically described as “lub-dub.” (**Chapter 11.4**)

Hepatic artery proper: A branch of the common hepatic artery that travels toward the liver and supplies it with oxygenated blood. (**Chapter 11.5**)

Hepatic portal system: A network of veins that carries nutrient-rich blood from the digestive organs and spleen to the liver for processing before it enters the general circulation. (**Chapter 11.5**)

Hepatic vein: The vein that carries deoxygenated blood from the liver to the inferior vena cava. (**Chapter 11.5**)

Hypertension: Refers to chronically elevated blood pressure greater than 120/80 mm Hg. (**Chapter 11.6**)

Hypervolemia: Excessive blood volume. (**Chapter 11.5**)

Hypovolemia: Low blood volume. (**Chapter 11.5**)

Hypovolemic shock: Caused by hemorrhage or significant fluid losses, often related to severe vomiting, diarrhea, or extensive burns. (**Chapter 11.6**)

Inferior mesenteric artery: A branch of the abdominal aorta that supplies oxygenated blood to the distal part of the large intestine, including the descending colon, sigmoid colon, and rectum. (**Chapter 11.5**)

Inferior phrenic artery: A counterpart of the superior phrenic artery and supplies blood to the inferior surface of the diaphragm. (**Chapter 11.5**)

Inferior vena cava: A large vein that carries deoxygenated blood from the lower limbs

and abdominopelvic region back to the right atrium of the heart. (Chapter 11.2, Chapter 11.5)

Interatrial septum: A thin fibromuscular wall that separates the right and left atria of the heart. (Chapter 11.2)

Intercalated disc: Specialized connections between cardiac muscle cells that contain gap junctions and desmosomes, allowing electrical impulses to pass quickly between cells and enabling the synchronized contraction of the heart muscle. (Chapter 11.2)

Internal carotid arteries: Major arteries that arise from the common carotid arteries and supply oxygenated blood to the brain, eyes, and other internal structures of the head. (Chapter 11.5)

Internal iliac artery: A branch of the common iliac artery that supplies blood to the pelvic organs, gluteal region, and medial thigh. (Chapter 11.5)

Internal iliac vein: A deep vein that drains blood from the pelvic organs and walls, joining with the external iliac vein to form the common iliac vein. (Chapter 11.5)

Internal jugular vein: A major vein that collects blood from the brain, face, and neck, and drains into the brachiocephalic vein. (Chapter 11.5)

Interventricular septum (ventricular septum): The wall or partition that separates the right and left ventricles of the heart. (Chapter 11.2)

Isovolumetric contraction: The phase in the cardiac cycle when the ventricles contract with no change in volume because all heart valves are closed, causing a rapid increase in ventricular pressure. (Chapter 11.4)

Isovolumetric ventricular relaxation phase: The early phase of ventricular diastole, when the ventricles begin to relax, pressure falls, and all heart valves are closed, so no blood enters or leaves the ventricles. (Chapter 11.4)

Lateral circumflex artery: A branch of the deep femoral artery that supplies blood to the muscles on the front and side of the thigh and the hip joint. (Chapter 11.5)

Lateral plantar artery: An artery branching from the posterior tibial artery that supplies blood to the outer (lateral) side of the sole of the foot. (Chapter 11.5)

Left common carotid artery: Branches directly from the aortic arch. (Chapter 11.5)

Left gastric artery: A branch of the celiac trunk that supplies blood to the lower esophagus and the upper part of the stomach along its lesser curvature. (Chapter 11.5)

Left subclavian artery: Branches directly from the aortic arch. (Chapter 11.5)

Ligamentum arteriosum: A small ligament that is the remnant of the ductus arteriosus after it closes following birth. It connects the aortic arch to the pulmonary artery. (**Chapter 11.5**)

Ligamentum venosum: A fibrous remnant of the fetal ductus venosus found in the liver after birth. (**Chapter 11.5**)

Lumen: A hollow central passageway through which blood flows. (**Chapter 11.5**)

Maxillary vein: A vein that drains blood from the deep parts of the face, including the maxillary region, and joins with other veins to form the retromandibular vein. (**Chapter 11.5**)

Medial plantar artery: An artery that branches from the posterior tibial artery and supplies blood to the inner (medial) side of the sole of the foot. (**Chapter 11.5**)

Median antebrachial vein: Parallels the ulnar vein, is more medial in location, and joins the basilic vein in the forearm. (**Chapter 11.5**)

Median cubital vein: A superficial vein located in the front of the elbow (cubital fossa) that connects the basilic and cephalic veins. It is commonly used for drawing blood (venipuncture). (**Chapter 11.5**)

Median sacral artery: A small artery that arises from the posterior surface of the abdominal aorta just before it splits into the common iliac arteries; it supplies blood to the sacrum and coccyx. (**Chapter 11.5**)

Mediastinum: Central portion of the thoracic cavity. (**Chapter 11.2**)

Microcirculation: The flow of blood through the smallest blood vessels—arterioles, capillaries, and venules—where exchange of gases, nutrients, and waste products occurs between blood and tissues. (**Chapter 11.5**)

Middle sacral vein: A vein that drains blood from the sacrum and coccyx, typically emptying into the left or right common iliac vein. (**Chapter 11.5**)

Mitral regurgitation: The most common valve disorder, detected in approximately 2% of the population. (**Chapter 11.6**)

Mitral valve: The valve between the left atrium and left ventricle; it has two flaps (cusps) and prevents backflow of blood into the left atrium during ventricular contraction. Also called the bicuspid valve. (**Chapter 11.2**)

Moderator band: A muscular band of heart tissue found in the right ventricle that carries part of the conduction system (right bundle branch) to the anterior papillary muscle, helping coordinate ventricular contraction. (**Chapter 11.2**)

Murmur: Used to describe an unusual sound coming from a heart valve that is caused by the turbulent flow of blood. (**Chapter 11.4**)

Muscular artery: A medium-sized artery that contains a thick layer of smooth muscle, allowing it to regulate blood flow by constricting or dilating. (**Chapter 11.5**)

Myocardial infarction (MI): The medical term for what is commonly known as a heart attack. (**Chapter 11.6**)

Myocardium: The middle and thickest layer of the heart wall, composed mainly of cardiac muscle cells responsible for the heart's contractions. (**Chapter 11.2**)

Obstructive shock: Caused by extracardiac conditions leading to a decrease in the left ventricular cardiac output and decreased delivery of oxygen to tissues. (**Chapter 11.6**)

Ovarian artery: Supplies blood to the ovary, the Fallopian tube, and the uterus, and is located within the suspensory ligament of the uterus. (**Chapter 11.5**)

Ovarian vein: The vein that drains blood from the ovaries and returns it to the inferior vena cava (right ovarian vein) or the left renal vein (left ovarian vein). (**Chapter 11.5**)

Palmar arches: Supply blood to the hand. (**Chapter 11.5**)

Palmar venous arches: Networks of interconnected veins located in the palm of the hand that collect blood from the fingers and hand, helping return it to the larger veins of the arm. (**Chapter 11.5**)

Papillary muscle: Small muscles inside the heart ventricles that attach to chordae tendineae and help prevent valve flaps from inverting during contraction. (**Chapter 11.2**)

Parietal pericardium: The outer layer of the serous pericardium that lines the inner surface of the fibrous pericardium. (**Chapter 11.2**)

Patent ductus arteriosus (PDA): A congenital condition in which the ductus arteriosus fails to close at birth. (**Chapter 11.6**)

Patent foramen ovale (PFO): A common congenital heart defect that occurs when the fossa ovalis in the interatrial septum, which is present during fetal circulation, does not fuse after birth. (**Chapter 11.6**)

Pectinate muscles: Muscular ridges found on the inner surface of the anterior right atrium of the heart. (**Chapter 11.2**)

Perfusion: The process of delivering blood to the body's tissues and organs to supply oxygen and nutrients. (**Chapter 11.5**)

Pericardial cavity: The space between the heart and the pericardium, filled with serous fluid to reduce friction during heart contractions. (**Chapter 11.2**)

Pericarditis: Swelling and irritation of the pericardium, the thin, saclike tissue surrounding the heart. (**Chapter 11.6**)

Pericardium: The serous membrane that surrounds the heart and reduces friction caused by the beating of the heart. (**Chapter 11.2**)

Peripheral artery disease (PAD): Caused by atherosclerosis, with narrowed or blocked arteries, causing reduced oxygenated blood flow to the lower extremities. (**Chapter 11.6**)

Plantar arch: An arterial arch located on the sole (plantar surface) of the foot, formed mainly by the lateral plantar artery, providing blood supply to the foot's plantar tissues. (**Chapter 11.5**)

Plantar veins: Veins located in the sole (bottom) of the foot that drain blood from the foot's tissues and return it toward the heart. (**Chapter 11.5**)

Plantar venous arch: A complex series of anastomoses in the feet and ankles through which the plantar veins flow. (**Chapter 11.5**)

Plaque: A fatty material including cholesterol, connective tissue, white blood cells, and smooth muscle cells. (**Chapter 11.6**)

Popliteal artery: The main artery located behind the knee that supplies blood to the knee joint and lower leg. (**Chapter 11.5**)

Popliteal vein: A deep vein located behind the knee that collects blood from the lower leg and drains into the femoral vein. (**Chapter 11.5**)

Posterior interventricular sulcus: A groove on the back (posterior) surface of the heart that marks the boundary between the left and right ventricles. (**Chapter 11.2**)

Posterior tibial artery: Provides blood to the muscles and skin on the posterior surface of the tibial region. (**Chapter 11.5**)

Posterior tibial vein: A vein that drains blood from the back (posterior) part of the lower leg and foot, carrying it upward toward the heart. (**Chapter 11.5**)

Preload: The volume of blood in the ventricles at the end of ventricular filling (diastole), just before the heart contracts. (**Chapter 11.4**)

Pulmonary artery: The blood vessel that carries deoxygenated blood from the right ventricle of the heart to the lungs for oxygenation. (**Chapter 11.2**, **Chapter 11.5**)

Pulmonary capillaries: Tiny blood vessels surrounding the alveoli in the lungs, where

the exchange of oxygen and carbon dioxide takes place between the blood and the air in the lungs. (Chapter 11.5)

Pulmonary circulation: The portion of the circulatory system that carries deoxygenated blood from the right side of the heart to the lungs to pick up oxygen and release carbon dioxide, and then returns oxygenated blood to the left side of the heart. (Chapter 11.2)

Pulmonary trunk: A large artery that carries blood away from the right ventricle. (Chapter 11.2, Chapter 11.5)

Pulmonary valve (pulmonic valve): A semilunar valve located at the base of the pulmonary trunk that prevents backflow of blood into the right ventricle after it contracts. (Chapter 11.2)

Pulmonary veins: Blood vessels that carry oxygen-rich blood from the lungs back to the left atrium of the heart. (Chapter 11.5)

Pulse: The expansion and recoiling of an artery as blood is pumped through it with each heartbeat; it can be felt manually or measured electronically. (Chapter 11.5)

Purkinje fibers: Specialized fibers that spread the electrical impulse throughout the ventricles, causing them to contract. (Chapter 11.3)

Radial artery: A major artery of the forearm that runs along the thumb side, commonly used to measure the pulse at the wrist. (Chapter 11.5)

Radial vein: A vein that runs along the lateral (thumb) side of the forearm, draining blood from the hand and forearm back toward the heart. (Chapter 11.5)

Renal artery: A blood vessel that branches off from the abdominal aorta and supplies oxygen-rich blood to the kidneys. (Chapter 11.5)

Renal vein: The vein that carries deoxygenated blood filtered by the kidneys back to the inferior vena cava. (Chapter 11.5)

Repolarization: The process by which cardiac muscle cells restore their resting electrical state after depolarization, allowing the heart muscle to relax. (Chapter 11.4)

Resistance: Anything that slows blood or counteracts blood flow. (Chapter 11.5)

Respiratory pump: A mechanism where pressure changes in the thoracic cavity during breathing help move blood toward the heart through the veins. (Chapter 11.5)

Right atrium: The heart's chamber that receives deoxygenated blood from the body's systemic circulation and directs it to the right ventricle. (Chapter 11.2)

Right common carotid artery: A major artery branching from the brachiocephalic artery that supplies oxygenated blood to the right side of the head and neck. (**Chapter 11.5**)

Right subclavian artery: A major artery branching from the brachiocephalic artery that supplies blood to the right arm and parts of the chest and shoulder. (**Chapter 11.5**)

Saphenous vein: A large superficial vein in the leg that drains blood from the foot and leg and empties into the deep venous system. The great saphenous vein is the longest vein in the body. (**Chapter 11.5**)

Semilunar valves: Valves located at the openings of the heart leading to the pulmonary trunk (pulmonary valve) and the aorta (aortic valve); they prevent backflow of blood into the ventricles after contraction. (**Chapter 11.2**)

Septum: A wall or partition that divides a structure into separate parts, such as the walls separating the chambers of the heart. (**Chapter 11.2**)

Serous pericardium: A thin, double-layered membrane around the heart that reduces friction. It includes the parietal layer (outer) and the visceral layer (inner, also called the epicardium). (**Chapter 11.2**)

Shock: A life-threatening condition where the body's tissues and organs don't receive enough blood and oxygen. (**Chapter 11.6**)

Shunts: Alternative paths for blood flow. (**Chapter 11.5**)

Sinoatrial (SA) node: A specialized clump of conducting cells located in the wall of the upper right atrium close to the opening of the superior vena cava. (**Chapter 11.3**)

Skeletal muscle pump: Helps the lower-pressure veins counteract the force of gravity, increasing pressure to return blood to the heart. (**Chapter 11.5**)

Splenic artery: A major branch of the celiac trunk that supplies oxygenated blood to the spleen. (**Chapter 11.5**)

Stroke volume (SV): The amount of blood pumped by each ventricle. (**Chapter 11.4**)

Subclavian arteries: Supply blood to the arms, chest, shoulders, back, and central nervous system. (**Chapter 11.5**)

Subclavian vein: A large vein that drains deoxygenated blood from the arms and shoulders and transports it to the superior vena cava. (**Chapter 11.5**)

Subscapular vein: Drains blood from the subscapular region and joins the cephalic vein to form the axillary vein. (**Chapter 11.5**)

Sulcus: A fat-filled groove on the surface of the heart that contains major coronary blood vessels (plural = sulci). (**Chapter 11.2**)

Superior mesenteric artery: A major artery that branches from the abdominal aorta and supplies oxygenated blood to most of the small intestine and part of the large intestine. (**Chapter 11.5**)

Superior vena cava: A large vein that carries deoxygenated blood from the head, neck, upper limbs, and chest back to the right atrium of the heart. (**Chapter 11.2**, **Chapter 11.5**)

Systemic circulation: Transports oxygenated blood to almost all tissues of the body, and returns deoxygenated blood to the heart to be sent through the pulmonary circulation. (**Chapter 11.2**)

Systole: Contraction of the heart. (**Chapter 11.4**)

Systolic pressure: The higher number in a blood pressure reading; it measures the pressure in the arteries when the heart contracts and pumps blood. (**Chapter 11.5**)

Tachycardia: A condition in which the resting heart rate for an adult is greater than 100 bpm. (**Chapter 11.4**)

Temporal vein: A vein that drains blood from the scalp and parts of the face, eventually contributing to the formation of the external jugular vein. (**Chapter 11.5**)

Testicular artery: A paired artery that arises from the abdominal aorta and supplies oxygenated blood to the testes in males. (**Chapter 11.5**)

Testicular vein: Flows from the scrotum, forming a portion of the spermatic cord. (**Chapter 11.5**)

Tetralogy of Fallot (ToF): A complex set of congenital heart defects that occurs in approximately 400 out of one million live births. (**Chapter 11.6**)

Thoracic aorta: The portion of the descending aorta located in the chest (thoracic) cavity that supplies blood to the chest wall and organs within the thorax. (**Chapter 11.5**)

Trabeculae carneae: Irregular ridges of cardiac muscle lining the inner walls of the ventricles, helping to reduce suction and improve heart efficiency during contraction. (**Chapter 11.2**)

Tricuspid valve: The valve between the right atrium and right ventricle that prevents backflow of blood when the ventricle contracts. (**Chapter 11.2**)

Trunk: A large artery. (**Chapter 11.5**)

Tunica externa: A sheath of connective tissue composed primarily of collagenous fibers. (Chapter 11.5)

Tunica interna: Composed of smooth epithelial and connective tissue layers. (Chapter 11.5)

Tunica media: The middle layer of the vessel wall. (Chapter 11.5)

Tunics: The three distinct layers that make up the walls of blood vessels. (Chapter 11.5)

Ulnar artery: A major artery of the forearm that runs along the little finger side, supplying blood to the medial aspect of the forearm and hand. (Chapter 11.5)

Ulnar vein: A vein that runs along the medial (pinky) side of the forearm, returning blood from the hand and forearm to the heart. (Chapter 11.5)

Umbilical arteries: Carry oxygen-depleted fetal blood, including wastes and carbon dioxide, to the placenta. (Chapter 11.5)

Umbilical vein: Carries oxygen-rich blood from the mother to the fetus. (Chapter 11.5)

Valve: A specialized structure that ensures one-way flow of blood. (Chapter 11.2)

Varicose veins: Occur in the superficial veins of the legs when defective valves allow blood to accumulate, causing them to distend, twist, and become visible on the surface of the skin. (Chapter 11.6)

Vasoconstriction: Decreases blood flow as the smooth muscle in the walls of the tunica media contracts, making the lumen narrower and increasing blood pressure. (Chapter 11.5)

Vasodilation: Increases blood flow as the smooth muscle relaxes, allowing the lumen to widen and blood pressure to drop. (Chapter 11.5)

Veins: Vessels that bring blood back to the heart. (Chapter 11.2, Chapter 11.5)

Ventricles: The two lower chambers of the heart that receive blood from the atria and pump it out to the lungs and the rest of the body. (Chapter 11.2)

Ventricular ejection phase: The second phase of ventricular systole, when the ventricles contract fully, forcing blood out through the open semilunar valves into the pulmonary trunk and aorta. (Chapter 11.4)

Ventricular fibrillation (V Fib): A disorganized heart rhythm that causes the ventricles to quiver instead of contract. (Chapter 11.6)

Ventricular tachycardia (V Tach): Refers to a very rapid heartbeat that originates in the ventricles. (Chapter 11.6)

Venules: Small blood vessels that receive blood from capillaries and transport it into larger veins, beginning the return flow of blood back to the heart. (**Chapter 11.5**)

Vertebral arteries: Arteries travel through the cervical vertebrae to supply blood to the brain. (**Chapter 11.5**)

Viscosity: A measure of a fluid's thickness or resistance to flow. (**Chapter 11.5**)

Visceral pericardium: The innermost layer of the serous pericardium that directly covers the heart's surface and proximal great vessels (**Chapter 11.2**)

PART XII

CHAPTER 12 LYMPHATIC SYSTEM

12.1 Introduction to the Lymphatic System and Immune Systems

Chapter Competency

Analyze how components of the cardiovascular system function in the body.

Learning Objectives

- Address major gross and microscopic structural components of the lymphatic system.
- Describe the flow of fluid through the lymphatic system.
- Illustrate the functional relationships among the lymphatic components.
- Describe the relationship between blood, tissue, and lymphatic fluids.

Imagine you are working as a nurse caring for a patient with swollen lymph nodes, signs of infection, or fluid accumulation in the tissues. During assessment, you monitor for fever, inflammation, wound drainage, immune response, and changes in swelling. To understand what these findings may indicate, you must understand how the lymphatic system returns fluid to the bloodstream, filters harmful substances, and works with the **immune system** to protect the body.

The **lymphatic system** is a network of lymphatic vessels, lymph, lymph nodes, and lymphatic organs that helps maintain fluid balance and support immunity. As blood circulates through capillaries, some fluid leaves the bloodstream and enters the surrounding tissues. The lymphatic system collects excess tissue fluid, now called lymph, and returns it to the cardiovascular system. Along the way, lymphatic structures help filter **pathogens**, abnormal cells, and other harmful materials.

In this chapter, you will explore the structure and function of the lymphatic and

immune systems. You will learn how lymph forms, how lymphatic vessels return fluid to circulation, and how lymph nodes, the thymus, spleen, tonsils, and other lymphatic tissues support immune defense. You will also examine the body's immune responses, including innate and adaptive immunity, and consider how lymphatic system disorders can affect fluid balance, infection defense, and overall health.

By mastering these concepts, you will gain a deeper understanding of how the lymphatic system supports circulation, fluid balance, and immunity. This foundation will help you connect lymphatic structure and function to infection prevention, inflammation, vaccination, edema, immune disorders, patient assessment, and disorders affecting the lymphatic and immune systems.

12.2 Functions of the Lymphatic System

The main functions of the lymphatic system are to collect excess fluid, transport lipids absorbed in the digestive tract to the blood, and carry out immune functions.

The lymphatic system drains body fluids and returns them to the bloodstream. Blood pressure causes leakage of fluid from the capillaries, resulting in the accumulation of fluid in the **interstitial space** (the spaces between individual cells in the tissue). In humans, 20 liters of plasma are released into the interstitial space of the tissues each day due to capillary filtration. After this filtrate is out of the bloodstream and in the tissue spaces, it is referred to as **interstitial fluid**. Of this fluid, 17 liters are reabsorbed directly by the blood vessels. The remaining three liters are picked up by the lymphatic system, which drains the excess fluid and empties it back into the bloodstream through a series of vessels, trunks, and ducts. Lymph is the term used to describe interstitial fluid once it has entered the lymphatic system. See Figure 12.1[1] for an illustration of the fluid cycle from plasma to interstitial fluid to lymph.

1. WisTech Open. (2025). *Fluid cycle by Nic Ashman* [Diagram]. Chippewa Valley Technical College. CC BY-NC 4.0.

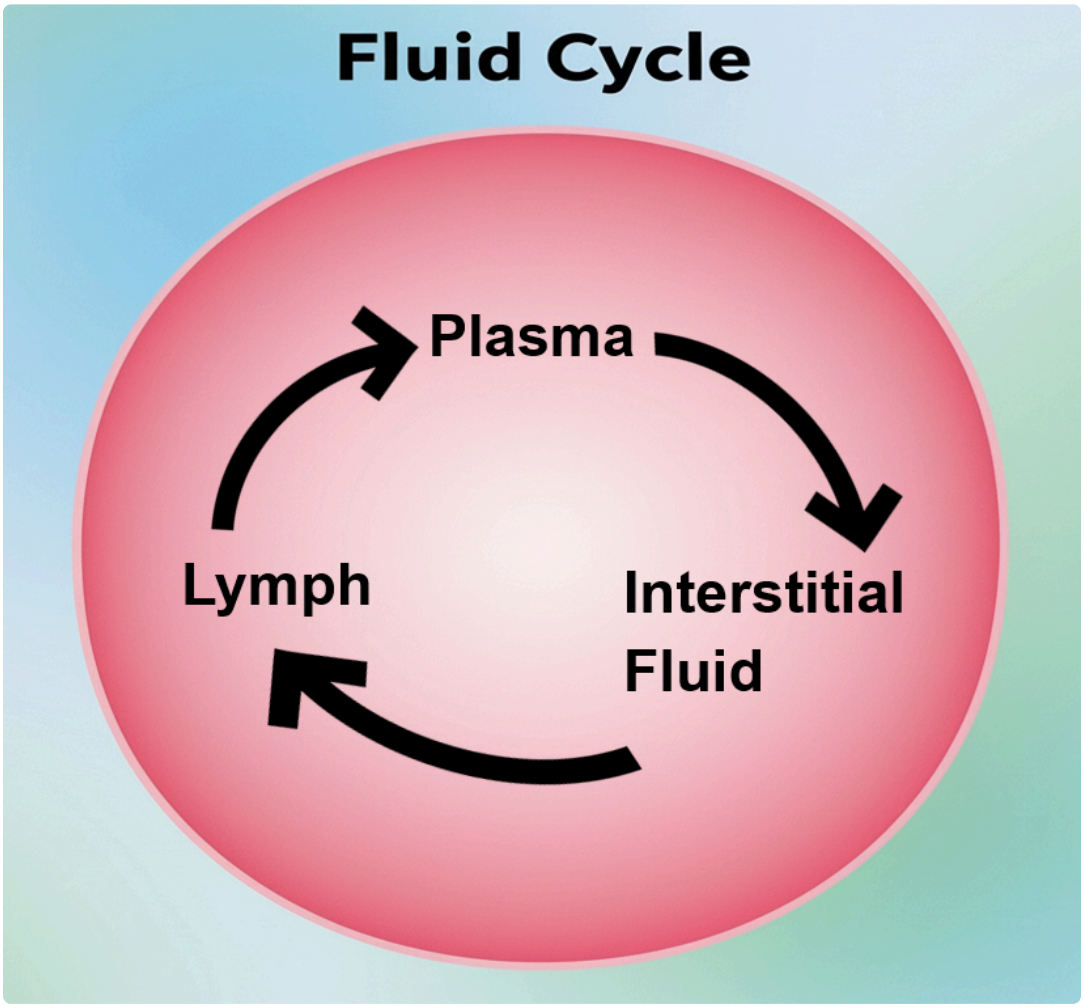


Figure 12.1 Fluid Cycle

The lymphatic system is also responsible for absorbing and transporting dietary lipids and fat-soluble vitamins from the small intestine, where the lymphatic system picks up these lipids and then returns them to the blood at the subclavian veins. Lipids are too big to be absorbed by the blood capillaries directly, like other dietary nutrients.

Cells of the immune system not only use lymphatic vessels to make their way from interstitial spaces back into the circulation, but they also use lymph nodes as major staging areas for the development of critical immune responses. **Lymph nodes** are the small, bean-shaped organs located throughout the lymphatic system.[2]

2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

12.3 Structure of the Lymphatic System

The lymphatic vessels begin as lymphatic capillaries, which feed into larger and larger lymphatic vessels, and eventually empty into the bloodstream by ducts. Along the way, the lymph travels through the **lymph nodes**, which are commonly found near the groin, armpits, neck, chest, and abdomen. See Figure 12.2[1] for an illustration of the lymphatic system.

1. Betts, J.G., Desaix, P., Johnson, E., Johnson, J.E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M.D., & Young, K.A. (2022). *Anatomy of the lymphatic and immune systems 21.2* [Diagram]. Anatomy and physiology, 2e. CC BY 4.0. https://openstax.org/books/anatomy-and-physiology-2e/pages/21-1-anatomy-of-the-lymphatic-and-immune-systems

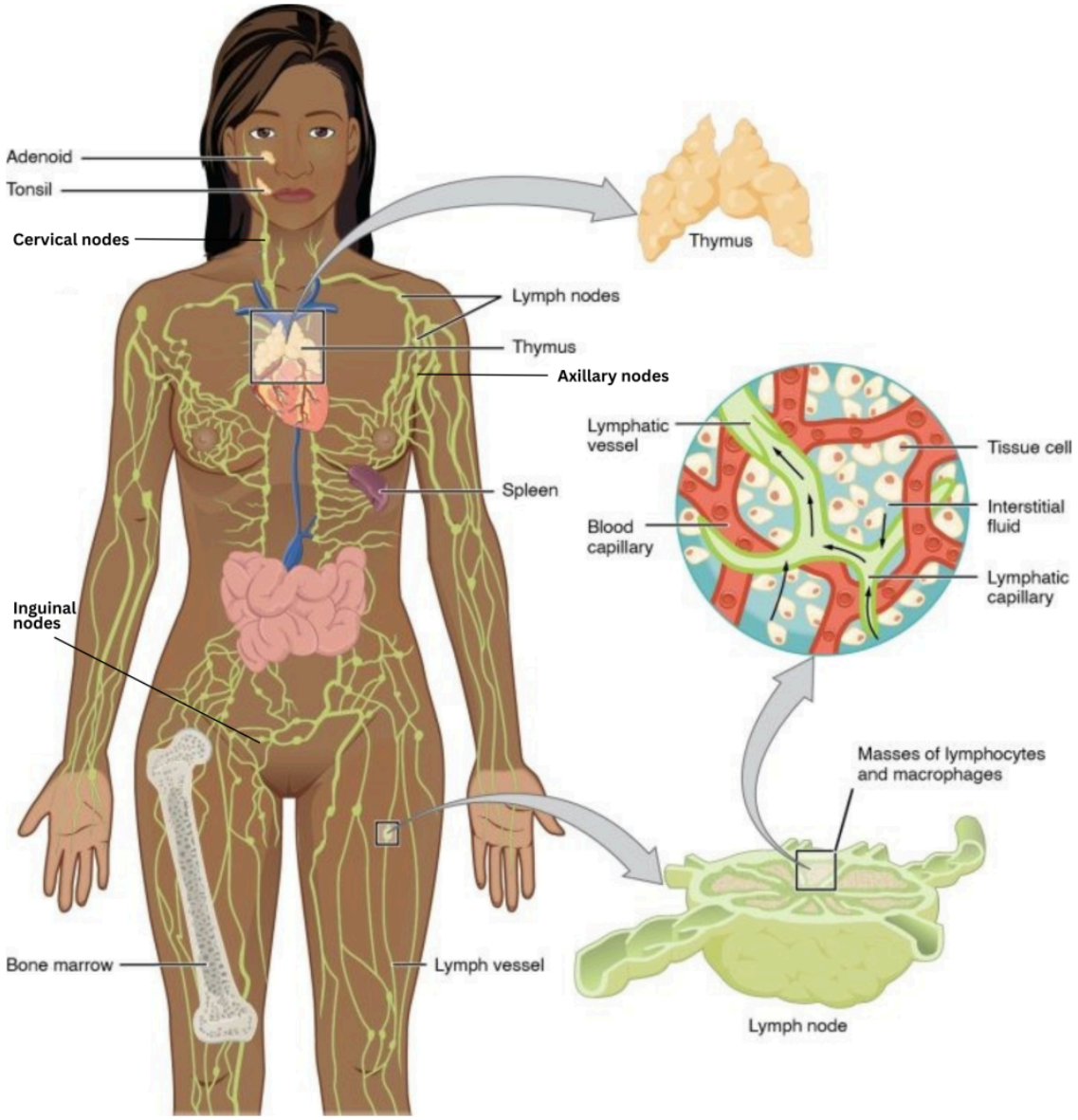


Figure 12.2 Lymphatic System

A major distinction between the lymphatic and cardiovascular systems in humans is that lymph is not actively pumped by the heart but is forced through the vessels by the movements of the body, the contraction of skeletal muscles during body movements, and breathing. One-way valves in lymphatic vessels keep the lymph moving toward the heart. Lymph flows from the lymphatic capillaries, through lymphatic vessels, and then is dumped into the circulatory system via the lymphatic ducts located at the junction of the jugular and subclavian veins in the neck.[2]

2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Lymphatic Capillaries

Lymphatic capillaries, also called the terminal lymphatics, are vessels where interstitial fluid enters the lymphatic system to become lymph fluid. Located in almost every tissue in the body, these vessels are woven among the arterioles and venules of the circulatory system in the soft connective tissues of the body. Exceptions are the central nervous system, bone marrow, bones, teeth, and the cornea of the eye, which do not contain lymph vessels. Lymphatic capillaries are formed by a one-cell-thick layer of endothelial cells and represent the open end of the system, allowing interstitial fluid to flow into them via overlapping cells. See Figure 12.3[3] for an illustration of lymphatic capillaries.

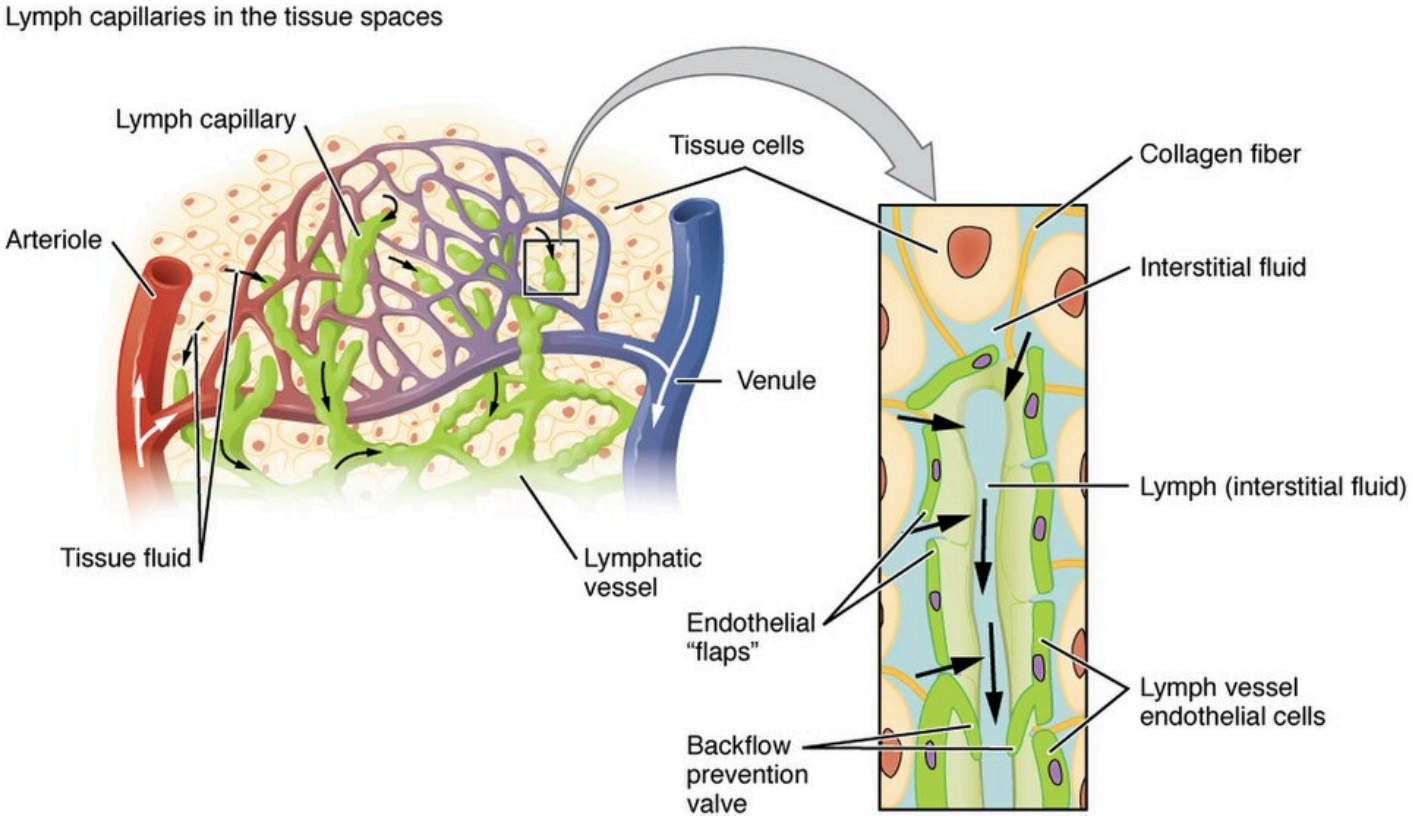


Figure 12.3 Lymphatic Capillaries

In the small intestine, lymphatic capillaries called **lacteals** are necessary for the transport of dietary lipids and lipid-soluble vitamins to the bloodstream. In the small intestine, dietary triglycerides combine with other lipids and proteins and enter the

3. OpenStax College. (2013). *2202_Lymphatic capillaries* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2202_Lymphatic_Capillaries.jpg

lacteals to form a milky fluid called **chyle**. The chyle then travels through the lymphatic system, eventually entering the bloodstream.[4]

Larger Lymphatic Vessels, Trunks, and Ducts

The lymphatic capillaries empty into larger lymphatic vessels, which are similar to veins in terms of their three-tunic structure and the presence of valves. These one-way valves are located fairly close to one another, and each one causes a bulge in the lymphatic vessel, giving the vessels a beaded appearance.

The superficial and deep lymphatics eventually merge to form larger lymphatic vessels known as **lymphatic trunks**. The overall drainage system of the body is asymmetrical. The right lymphatic duct receives lymph from only the upper right side of the body. The lymph from the rest of the body enters the bloodstream through the much larger thoracic duct via all the remaining lymphatic trunks.

In general, lymphatic vessels of the subcutaneous tissues of the skin, that is, the superficial lymphatics, follow the same routes as veins, whereas the deep lymphatic vessels of the viscera generally follow the paths of arteries.[5] See Figure 12.4[6] for an illustration of lymphatic and thoracic ducts.

4. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

5. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

6. OpenStax College. (2013). *2203_Lymphatic trunks and ducts system* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2203_Lymphatic_Trunks_and_Ducts_System.jpg

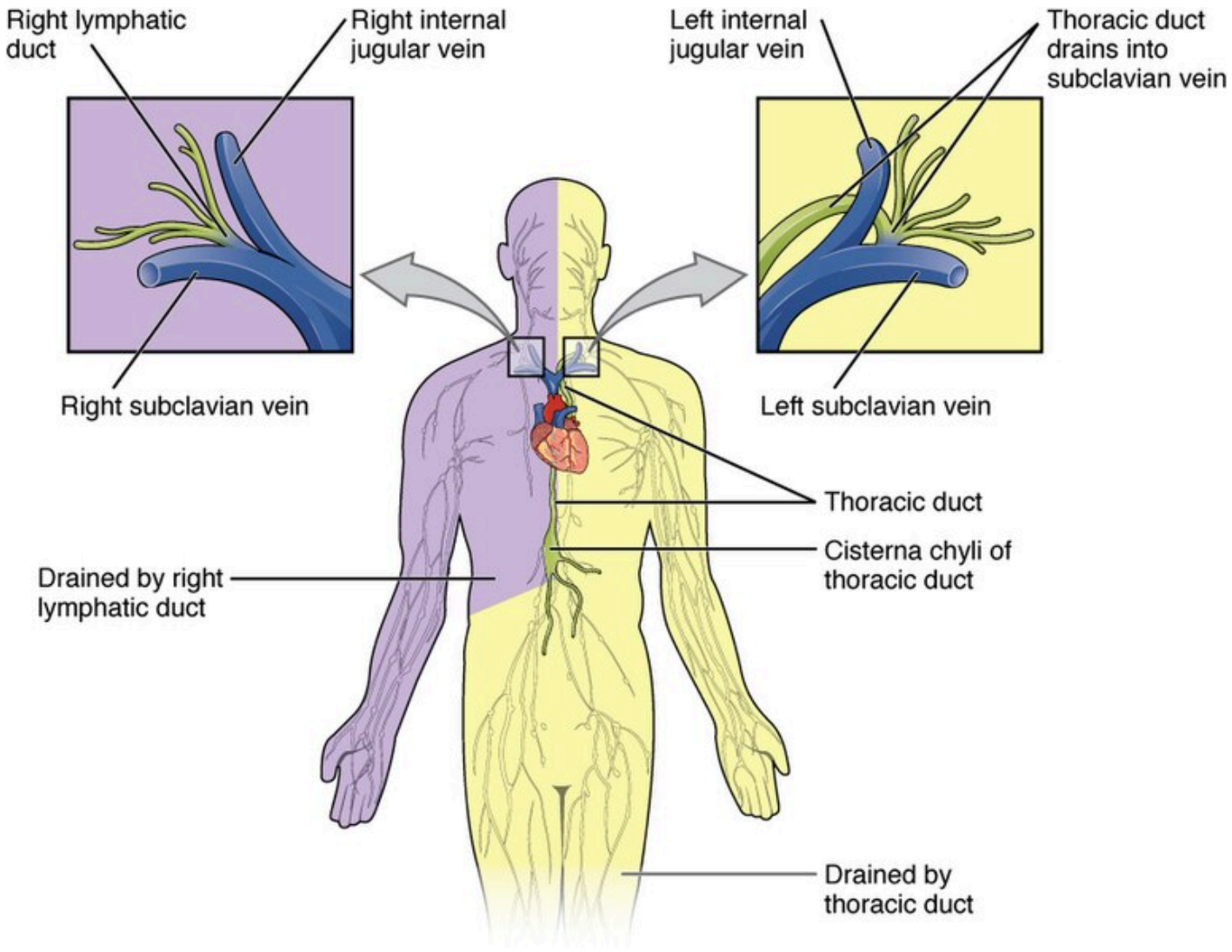


Figure 12.4 Lymphatic and Thoracic Ducts

Thymus

The **thymus gland** is a bi-lobed organ found in the space between the sternum and the aorta of the heart. Connective tissue holds the lobes closely together but also separates them and forms a capsule. The thymus is involved in the development and

maturation of T-cells and is particularly active during infancy and childhood, and begins to shrink during puberty.[7] See Figure 12.5[8] for an illustration of the thymus.

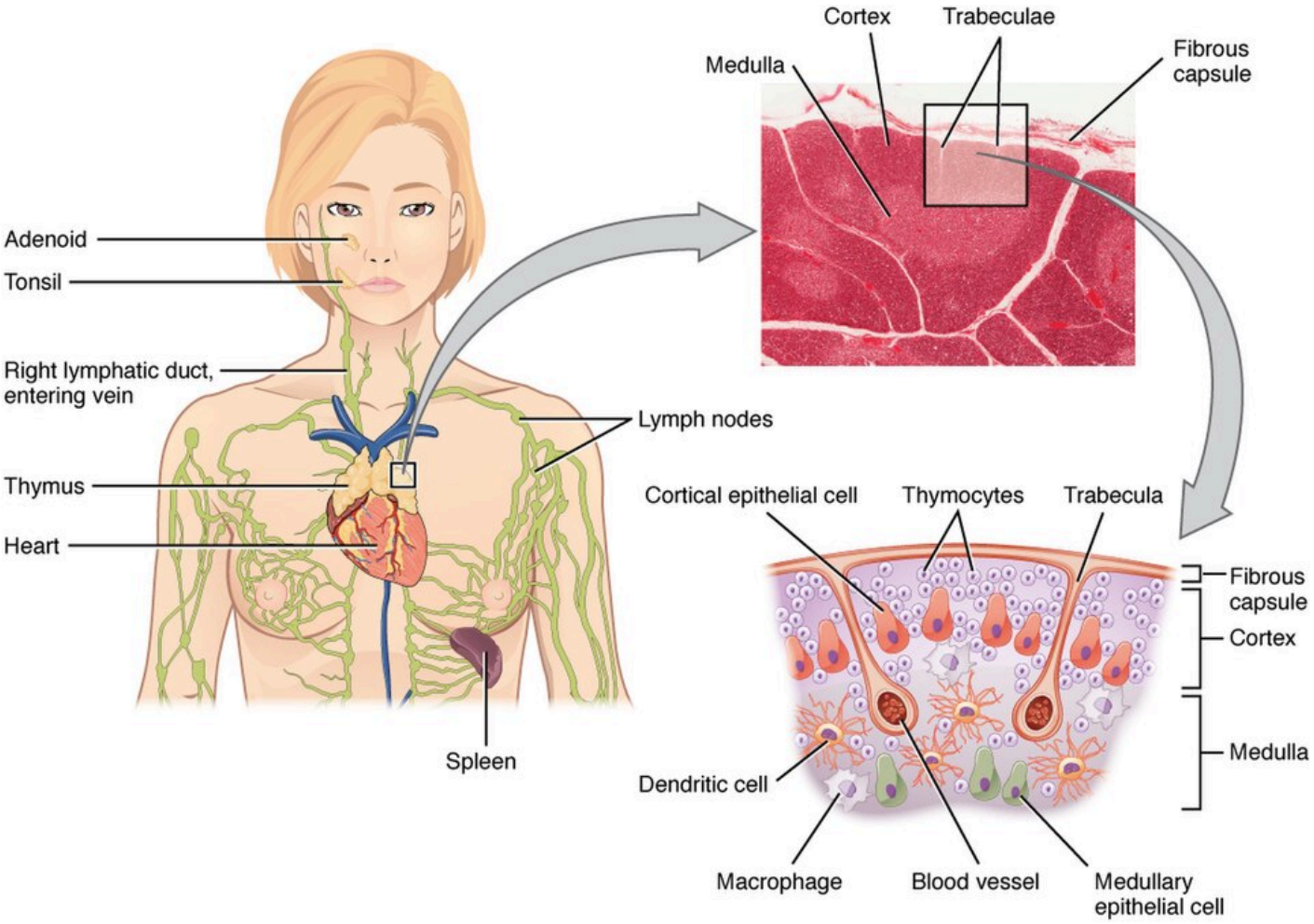


Figure 12.5 Thymus

Lymph Nodes

Humans have about 500–600 lymph nodes throughout the body, with major locations being the groin, armpits, neck, chest, and abdomen. Lymph nodes function to remove debris and pathogens from the lymph and are, thus, sometimes referred to as

7. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

8. OpenStax College (2013). *2206_The location structure and histology of the thymus* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2206_The_Location_Structure_and_Histology_of_the_Thymus.jpg

the “filters of the lymph.” Any bacteria that infect the interstitial fluid are taken up by the lymphatic capillaries and transported to a regional lymph node. Dendritic cells (a special type of phagocyte) and macrophages within this organ internalize and kill many of the pathogens that pass through, thereby removing them from the body. The lymph node is also the site of specific immunity responses mediated by T cells, B cells, and accessory cells of the specific immune system.[9] See Figure 12.6[10] for an illustration of a lymph node.

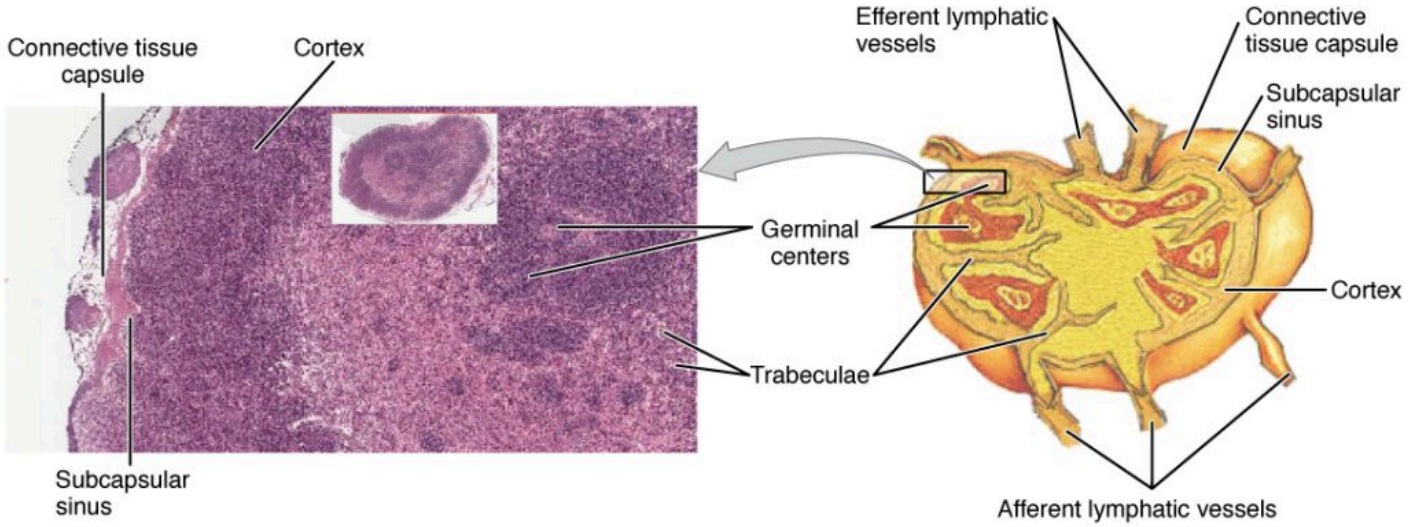


Figure 12.6 Lymph Node

Spleen

In addition to the lymph nodes, the **spleen** is a major secondary lymphoid organ. It is about 12 cm (5 in) long. The spleen is a fragile organ without a strong capsule and is dark red due to its extensive vascularization. The spleen is sometimes called the “filter of the blood” because of the presence of macrophages and dendritic cells that remove microbes and other materials from the blood, including old red blood cells. The spleen also functions as the location of immune responses to blood-borne pathogens.

The spleen is made up of red pulp, consisting mostly of red blood cells, and white pulp, consisting of lymphatic tissue. Thus, the red pulp primarily functions as a filtration system of the blood, using cells of the relatively nonspecific immune system, and the

9. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

10. OpenStax. (2013). *2207_Structure and histology of a lymph node* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2207_Structure_and_Histology_of_a_Lymph_Node.jpg

white pulp is where adaptive T and B cell responses are mounted. See Figure 12.7[11] for an illustration of the spleen.

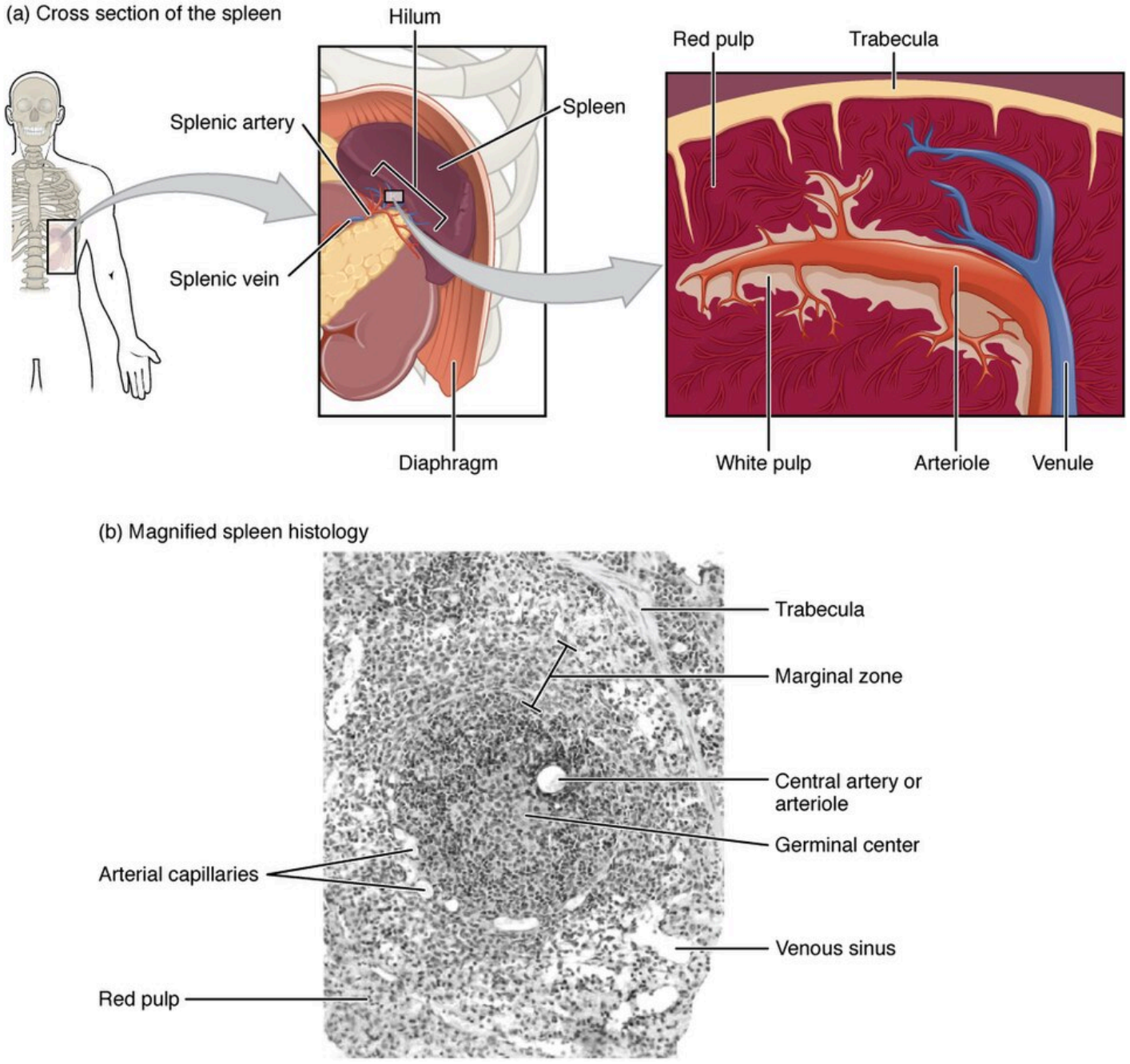


Figure 12.7 Spleen

11. OpenStax. (2013). *2208_Spleen* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2208_Spleen.jpg

Lymphoid Nodules

The other lymphoid tissues, the **lymphoid nodules**, are similar to the spleen and lymph nodes in that they consist of a dense cluster of lymphocytes without a surrounding fibrous capsule. These nodules are located in the respiratory and digestive tracts, areas routinely exposed to environmental pathogens.

Tonsils are lymphoid nodules located along the inner surface of the pharynx (throat) and are important in developing immunity to oral pathogens. The tonsils include the palatine tonsils located at the back of the throat; the pharyngeal tonsil, commonly referred to as the adenoid, located in the throat behind the nose; and the lingual tonsils found at the base of the tongue. When tonsils are swollen, it is an indication of an active immune response to infection.

Histologically, tonsils do not contain a complete capsule, and the epithelial layer invaginates deeply into the interior of the tonsil to form tonsillar crypts. These structures, which accumulate all sorts of materials taken into the body through eating and breathing, actually "encourage" pathogens to penetrate deep into the tonsillar tissues, where they are acted on by numerous lymphoid follicles and eliminated. This seems to be the major function of tonsils—to help children's bodies recognize, destroy, and develop immunity to common environmental pathogens so that they will be protected in their later lives.

Tonsils are often removed in children who have recurrent throat infections, especially those involving the palatine tonsils on either side of the throat, whose swelling may interfere with their breathing and/or swallowing.[12] See Figure 12.8[13] for an illustration of the tonsils.

12. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

13. OpenStax. (2013). *2209_Location and histology of tonsils* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2209_Location_and_Histology_of_Tonsils.jpg

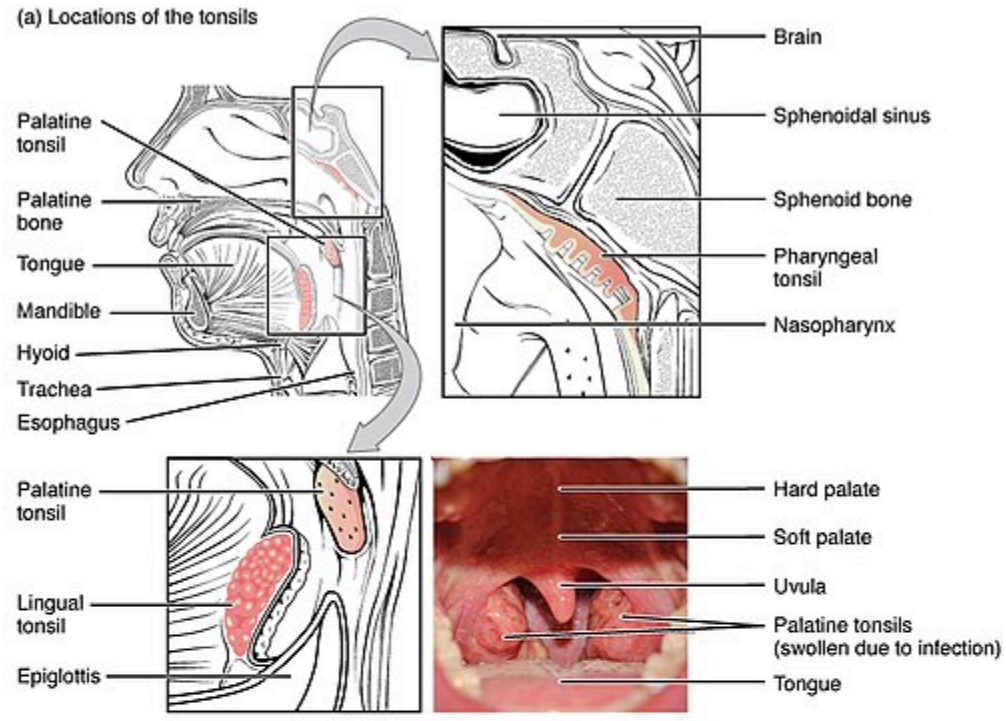


Figure 12.8 Tonsils

Mucosa-Associated Lymphoid Tissue

Mucosa-associated lymphoid tissue (MALT) makes up dome-shaped structures found deep to the mucosa of the gastrointestinal tract, breast tissue, lungs, and eyes. Peyer's patches, a type of MALT in the small intestine, are especially important for immune responses against ingested substances. Peyer's patches contain specialized cells that sample material from the intestinal lumen and transport it to nearby follicles so that

adaptive immune responses to potential pathogens can be mounted. A similar process occurs involving MALT in the mucosa and submucosa of the appendix. A blockage of the lumen triggers these cells to elicit an inflammatory response that can lead to appendicitis.[14] See Figure 12.9[15] for an illustration of mucosa-associated lymphoid tissue.

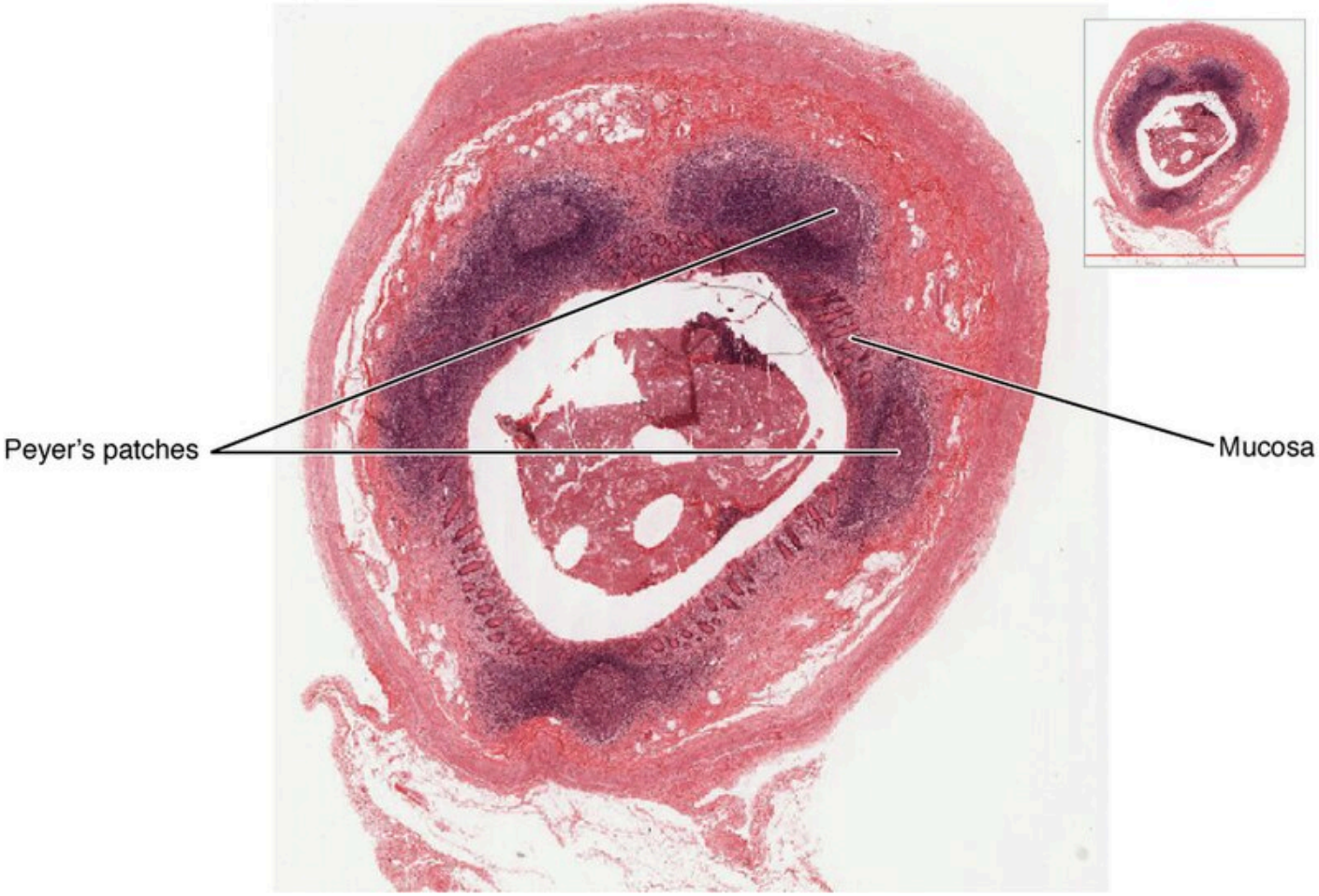


Figure 12.9 Mucosa-Associated Lymphoid Tissue (MALT)

14. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

15. OpenStax College. (2013). *2210_Mucosa_Associated_Lymphoid_Tissue_(MALT)_Nodule* [Image]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2210_Mucosa_Associated_Lymphoid_Tissue_(MALT)_Nodule.jpg

Videos

Watch the video “The Lymphatic System Overview, Animation” below to learn about the lymphatic system.[16]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

16. Alila Medical Media. (2018, November 20). *The lymphatic system overview, animation* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=cCPyWFK0IKs

12.4 Immune System

The immune system can be divided into two overlapping mechanisms to destroy a wide variety of pathogens: the nonspecific (innate) immune response and the specific (adaptive) immune response. The nonspecific immune response is relatively rapid but nonspecific in that it will respond to any pathogen, but as a drawback, this response does not create a memory of the pathogen. Nonspecific immunity will, however, help to initiate the specific (adaptive) immune response, which is slower in its development during an initial infection with a pathogen, but is highly specific and effective at attacking pathogens. The specific (adaptive) immune response requires exposure to a pathogen for the body to recognize it as a threat and respond. After the adaptive immune system has been exposed to a pathogen, it develops memory cells to recognize this pathogen in the future and quickly mount a defense.[1]

Nonspecific (Innate) Immune Response

The innate immune response begins with physical barriers that prevent pathogens from entering the body, destroy them after they enter, or flush them out before they can establish themselves in the body's soft tissues. Nonspecific barrier defenses are part of the body's most basic defense mechanisms. The nonspecific defenses are not a response to infections, but they are continuously working to protect against a broad range of pathogens. The different modes of nonspecific defenses are associated with the external surfaces of the body, where pathogens may try to enter.[2] Barrier defenses are summarized in Table 12.4a.

Table 12.4a. Barrier Defenses[3]

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
3. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Structure	Protective Aspect
Skin: Epidermal Surface	Keratinized cells of the surface, Langerhans cells
Skin: Sweat/Oil Glands	Low pH, washing action
Mouth: Salivary Glands/Saliva	Lysozymes, antibodies
Stomach: Gastric Juice	Low pH
Mucosal Surfaces	Mucus
Normal Flora (nonpathogenic bacteria) of Mucosal Tissues	Prevent pathogens from growing on mucosal surfaces

The skin is the primary barrier to microorganisms entering the body. The skin is covered with multiple layers of dead, keratinized epithelium that is too dry for bacteria to grow on, but as these cells are continuously sloughed off from the skin, they carry bacteria and other pathogens with them. Additionally, sweat and other skin secretions may lower pH, contain toxic lipids, and physically wash microbes away. In the mouth, saliva is rich in lysozyme, an enzyme that destroys bacteria. Furthermore, the acidic environment of the stomach is fatal to many pathogens that enter the gastrointestinal system. Additionally, the mucus layer of the gastrointestinal tract, respiratory tract, reproductive tract, urinary tract, eyes, ears, and nose traps microbes and debris and facilitates their removal. In the upper respiratory tract, ciliated epithelial cells move potentially contaminated mucus upwards to the mouth, where it is swallowed and ends up in the harsh acidic environment of the stomach. Considering how often we breathe compared to how often we eat or perform other activities that expose us to pathogens, it is not surprising that multiple barrier mechanisms have evolved to work together to protect this vital area.

Video

Watch the video "Immune and Lymphatic System Explained (Structure and Function Basics)" below to learn more about the immune and lymphatic systems.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Cells of the Innate Immune Response

A phagocyte is a cell that is able to surround and engulf a particle or cell, a process called **phagocytosis**. The phagocytes of the immune system engulf other particles or

cells, either to clean an area of debris or old cells or to kill pathogenic organisms such as bacteria. The phagocytes are the body's fast-acting, first line of immunological defense against organisms that have breached barrier defenses and have entered the vulnerable tissues of the body.

Many cells of the immune system have a phagocytic ability, at least at some point during their life cycles. Phagocytosis is an important and effective mechanism of destroying pathogens during innate immune responses. The phagocyte takes the organism inside itself as a phagosome, which subsequently fuses with a lysosome and its digestive enzymes, effectively killing many pathogens. On the other hand, some bacteria, including *Mycobacteria* tuberculosis, the cause of tuberculosis, may be resistant to these enzymes and are, therefore, much more difficult to clear from the body. Macrophages, neutrophils, and dendritic cells are the major phagocytes of the immune system.

A **macrophage** is an irregularly shaped phagocyte that is the most versatile of the phagocytes in the body. Macrophages can move through tissues and squeeze through capillary walls. They not only participate in innate immune responses but also have evolved to cooperate with lymphocytes as part of the specific immune response. Macrophages exist in many tissues of the body, either freely roaming or fixed within specific tissues such as lymph nodes. When pathogens breach the body's barrier defenses, macrophages are the first line of defense. They are called different names, depending on the tissue: Kupffer cells in the liver, histiocytes in connective tissue, and alveolar macrophages in the lungs.

A **neutrophil** is a phagocytic cell that is attracted to infected tissues. Neutrophils can be thought of as military reinforcements that are called into a battle to hasten the destruction of the enemy. Although usually thought of as the primary pathogen-killing cell of the inflammatory process of the innate immune response, new research has suggested that neutrophils play a role in the adaptive immune response as well, just as macrophages do.

A **monocyte** is a circulating cell that differentiates into either a macrophage or dendritic cell, which can be rapidly attracted to areas of infection.[4]

See Table 12.4b for a summary of phagocytic cells of the immune system.

Table 12.4b. Phagocytic Cells of the Innate Immune System[5]

4. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

5. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young,

K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Cell	Cell type	Primary Location	Function in the Innate Immune Response
Macrophage	Agranulocyte	Body cavities/organs	Phagocytosis
Neutrophil	Granulocyte	Blood	Phagocytosis
Monocyte	Agranulocyte	Blood	Precursor of macrophage/dendritic cell

Natural Killer Cells

Natural killer (NK) cells are a type of lymphocyte that have the ability to cause apoptosis (programmed cell death) in cells infected with intracellular pathogens such as bacteria or viruses. They also destroy other abnormal cells, such as cancer cells. NK cells recognize these cells by mechanisms that are still not well-understood.[6]

Inflammatory Response

The hallmark of the innate immune response is inflammation. Inflammation is something everyone has experienced when injured. For example, cutting a finger, stubbing a toe, or any injury that causes tissue damage will result in inflammation with four characteristics: heat, redness, pain, and swelling. "Loss of function" is sometimes mentioned as a fifth characteristic of inflammation. Note that inflammation does not have to be initiated by an infection but can also be caused by tissue injuries.

The release of damaged cell contents into the site of injury is enough to stimulate the inflammatory response, even if no pathogens enter. For example, hitting your thumb with a hammer initiates the inflammatory response. The inflammatory reaction brings in phagocytic cells to the damaged area to clear cellular debris and to set the stage for wound repair. See Figure 12.10[7] for an illustration of the inflammatory response.

6. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

7. OpenStax College. (2019). *2213_Inflammatory process* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2213_Inflammatory_Process.jpg

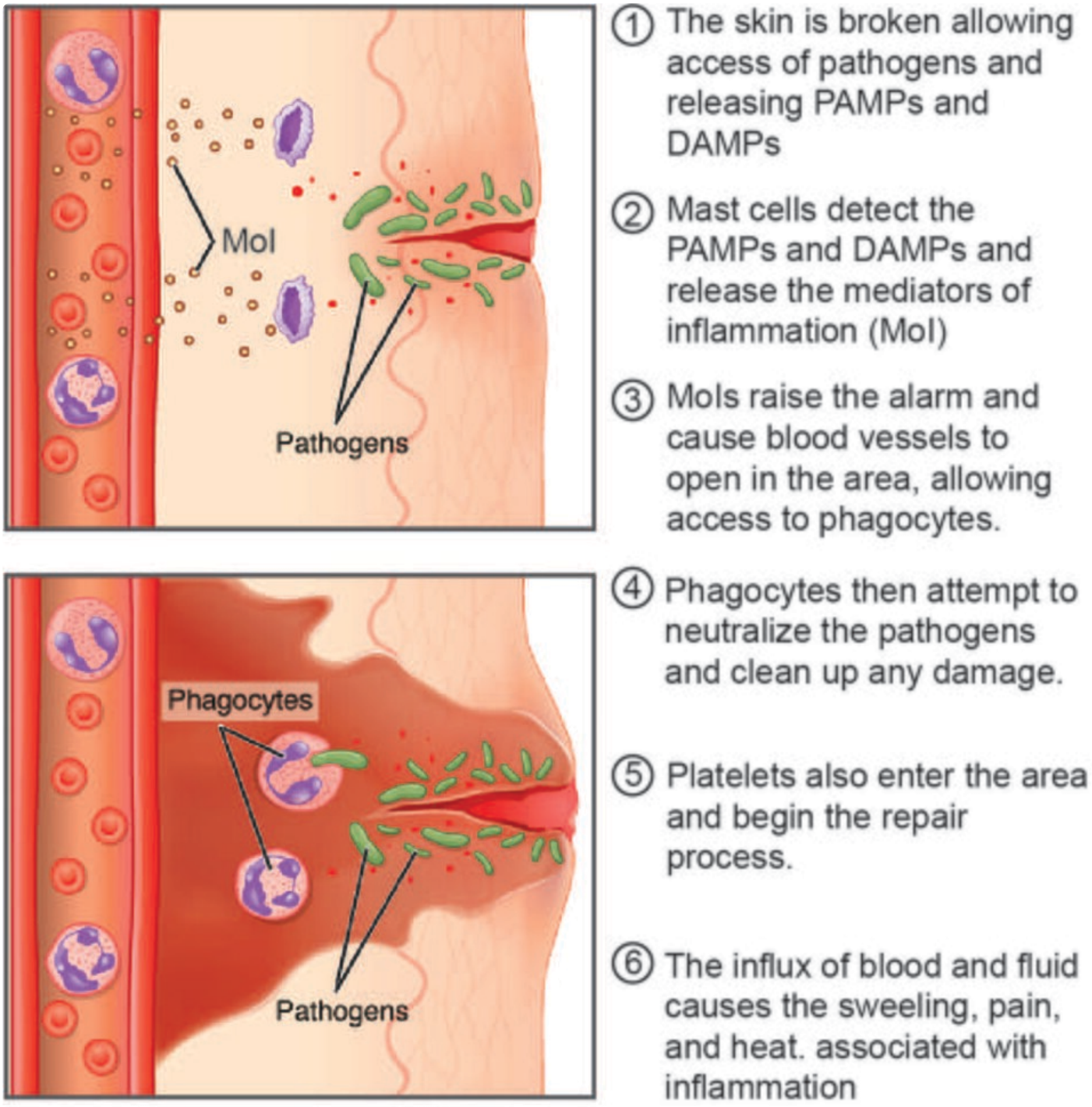


Figure 12.10 Inflammatory Response

This reaction also brings in the cells of the innate immune system, allowing them to get rid of the sources of a possible infection. Inflammation is part of a very basic form of immune response. The process not only brings fluid and cells into the site to destroy

the pathogen and remove it and debris from the site, but also helps to isolate the site, limiting the spread of the pathogen.

Acute inflammation is a short-term inflammatory response. If the cause of the inflammation is not resolved, however, it can lead to chronic inflammation, which is associated with major tissue destruction and fibrosis. **Chronic inflammation** is ongoing inflammation. It can be caused by foreign bodies, persistent pathogens, and autoimmune diseases such as rheumatoid arthritis.

There are four important parts to the inflammatory response: tissue injury, vasodilation, increased vessel permeability, and recruitment of phagocytes.[8]

Tissue Injury

The released contents of injured cells stimulate the release of mast cell granules and their potent inflammatory chemicals, such as histamine, leukotrienes, and prostaglandins. **Histamine** increases the diameter of local blood vessels (vasodilation), causing an increase in blood flow to the damaged area. Histamine also increases the permeability of local capillaries, causing plasma to leak out and form interstitial fluid. This causes the swelling associated with inflammation.

Additionally, injured cells, phagocytes, and basophils are sources of inflammatory chemicals, including prostaglandins and leukotrienes. Leukotrienes attract neutrophils from the blood and increase vessel permeability. Prostaglandins cause vasodilation and are a major cause of the pain associated with inflammation. Nonsteroidal anti-inflammatory drugs such as aspirin and ibuprofen relieve pain by inhibiting prostaglandin production.

Vasodilation

Many inflammatory chemicals, such as histamine, are vasodilators that increase the diameters of local capillaries. This causes increased blood flow to the area and is responsible for the heat and redness of inflamed tissue. It allows greater access of the blood to the site of inflammation.

8. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Increased Vessel Permeability

At the same time, inflammatory chemicals increase the permeability of the local vessels, causing leakage of fluid into the interstitial space, resulting in the swelling, or edema, associated with inflammation.

Recruitment of Phagocytes

Any type of invasion or tissue injury attracts neutrophils from the blood to the site of infection. Neutrophils are the first responders, and then macrophages are recruited to clean up the debris left over at the site. When local infections are severe, neutrophils are attracted to the sites of infection in large numbers, and as they phagocytize the pathogens and subsequently die, their accumulated cellular remains are visible as pus at the infection site.

Inflammation is valuable for many reasons. Not only are the pathogens killed and debris removed, but also the increase in vessel permeability encourages the entry of clotting factors, the first step towards wound repair. Inflammation also facilitates the transport of antigens to lymph nodes for the development of the adaptive immune response.

Specific (Adaptive) Immune Response

The slower but more effective **specific or adaptive immune response** is primarily controlled by lymphocytes, which help control immune responses. There are two main groups of lymphocytes, called B cells and T cells, both of which are formed in bone marrow. B cells are involved in humoral immunity, and T cells are involved in cell-mediated defenses.[9] See Figure 12.11[10] for an overview of the specific immune response.

9. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

10. WisTech Open. (2024). *Immune_Response 2* [Chart]. Chippewa Valley Technical College. CC BY-NC 4.0. https://wtcs.pressbooks.pub/healthalts/chapter/4-2-review-of-anatomy-and-physiology-of-the-immune-system/

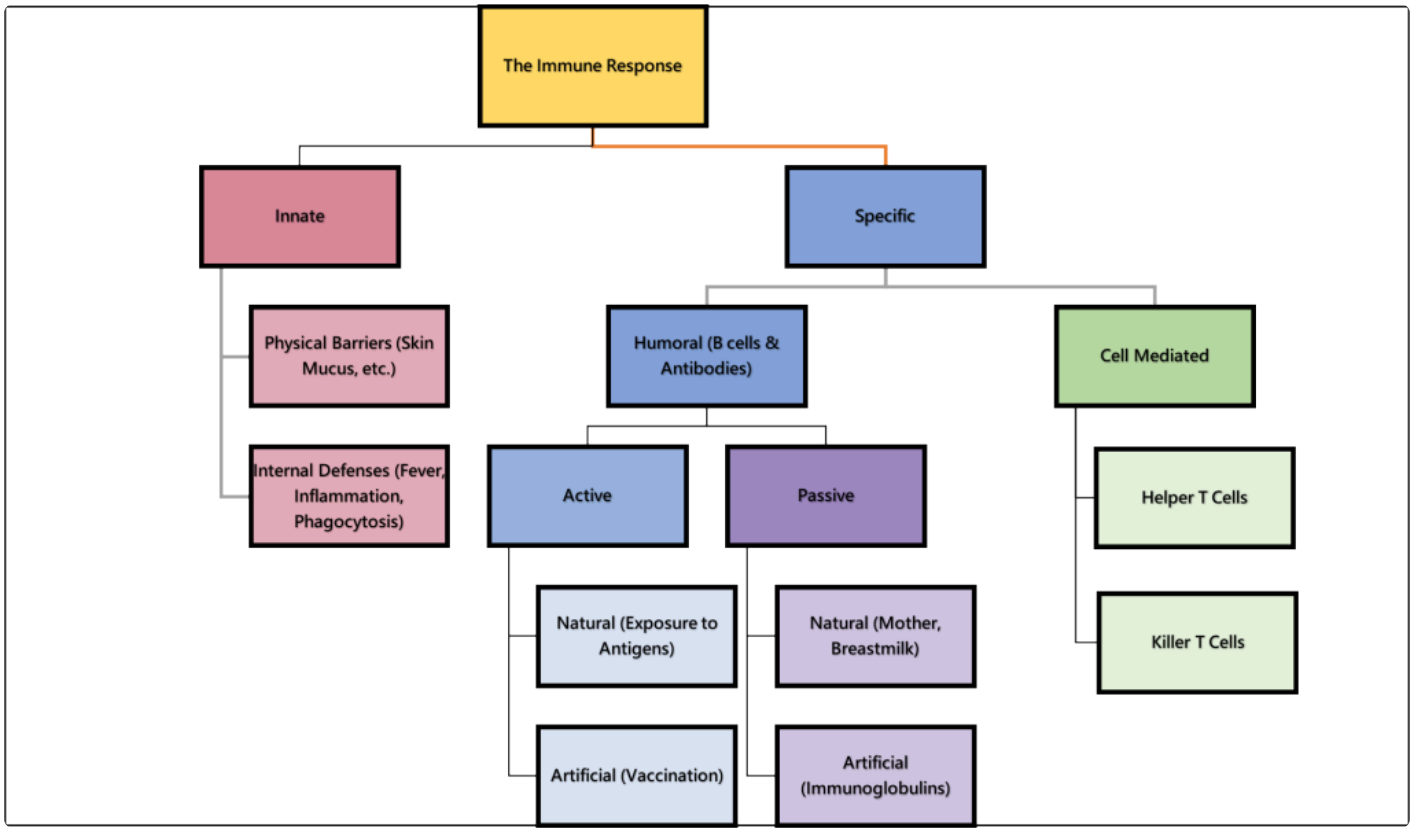


Figure 12.11 Immune Response

Humoral Immunity (B cells and Antibodies)

Humoral immunity refers to the function of B cells and their production of antibodies. B cells originate and develop in the bone marrow and then migrate in body fluids through the lymph nodes, spleen, and blood to seek out and destroy pathogens in the interstitial spaces. B cells make Y-shaped proteins called **antibodies** that destroy pathogens based on their antigens. **Antigens** are markers that tell the immune system whether something in the body is harmful or not. Antigens are found on viruses, bacteria, cancer cells, and even normal cells of the body. Each antigen has a unique shape that the immune system reads like a name tag to know whether or not it belongs in that person's body. Antibodies are very specific to the antigens they recognize and destroy. They fit onto the antigen like a key to a lock.

When a B cell finds an abnormal cell with an antigen for which it has antibodies, it binds to it and responds by cloning itself into many B cells and also releases thousands of antibodies per second to attack the pathogen. Some B cells become memory B cells

that are involved in immunological memory to ensure a stronger and faster antibody response if the body is exposed to the same antigen in the future.[11]

Cell-Mediated Response (T cells)

When innate immunity and humoral immunity are not effective in defending against pathogens or abnormal cells, the **cell-mediated response** uses lymphocytes called T cells to destroy the abnormal cells. There are two major types of T cells called helper T cells and cytotoxic T cells:

- Helper T (CD4) cells use chemical messengers to activate the specific immune response. They stimulate B cells to make antibodies and help activate the cytotoxic T cells.
- Cytotoxic T (CD8) cells directly kill cells that have been invaded by a virus or are otherwise abnormal.

During a primary specific immune response, both memory T cells and effector T cells are generated. Memory T cells are long-lived and can even persist for a lifetime. Memory cells act rapidly, so any subsequent exposure to the pathogen will elicit a very rapid T cell response. This rapid response generates large numbers of effector T cells so fast that the pathogen is often overwhelmed before it can cause any symptoms of disease. This is what is meant by immunity to a disease.[12]

Active Versus Passive Immunity

Immunity to pathogens and the ability to control pathogen growth so that tissue damage is limited can be acquired by (1) the active development of an immune response in the infected individual or (2) the passive transfer of immune components from an immune individual to a nonimmune one. Both active and passive immunity have examples in the natural world and as part of medicine.

Active immunity is the resistance to pathogens acquired during an adaptive immune response within an individual. Active immunity can be acquired naturally

11. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Health alterations.* Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthalts/
12. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Health alterations*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthalts/

through exposure to a pathogen or artificially through the use of vaccines. A vaccine contains a killed or weakened pathogen or its components. When administered to a healthy individual, it causes a weakened primary immune response and the development of immunological memory. With the administration of vaccines, one can avoid the damage from disease that results from exposure to a pathogen, yet reap the benefits of protection from immunological memory. The advent of vaccines was one of the major medical advances of the twentieth century and led to the eradication of smallpox and the control of many infectious diseases, including polio, measles, and whooping cough.

Passive immunity arises from the transfer of antibodies to an individual without mounting their own active immune response. Naturally acquired passive immunity is seen during fetal development when antibodies are transferred from the maternal circulation to the fetus via the placenta, thus protecting the fetus from infection and protecting the newborn for the first few months of its life. A newborn also benefits from the antibodies it obtains from its mother's milk during breastfeeding. Therefore, the fetus and newborn benefit from the immunological memory based on the pathogens to which the pregnant mother has been exposed.

Artificially acquired passive immunity typically involves injections of immunoglobulins taken from donated human blood previously exposed to a specific pathogen. This treatment is a fast-acting method of temporarily protecting an individual who has had a possible exposure to a pathogen or has an immunodeficiency disease and is not capable of creating their own antibodies. The downside to both types of passive immunity is the lack of the development of immunological memory. Once the antibodies are transferred, they are effective for only a limited time before they degrade.[13]

See Table 12.4c for a summary of natural and artificial active and passive immunity.

Table 12.4c. Active Versus Passive Immunity[14]

13. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

14. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Type of Immunity	Natural	Artificial
Active	Adaptive immune response	Vaccine response
Passive	Transplacental antibodies and breastfeeding	Immune globulin injections

12.5 Lymphatic System Disorders

Autoimmune Reactions

Autoimmune reactions occur when the immune system initiates a response against the body's own healthy cells, tissues, or organs. There are a number of disorders that can cause autoimmune reactions. These disorders are chronic and can affect a variety of tissue types or body systems. Some common autoimmune disorders are as follows:

- Rheumatoid arthritis
- Lupus
- Psoriasis
- Crohn's disease
- Celiac disease
- Ulcerative colitis
- Type 1 diabetes
- Multiple sclerosis

Risk factors for developing an autoimmune disorder include certain viral infections, being female, family history of autoimmune conditions, already having one autoimmune disease, smoking, and exposure to certain chemicals, like pollution.

The signs, symptoms, and treatment of autoimmune reactions depend on the specific disorder that is present. With some autoimmune disorders, there may be times when there are no symptoms (remission) or times when symptoms are present (exacerbation). Even though there may be periods of remission, autoimmune disorders are chronic conditions that cannot be cured.[1,2]

1. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/
2. Mayo Clinic. (2024). *Autoimmune diseases*. https://my.clevelandclinic.org/health/diseases/21624-autoimmune-diseases

Cancer

Cancer is a condition of uncontrolled abnormal cell division. **Malignant cells** exhibit uncontrolled growth and rapidly divide, subsequently invading and causing damage to normal functioning cells. Some cancers also disrupt apoptosis, programmed cell death, to regulate the cell population. Malignant cells also have the potential to **metastasize**, or spread, to different parts of the body. When cells metastasize, they spread through the blood or lymphatic system. The spread of cancer cells and their rapid replication and invasion in other areas of the body complicate medical treatment, making it more difficult to rid the body of these abnormal invasive cells.

Benign cells grow and divide in a more controlled manner, remaining localized to a certain area.[3]

See Figure 12.12[4] for an illustration comparing benign and malignant tumors.

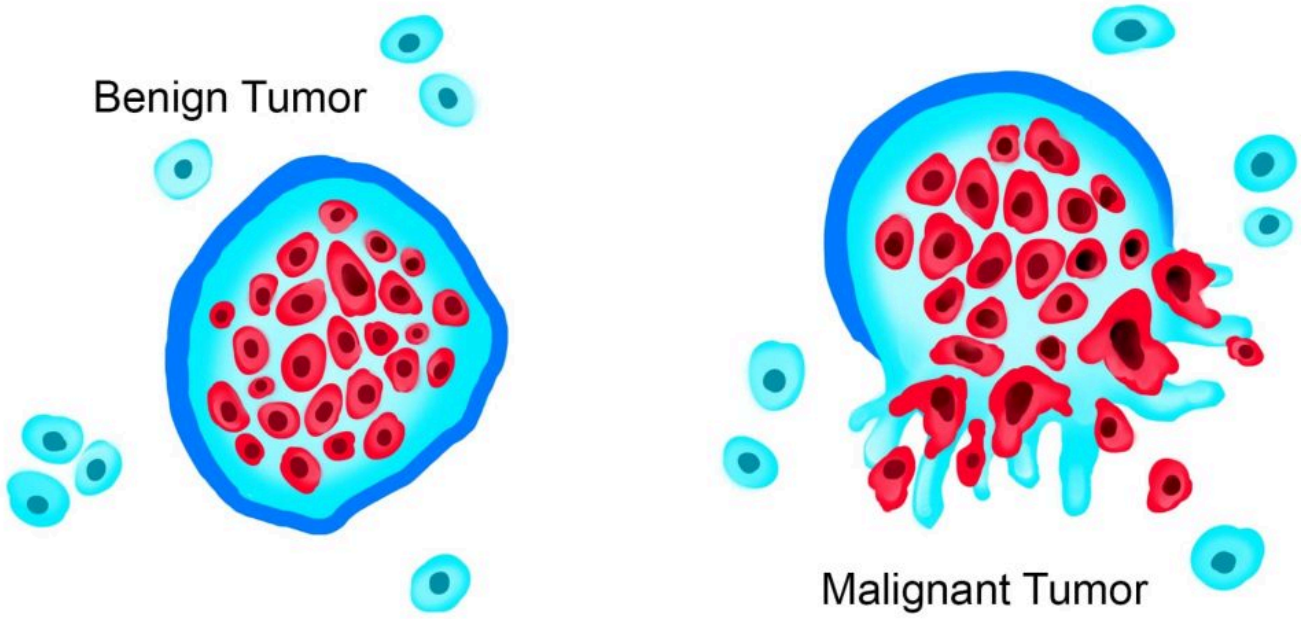


Figure 12.12 Benign and Malignant Tumors

3. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/
4. WolfpackBME. (2022). *Tumor types MTK* [Illustration]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Tumor_Types_MTK.jpg

Metastasis

Metastasis is the spread of cancer cells to other parts of the body. See Figure 12.13[5] for an illustration of metastasis of a primary tumor.

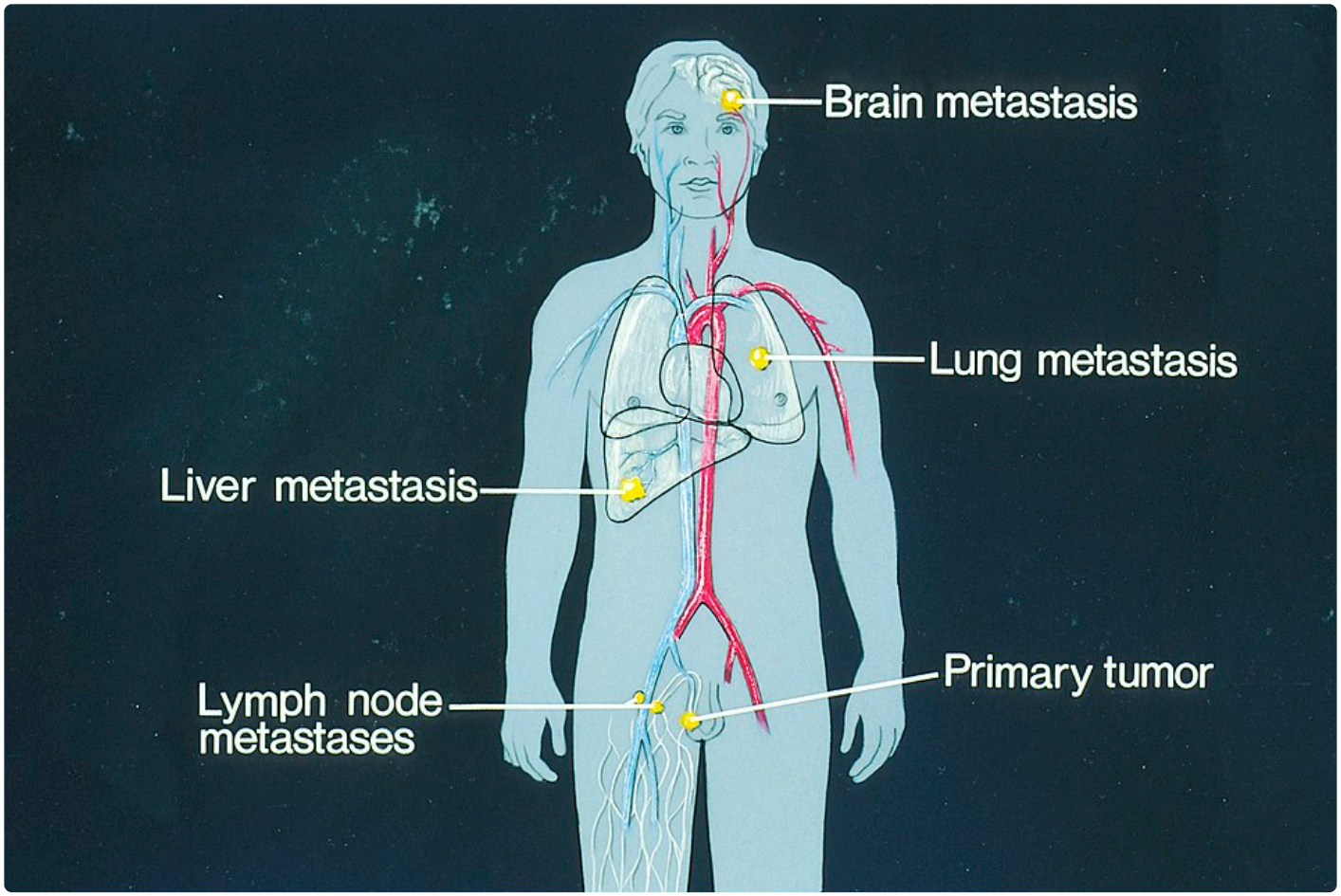


Figure 12.13 Metastasis

Common sites of metastasis include the following areas:

- Lungs: The lungs are a frequent site of metastasis because they receive a large volume of blood from the body's circulation. Cancer cells circulating in the bloodstream can easily lodge in the small blood vessels of the lungs, leading to secondary tumor formation.
- Liver: The liver plays a significant role in blood filtration, making it another common

5. National Cancer Institute. (1988). *Sites of potential metastases illustration* [Diagram]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Sites_of_potential_metastases_illustration.jpg

site for metastasis.

- Bones: Many cancers, such as breast, lung, and prostate cancer, tend to metastasize to the bones.
- Brain: Cancer cells can reach the brain through the bloodstream.
- Lymph nodes: Lymph nodes play a role in filtering lymph. Tumors located in proximity to the lymph nodes, especially breast, gastrointestinal, urological, gynecological, and some skin cancers, are more likely to spread through the lymphatic system. For this reason, lymph nodes and surrounding lymphatic vessels are sometimes surgically removed during procedures such as a mastectomy to reduce the risk of metastasis, since cancer cells can travel through the lymphatic pathways to other areas of the body.
- Small and large Intestines: The small and large intestines, including the colon and rectum, are susceptible to metastasis, particularly in colorectal cancer. Cancer cells from the colon can also spread to nearby lymph nodes and to the liver.
- Adrenal glands: The adrenal glands that sit on top of the kidneys can be affected by metastatic cancer. The adrenal glands have a rich blood supply, making them potential targets for cancer cells circulating in the bloodstream.
- Skin: Melanoma, a type of skin cancer, has a propensity to spread to other parts of the body, including distant skin sites and internal organs.
- Ovaries: In women, ovarian metastasis can occur from cancers that have spread through the bloodstream or lymphatic system. Breast, colorectal, and stomach cancers are examples of cancers that can metastasize to the ovaries.
- Kidneys: Kidney metastasis can occur when cancer cells from other parts of the body reach the kidneys through the bloodstream. The kidneys filter the blood, making them a potential site for cancer cells to become trapped.

Hypersensitivity Reactions

The body's immune responses are designed to protect us against threats, including infections and cancer. However, an individual's immune system can have an exaggerated immune response triggered by exposure to a specific antigen, referred to as a **hypersensitivity reaction**. This kind of exaggerated reaction can damage normal tissues and cause a range of health issues.

Allergic responses are specific types of hypersensitivity reactions that arise when the immune system reacts to allergens. **Allergens** are substances that are generally

harmless to most individuals. Common allergens include pollen, dust mites, pet dander, certain foods, and insect venom. When a person with allergies encounters these allergens, their immune system goes into overdrive, releasing histamines and other inflammatory molecules that trigger symptoms such as itching, sneezing, wheezing, hives, or anaphylaxis (further described below).

Allergies can be diagnosed with skin and blood testing. Allergy symptoms can be treated with antihistamines, steroids, or other anti-inflammatory medications. In certain types of allergic reactions, blood transfusions may be required. When possible, individuals with allergies should stay away from identified triggers.[6,7]

Anaphylaxis

Anaphylaxis is a severe, potentially life-threatening allergic reaction that can cause bronchoconstriction and swelling of the throat, leading to obstruction of the airway, as well as decreased cardiac output that can lead to shock. Recognition of early symptoms and signs of anaphylaxis and prompt intervention are crucial. Treatment typically involves the administration of epinephrine to dilate the airway and increase blood pressure to stabilize the patient's condition.

Immunodeficiencies

Immunodeficiency refers to an inadequate immune response caused by immune system dysfunction. An individual who has an impaired or weakened immune system is referred to as **immunocompromised**. Immunodeficiencies can be inherited or acquired.

Inherited immunodeficiencies arise from genetic mutations that affect specific components of the immune response. Individuals can also acquire immunodeficiencies, such as acquired immunodeficiency syndrome (AIDS), caused by the human immunodeficiency virus (HIV).

Those with immunodeficiencies are at risk for opportunistic infections. **Opportunistic infections** are infections that occur more often or are more severe in people with

6. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e.* Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/
7. Mayo Clinic. (2024). *Allergies*. https://www.mayoclinic.org/diseases-conditions/allergies/symptoms-causes/syc-20351497

weakened immune systems than in people with healthy immune systems. An example of an opportunistic infection is pneumonia caused by Candida, a type of yeast.[8]

Lymphedema

Lymphedema is a chronic disease in which there is an increase of lymphatic fluid in the body. The increase in lymphatic fluid overwhelms the lymphatic system and leads to edema and skin changes. Swelling from lymphedema can occur in the extremities, genitals, face, or torso. See Figure 12.14[9] for an image of different stages of lymphedema of the lower extremities.

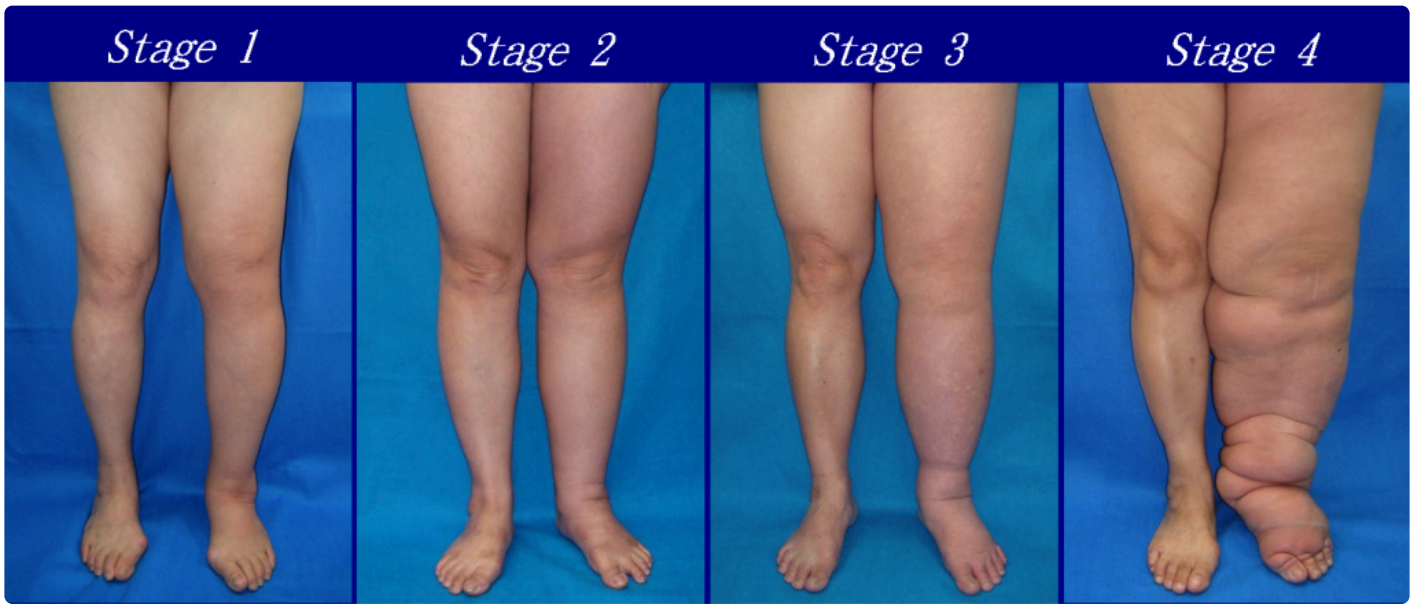


Figure 12.14 Lower Limb Lymphedema

Range of motion may be restricted in affected areas due to extreme swelling. Other signs and symptoms are pain, changes in sensation, and feelings of heaviness in the limbs. Over time, the skin in the affected area becomes hard and darkened, and swelling cannot be relieved by elevation. In some individuals, lymph fluid may even leak through the skin.

8. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/
9. DocHealer. (2017). *Lower limb lymphedema* [Photograph]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Lower_Limb_Lymphedema.png

Lymphedema can be a primary or secondary condition. In primary lymphedema, the cause is genetic and leads to impairment of the lymphatic system. Injury to the lymphatic system or removal of lymph nodes (during cancer treatment) can cause secondary lymphedema.

Lymphedema is a progressive condition that has no cure, but treatments are available. Treatment may consist of compression therapy, lymphatic massage, good skin care, or surgical procedures.[10]

Lymphoma

Lymphoma is a form of cancer in which masses of malignant T and/or B lymphocytes collect in lymph nodes, the spleen, the liver, and other tissues. The malignant leukocytes do not function properly, causing an increased risk for severe infection. Some types of lymphoma progress slowly and respond well to treatment, but others progress quickly and require aggressive treatment, without which they are rapidly fatal. There are two main types of lymphoma: Hodgkin lymphoma and non-Hodgkin lymphoma.[11,12]

Hodgkin Lymphoma

In Hodgkin lymphoma, lymphocytes grow out of control, causing swollen lymph nodes and growths throughout the body. Treatments for Hodgkin lymphoma include chemotherapy, radiation therapy, targeted therapy (drugs or other substances that attack specific cancer cells with less harm to normal cells), and cancer immunotherapy. Hodgkin lymphoma can usually be cured if it is found and treated early.

Non-Hodgkin Lymphoma

Non-Hodgkin lymphoma (NHL) is a diverse group of blood cancers that includes all

10. Sleigh, B. C., & Manna, B. (2023). *Lymphedema*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK537239/
11. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/
12. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

types of lymphoma except Hodgkin's lymphoma. Non-Hodgkin lymphoma is much less predictable than Hodgkin lymphoma and is more likely to metastasize. The prognosis depends on the type of white blood cell, the stage of the cancer, and the treatment options.

Human Immunodeficiency Virus (HIV)

Human immunodeficiency virus (HIV) is transmitted through semen, vaginal fluids, and blood and causes acquired immunodeficiency syndrome (AIDS). Individuals participating in unprotected sex with multiple partners or sharing needles with other intravenous drug users are at the highest risk of exposure to HIV. Infants are also at risk of contracting HIV if their mother is infected with the virus.

Flu-like symptoms may occur one to two weeks after exposure to HIV. These symptoms are followed by seroconversion, with clearance of the virus from the plasma and simultaneous elevated levels of anti-HIV antibodies. These antibodies are the basis for most initial HIV screening performed in the United States. Because seroconversion takes different lengths of time in different individuals, multiple tests must be performed months apart to confirm or refute the diagnosis.

After seroconversion, the amount of virus circulating in the blood stays at a low level for several years. During this time, the levels of CD4+ cells (helper T cells) decline steadily. If left untreated, the immune response becomes so weak that opportunistic disease from normally harmless organisms (such as yeast) results in death.

Treatment consists of medications that target virally encoded proteins necessary for viral replication in cells. By targeting the virus itself and sparing the cells, this approach has been very successful in significantly prolonging the lives of HIV-positive individuals. On the other hand, an HIV vaccine has been in development for over 30 years, but has been unsuccessful because the virus mutates rapidly to evade the immune system. Scientists continue to research parts of the virus that do not change and, thus, would be good targets for a vaccine.[13]

13. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Mononucleosis

Infectious mononucleosis (commonly called “mono” or the kissing disease) is caused by the Epstein-Barr virus and is spread through saliva. Teens and young adults are most likely to become infected with mononucleosis with classic signs and symptoms, but young children may also become infected with mononucleosis with few symptoms, so they may go undiagnosed. Signs and symptoms of mononucleosis may include the following[14]:

- Fatigue
- Sore throat that doesn’t improve after treatment with antibiotics
- Fever
- Swollen lymph nodes in the neck and armpits
- Swollen tonsils
- Headache
- Skin rash
- Enlarged spleen

The virus has an **incubation period** (the length of time before symptoms appear after being exposed to the virus) of about four to six weeks, although in young children this period may be shorter. There are no medications available to treat infectious mononucleosis; therefore, treatment mainly involves resting, eating a healthy diet, and drinking plenty of fluids.[15]

Myasthenia Gravis

Myasthenia gravis is a chronic, autoimmune neuromuscular disease that causes weakness in voluntary muscles, including those required for breathing and swallowing. Onset of symptoms can be rapid and include abnormal weakness of voluntary muscles (myasthenia), weakness of the eye muscles (ocular myasthenia), drooping of one or both eyelids (ptosis), blurred or double vision (diplopia), difficulty swallowing (dysphagia),

14. Mayo Clinic. (2022). *Mononucleosis*. https://www.mayoclinic.org/diseases-conditions/mononucleosis/symptoms-causes/syc-20350328

15. Mayo Clinic. (2022). *Mononucleosis*. https://www.mayoclinic.org/diseases-conditions/mononucleosis/symptoms-causes/syc-20350328

shortness of breath (dyspnea), and/or impaired speech (dysarthria). Figure 12.15[16] depicts ptosis related to myasthenia gravis.

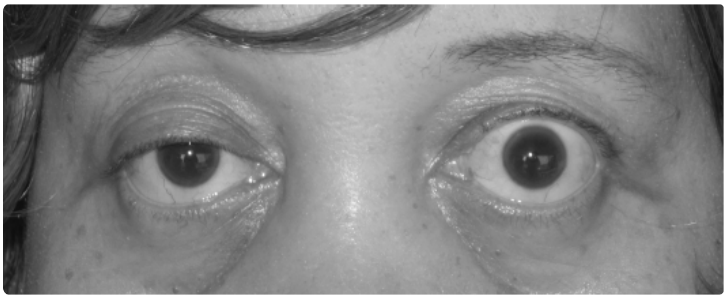


Figure 12.15 Ptosis Related to Myasthenia Gravis

Sometimes the muscles that control breathing weaken to the point where a person needs a ventilator to breathe. This is called a myasthenic crisis and requires immediate emergency medical care. A myasthenic crisis may be triggered by infection, stress, surgery, or an adverse reaction to medication.[17]

Myasthenia gravis is diagnosed by health care providers based on a physical exam, blood tests, and electromyography (EMG). Myasthenia gravis is treated with medications that improve neuromuscular transmission and increase muscle strength. Immunosuppressive medications may be prescribed to impact the autoimmune response. In some cases, a thymectomy (i.e., removal of the thymus) may be performed to rebalance the immune system and decrease myasthenia gravis symptoms.[19]

16. Stevenfruitsmaak. (2008). *Ptosis myasthenia gravis* [Photograph]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Ptosis_myasthenia_gravis.jpg
17. [18]
18. [15]
19. [20]
20. [16]

12.6 Career Connections Related to the Lymphatic System

The lymphatic system includes lymph, lymphatic vessels, lymph nodes, lymphatic organs, and immune cells. It helps return fluid to the bloodstream, absorbs fats from the digestive system, and supports the body's immune defenses. When the lymphatic or immune system is affected by infection, inflammation, cancer, allergies, or other conditions, many professionals may help with testing, treatment, patient care, and support. Careers related to the lymphatic system can include medical laboratory technicians, phlebotomists, medical assistants, registered nurses, and nursing assistants.

Medical Laboratory Technician

Medical laboratory technicians perform laboratory tests on blood and other body fluids that help providers diagnose and monitor disease. This career connects to the lymphatic system because laboratory tests can provide information about infection, inflammation, immune responses, and blood cell counts. Medical laboratory technicians may prepare specimens, operate laboratory instruments, record results, and follow quality control and safety procedures.

Phlebotomist

Phlebotomists are health care professionals who collect blood samples for testing, donation, or research. Blood tests are often used to evaluate infection, immune activity, inflammation, and other conditions related to the lymphatic and immune systems. Phlebotomists use knowledge of anatomy, infection prevention, patient identification, specimen labeling, and safety procedures to help ensure accurate test results and patient safety.

Medical Assistant

Medical assistants work in clinics and other health care settings where they support patient care and office procedures. In allergy, immunology, oncology, primary care, or infectious disease settings, medical assistants may help room patients, collect health information, record symptoms, prepare patients for examinations, assist with basic procedures, support documentation, and communicate follow-up instructions.

Registered Nurse

Registered nurses provide patient care, education, and support in hospitals, clinics, long-term care facilities, and community settings. This career connects to the lymphatic system because nurses may care for patients with infections, immune system disorders, cancer, lymphedema, or allergic conditions. They may monitor symptoms, administer medications, provide patient education, support infection prevention, and coordinate care with other members of the health care team.

Nursing Assistant

Nursing assistants provide basic care and help patients with daily activities under the supervision of licensed nursing staff. This career connects to the lymphatic system because nursing assistants may help care for patients who have infections, cancer, swelling, weakness, or limited mobility. They may assist with bathing, dressing, repositioning, vital signs, comfort measures, and reporting changes in a patient's condition.

Take a Closer Look

Explore careers related to the human body's lymphatic system on these websites.

- Medical laboratory careers from ASCP's What's My Next
- Phlebotomy from the American Society for Clinical Pathology

- Medical assistant from the American Association of Medical Assistants
- Registered nurse from the American Nurses Association
- Nursing assistant and orderly careers from the U.S. Bureau of Labor Statistics
- Careers in allergy and immunology from the American Academy of Allergy, Asthma & Immunology

12.7 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

12.8 Glossary

Active immunity: Immunity developed when the body produces its own antibodies after exposure to a pathogen or vaccination. (**Chapter 12.4**)

Acute inflammation: A rapid immune response to injury or infection characterized by redness, heat, swelling, pain, and loss of function. (**Chapter 12.4**)

Allergens: Substances that trigger an allergic immune response in sensitive individuals. (**Chapter 12.5**)

Allergic responses: Specific types of hypersensitivity reactions that arise when the immune system reacts to allergens. (**Chapter 12.5**)

Allergist: A physician who specializes in the study and treatment of allergies and asthma. (**Chapter 12.6**)

Anaphylaxis: A severe, potentially life-threatening allergic reaction that can cause bronchoconstriction and swelling of the throat, leading to obstruction of the airway, as well as decreased cardiac output that can lead to shock. (**Chapter 12.5**)

Antibodies: Proteins produced by B cells that specifically recognize and bind to foreign antigens to help neutralize or destroy them. (**Chapter 12.4**)

Antigens: Substances that may trigger a defensive response from leukocytes of the immune system if the body does not recognize the antigen as belonging to "self." (**Chapter 12.4**)

Benign cells: Grow and divide in a more controlled manner, remaining localized to a certain area. (**Chapter 12.5**)

Cancer: A generic term for many diseases in which cells escape regulatory signals. (**Chapter 12.5**)

Cell-mediated response: An immune response that involves T cells attacking infected or abnormal body cells directly, without using antibodies. (**Chapter 12.4**)

Chronic inflammation: Ongoing inflammation caused by foreign bodies, persistent pathogens, and autoimmune diseases such as rheumatoid arthritis. (**Chapter 12.4**)

Chyle: A milky fluid consisting of dietary triglycerides combined with other lipids and proteins that enters lacteals during fat absorption. (**Chapter 12.3**)

Histamine: A chemical released during inflammation that causes vasodilation and

increased capillary permeability, leading to swelling and redness at the injury site. (Chapter 12.4)

Humoral immunity: Immunity involving B cells that produce antibodies to target and neutralize pathogens. (Chapter 12.4)

Hypersensitivity reaction: An exaggerated or inappropriate immune response to an antigen that causes tissue damage. (Chapter 12.5)

Immune system: A complex collection of cells and organs that destroy or neutralize pathogens that would otherwise cause disease or death. (Chapter 12.1)

Immunocompromised: An individual who has an impaired or weakened immune system. (Chapter 12.5)

Immunodeficiency: Refers to an inadequate immune response caused by immune system dysfunction. (Chapter 12.5)

Immunologist: A physician who specializes in the study and treatment of immune system disorders. (Chapter 12.6)

Immunology: The study of disorders of the immune system. (Chapter 12.6)

Incubation period: The length of time before symptoms appear after being exposed to the virus. (Chapter 12.5)

Interstitial fluid: The fluid that surrounds body cells and facilitates the exchange of nutrients, oxygen, and waste between blood and cells. (Chapter 12.2)

Interstitial space: The spaces between individual cells in the tissue. (Chapter 12.2)

Lacteals: Specialized lymphatic capillaries in the small intestine that absorb dietary fats and transport them as chyle. (Chapter 12.3)

Lymphatic capillaries: Small, thin-walled vessels that absorb interstitial fluid and transport lymph to larger lymphatic vessels. (Chapter 12.3)

Lymphatic system: A system of vessels, cells, and organs that carries excess fluids to the bloodstream and filters pathogens from the blood. (Chapter 12.1)

Lymphatic trunks: Large vessels that drain lymph from specific regions of the body and empty it into one of two lymphatic ducts. (Chapter 12.3)

Lymphedema: A chronic disease in which there is an increase of lymphatic fluid in the body. (Chapter 12.5)

Lymph node: Small, bean-shaped organs located throughout the lymphatic system,

commonly found near the groin, armpits, neck, chest, and abdomen. (Chapter 12.2, Chapter 12.3)

Lymphoid nodules: Consist of a dense cluster of lymphocytes without a surrounding fibrous capsule. (Chapter 12.3)

Lymphoma: A form of cancer in which masses of malignant T and/or B lymphocytes collect in lymph nodes, the spleen, the liver, and other tissues. (Chapter 12.5)

Macrophage: A phagocytic cell in the bone marrow, liver, and spleen that removes worn-out red blood cells from circulation. (Chapter 12.4)

Malignant cells: Exhibit uncontrolled growth and rapidly divide, subsequently invading and causing damage to normal functioning cells. (Chapter 12.5)

Metastasis: The spread of cancer cells to other parts of the body. (Chapter 12.5)

Metastasize: The process by which cancer cells spread from the original tumor to other parts of the body. (Chapter 12.5)

Monocyte: A circulating cell that differentiates into either a macrophage or dendritic cell, which can be rapidly attracted to areas of infection. (Chapter 12.4)

Neutrophil: A type of granular white blood cell that makes up 50–70% of leukocytes and is essential for fighting bacterial infections. (Chapter 12.4)

Opportunistic infections: Infections that occur more often or are more severe in people with weakened immune systems than in people with healthy immune systems. (Chapter 12.5)

Passive immunity: Immunity gained by receiving antibodies from another source, providing temporary protection without the body producing its own antibodies. (Chapter 12.4)

Pathogens: Disease-causing organisms. (Chapter 12.1)

Phagocytosis: A type of endocytosis where the cell engulfs large particles or microorganisms (“cell eating”); commonly performed by immune cells like macrophages. (Chapter 12.4)

Specific (Adaptive) immune response: The body’s targeted defense against specific pathogens, involving activation of lymphocytes (B and T cells) that recognize and remember particular antigens. (Chapter 12.4)

Spleen: A major secondary lymphoid organ. (Chapter 12.3)

Thymus gland: A bi-lobed organ between the sternum and aorta that supports T-cell development and is most active during childhood, shrinking after puberty. (**Chapter 12.3**)

Tonsils: Lymphoid nodules located along the inner surface of the pharynx (throat) and are important in developing immunity to oral pathogens. (**Chapter 12.3**)

PART XIII

CHAPTER 13 RESPIRATORY SYSTEM

13.1 Introduction to the Respiratory System

Chapter Competency

Analyze how components of the respiratory system function in the body.

Learning Objectives

- Identify the gross and microscopic structural components of the respiratory system.
- Correlate the structural components of the respiratory system with their functions.
- Explain the mechanics of ventilation with reference to respiratory volumes and capacities.
- Summarize the functions of the respiratory system.

Imagine you are working as a respiratory therapist caring for a patient who is short of breath. As you assess the patient, you monitor breathing rate, oxygen levels, carbon dioxide levels, breath sounds, airway status, and response to respiratory treatments. To provide safe and effective care, you must understand how air moves through the respiratory system, how oxygen enters the blood, how carbon dioxide is removed, and how changes in ventilation can affect the entire body.

The respiratory system is responsible for bringing oxygen into the body and removing carbon dioxide, a waste product of cellular metabolism. Every cell needs oxygen to produce energy in the form of adenosine triphosphate (ATP), and carbon dioxide must be eliminated to help maintain acid-base balance. The respiratory system also supports functions such as sensing odors and producing speech. It works closely with the cardiovascular system, which transports oxygen from the lungs to body tissues and returns carbon dioxide from the tissues to the lungs for exhalation.

In this chapter, you will explore the structure and function of the respiratory system. You will learn about the upper and lower respiratory structures, including the nose, pharynx, larynx, trachea, bronchial tree, lungs, and alveoli. You will examine how the conducting zone moves air and how the respiratory zone allows gas exchange between the alveoli and capillaries. You will also study pulmonary ventilation, including inspiration, expiration, respiratory control, breathing patterns, and respiratory volumes and capacities. Finally, you will learn about common respiratory disorders and how changes in airway function, gas exchange, or ventilation can affect health.

By mastering these concepts, you will gain a deeper understanding of how the respiratory system supports oxygen delivery, carbon dioxide removal, acid-base balance, communication, and homeostasis. This foundation will help you connect respiratory structure and function to respiratory assessment, oxygenation, ventilation, airway management, patient monitoring, respiratory treatments, and disorders affecting breathing and gas exchange.

13.2 Functions of the Respiratory System

The primary functions of the major organs of the respiratory system include the following:

- Take in oxygen needed by the body's cells and remove the waste product carbon dioxide
- Help maintain acid-base balance
- Sense odors
- Produce speech

Functionally, the respiratory system can be divided into a conducting zone and a respiratory zone. The **conducting zone** of the respiratory system includes the organs and structures through which air passes but they are not directly involved in gas exchange. Gas exchange occurs in the **respiratory zone**.[1]

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

13.3 Anatomy of the Respiratory System

Anatomically, the respiratory system can be divided into upper and lower respiratory systems. The upper respiratory system consists of the nose and pharynx, while the lower respiratory system includes the larynx, trachea, bronchial tree, and alveoli.[1]

See Figure 13.1[2] for an illustration of the major structures of the respiratory system.

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. OpenStax College. (2013). *2301_Major_Respiratory_Organs* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2301_Major_Respiratory_Organs.jpg

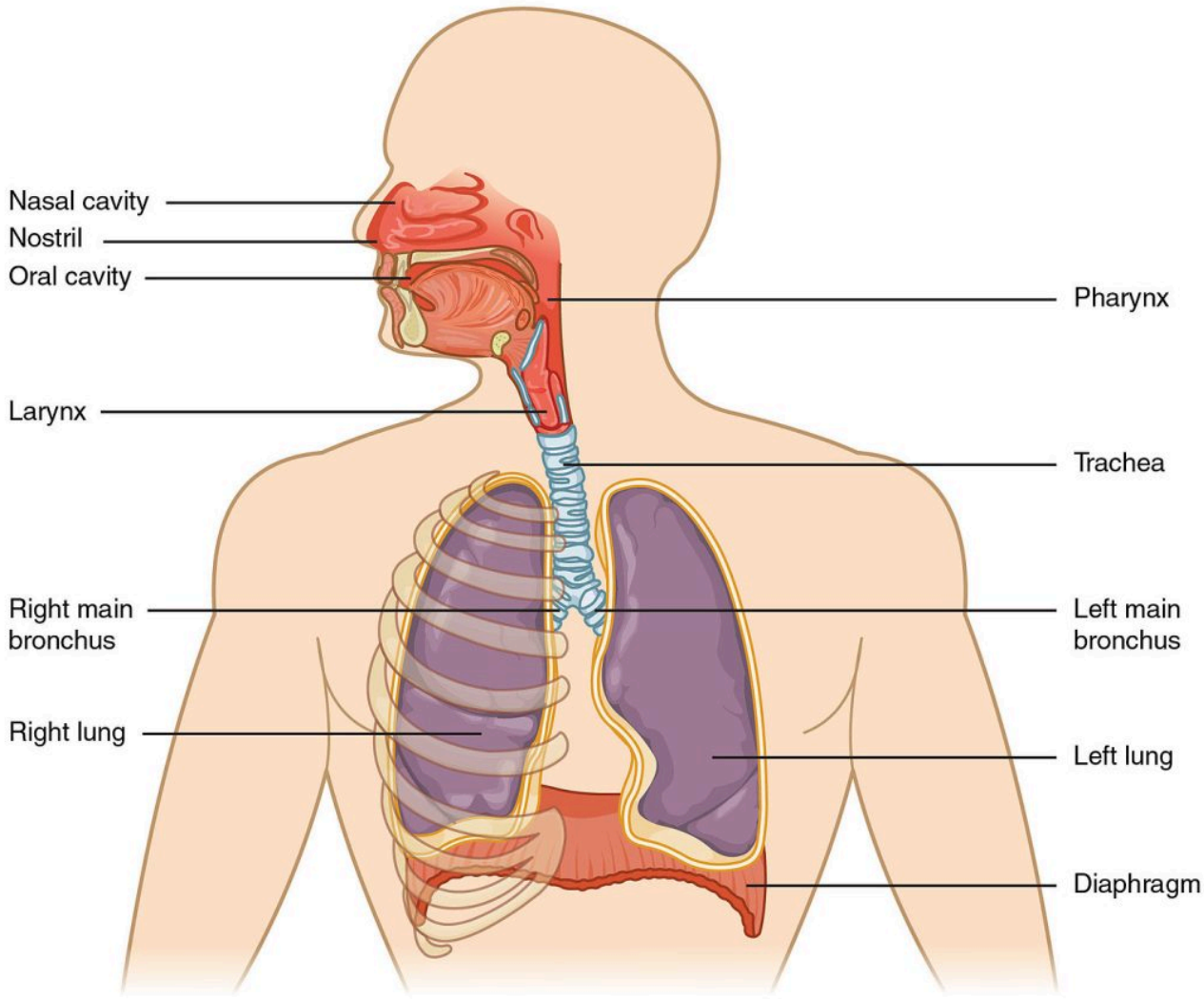


Figure 13.1 Major Respiratory Structures

Upper Respiratory System

See Figure 13.2[3] for an illustration of the structures of the upper airway.

3. OpenStax College. (2013). *2303_Anatomy_of_Nose-Pharynx-Mouth-Larynx* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2303_Anatomy_of_Nose-Pharynx-Mouth-Larynx.jpg

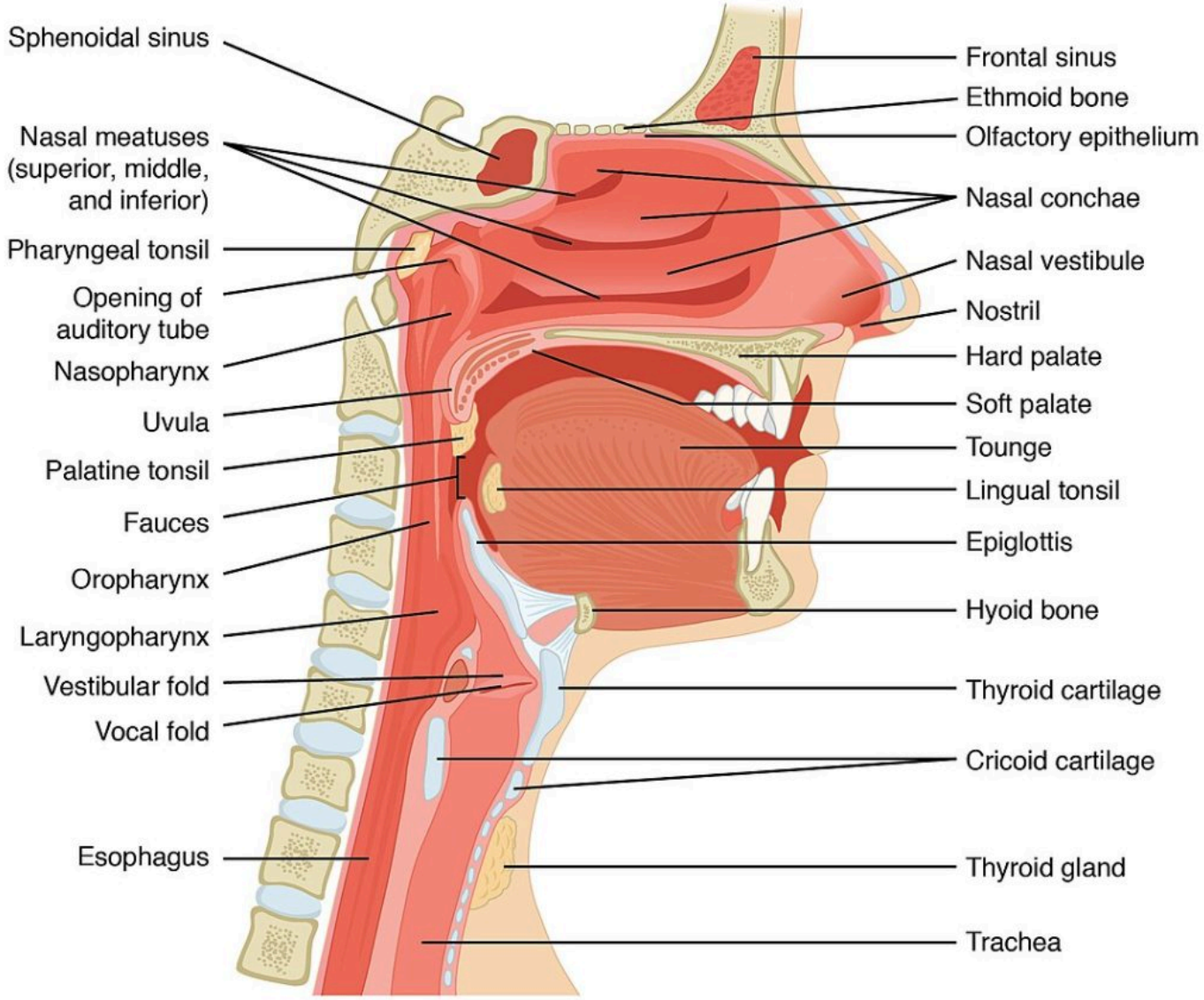


Figure 13.2 Upper Airway

Nose

The main entrance and exit for the respiratory system is the nose. The nose can be divided into two major sections: the external nose (outward projection) and the internal nose (the nasal cavity or the space inside the nose).

The **nares** (nostrils) allow air into the nasal cavity, which is separated into left and right sections by the nasal septum. The floor of the nasal cavity (and the roof of the mouth) is composed of the palate. The anterior hard palate is composed of bone. The posterior soft palate consists of muscle tissue.

Each lateral wall of the nasal cavity has three bony projections called the superior,

middle, and inferior nasal conchae. **Nasal conchae** serve to increase the surface area of the nasal cavity and to disrupt the flow of air as it enters the nose, causing air to bounce along the epithelium, where it is cleaned, warmed, and humidified.

At the posterior region of the nasal cavity, air exits through the **internal nares**, the openings between the nasal cavity and the nasopharynx.

Several bones that form the walls of the nasal cavity have air-containing spaces called the **paranasal sinuses**, which serve to warm and humidify incoming air. Sinuses are lined with a mucous membrane. Each paranasal sinus is named for its associated bone: the frontal sinus, the maxillary sinus, the sphenoidal sinus, and the ethmoidal sinus. The sinuses produce mucus and lighten the weight of the skull. In addition, the sinuses act as resonating chambers for the voice, amplifying and enriching vocal tone. When the sinuses become congested during a cold, the resonance is altered, causing the voice to sound muffled, nasal, or "stuffy."

The nares and the anterior portion of the nasal cavity are lined with mucous membranes containing sebaceous glands and hairs to prevent the passage of large debris, such as dirt, through the nasal cavity. An olfactory epithelium used to detect odors lines the roof of the nasal cavity.

The conchae, meatuses, and paranasal sinuses are lined by respiratory epithelium composed of pseudostratified ciliated columnar epithelium. The epithelium contains goblet cells, one of the specialized, columnar epithelial cells that produce mucus to trap debris. The cilia of the respiratory epithelium help remove the mucus and debris from the nasal cavity with a constant beating motion, sweeping materials towards the throat to be swallowed. Interestingly, cold air slows the movement of the cilia, resulting in the accumulation of mucus that may, in turn, lead to a runny nose during cold weather. This moist epithelium functions to warm and humidify incoming air. Capillaries located just beneath the nasal epithelium warm the air by convection. Serous and mucous-producing cells also secrete the lysozyme enzyme and proteins called defensins, which have antibacterial properties. Immune cells that patrol the connective tissue deep to the respiratory epithelium provide additional protection.

See Figure 13.3[4] for an illustration of the sinuses.

4. Komorniczak, M. (2009). *Paranasal_sinuses_numbers* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Paranasal_sinuses_numbers.svg

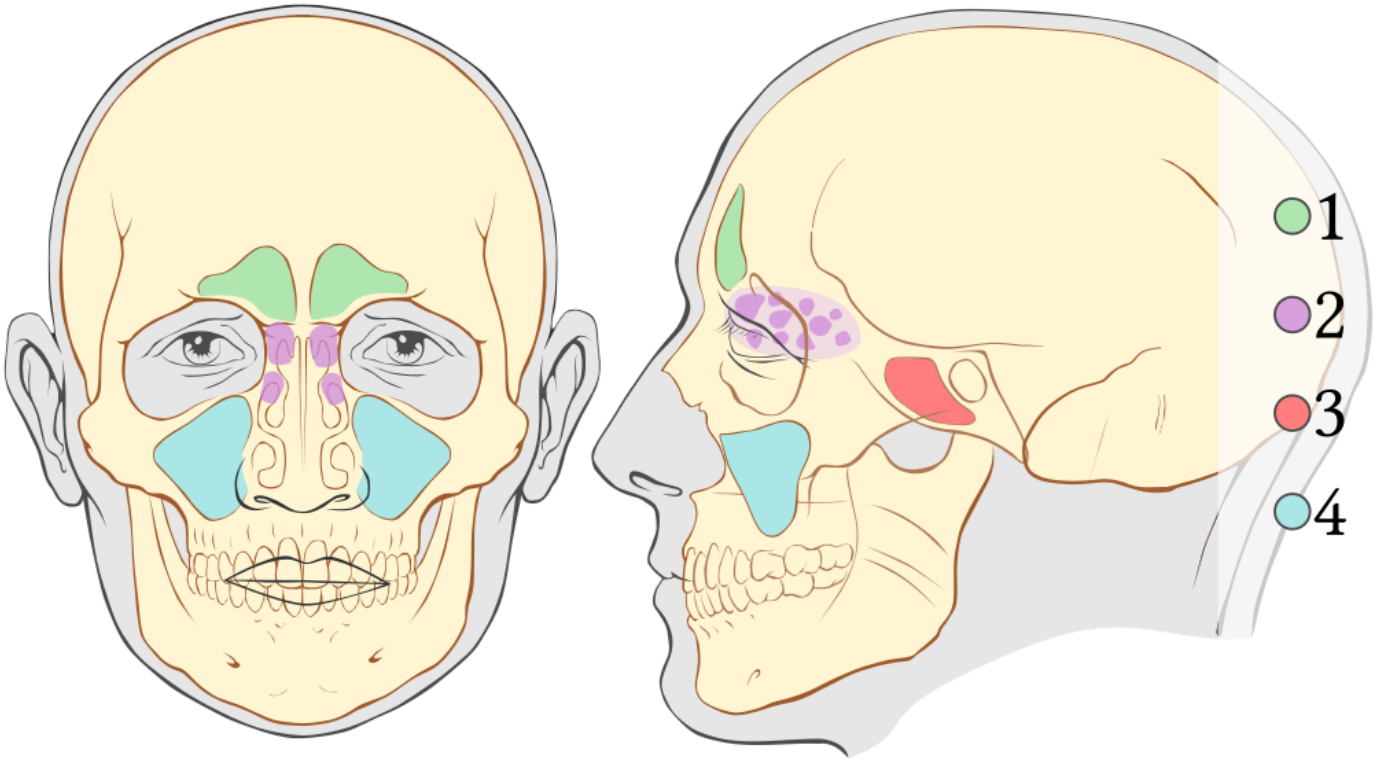


Figure 13.3 Sinuses: (1) Frontal Sinuses, (2) Ethmoid Sinuses, (3) Sphenoid Sinuses, and (4) Maxillary Sinuses

Pharynx

The **pharynx** (throat) is a tube formed by skeletal muscle and lined by a mucous membrane that is continuous with that of the nasal cavities. The pharynx is divided into three major regions: the nasopharynx, the oropharynx, and the laryngopharynx. See Figure 13.4[5] for an illustration of these three regions of the pharynx.

5. OpenStax College. (2013). *2305_Divisions_of_the_Pharynx* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2305_Divisions_of_the_Pharynx.jpg

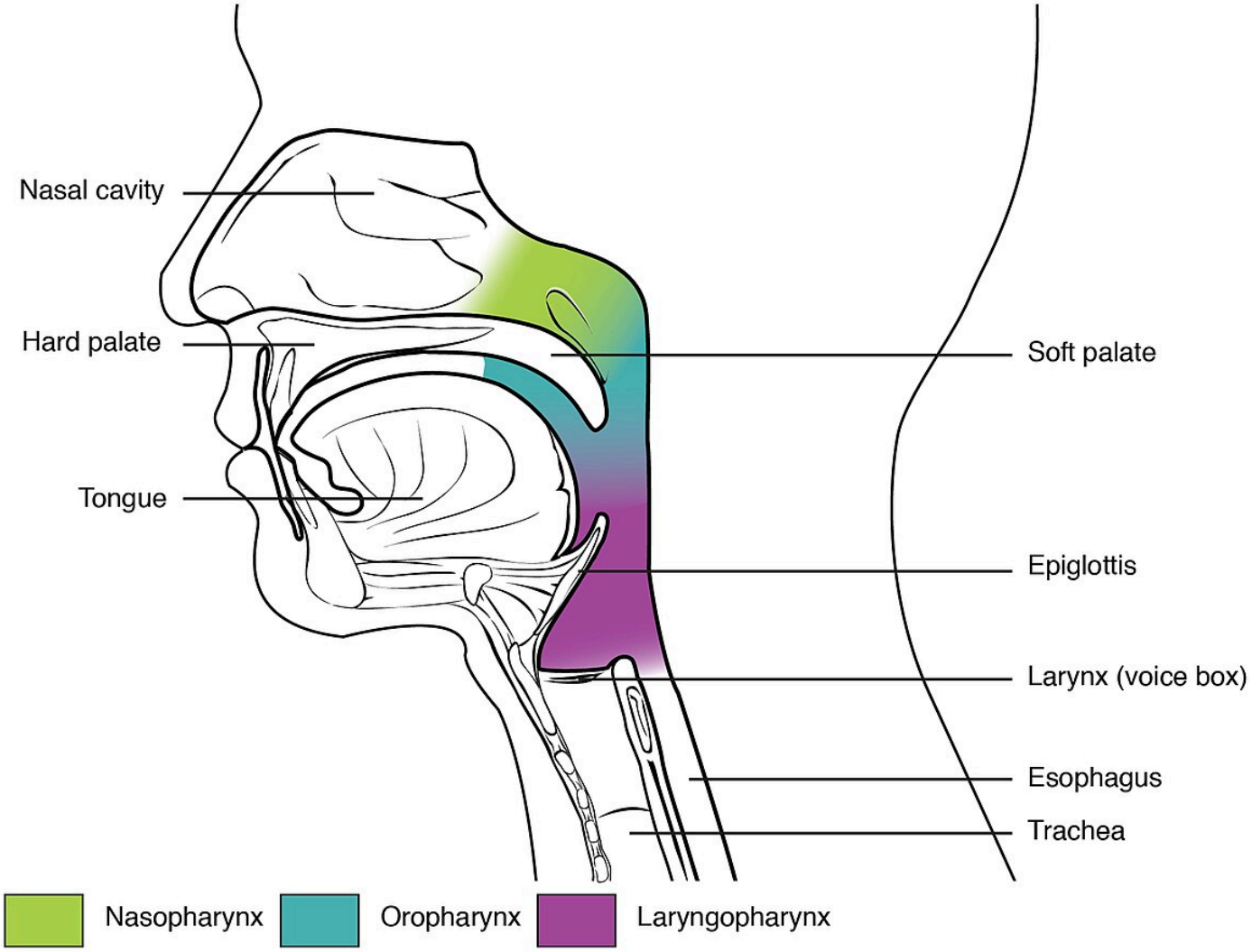


Figure 13.4 Divisions of the Pharynx: Nasopharynx, Oropharynx, and Laryngopharynx

The **nasopharynx** is posterior to the nasal cavity, and it serves only as an airway. At the posterior aspect of the nasopharynx is the pharyngeal tonsil. A pharyngeal tonsil, also called an adenoid, is a mass of lymphoid tissue similar to a lymph node. The function of the pharyngeal tonsil is not well understood, but it contains a rich supply of lymphocytes and is covered with ciliated epithelium that traps and destroys pathogens that enter during inhalation. The pharyngeal tonsil is large in children but tends to get smaller with age and may even disappear.

The **uvula** is a small, teardrop-shaped structure located at the apex of the soft palate. Both the uvula and soft palate move like a pendulum during swallowing, swinging upward to close off the nasopharynx to prevent ingested materials from entering the nasal cavity. In addition, auditory (eustachian) tubes from the ear open into the

nasopharynx. This connection is why colds often lead to ear infections. Refer back to Figure 13.2 to view the uvula.

The inferior nasopharynx leads into the **oropharynx**, a passageway for both air, liquids, and food. The oropharynx contains two distinct sets of tonsils, the palatine and lingual tonsils. The palatine tonsils are a pair of structures located on each side of the oropharynx. The lingual tonsils are located at the base of the tongue. Similar to the pharyngeal tonsil, the palatine and lingual tonsils are composed of lymphoid tissue and trap and destroy pathogens entering the body through the oral or nasal cavities.

The **laryngopharynx** (also known as the hypopharynx) is inferior to the oropharynx and posterior to the larynx. It continues the passageway for food and air until the digestive and respiratory systems split. Anteriorly, the laryngopharynx opens into the larynx, and posteriorly, it enters the esophagus.

Lower Respiratory System

Larynx

The **larynx** (also known as the voice box) is a cartilaginous structure that connects the pharynx to the trachea and helps regulate the volume of air that enters and leaves the lungs. The larynx is composed of nine pieces of cartilage. The three largest cartilage pieces form the major structure of the larynx—the thyroid cartilage (anterior), epiglottis (superior), and cricoid cartilage (inferior).

The thyroid cartilage is the largest piece of cartilage that makes up the larynx. The thyroid cartilage consists of the laryngeal prominence, or “Adam’s apple,” which tends to be more prominent with increasing levels of testosterone. The thick cricoid cartilage forms a ring, with a wide posterior region and a thinner anterior region. Both these structures are made of hyaline cartilage. The cricothyroid ligament (or membrane) is a structure located between these two cartilages. It is the structure that is cut during a cricothyrotomy for emergency airway access if the upper airway is obstructed.

The **epiglottis** is a very flexible piece of elastic cartilage that covers the opening of the larynx during swallowing to prevent food and drink from entering the lower airway. The glottis is the opening inside the larynx, which also contains the vocal folds or cords. Air passes through this opening when breathing and making speech; the glottis is widened during breathing but narrowed during voice production, allowing the passing air to make the vocal folds vibrate and produce sound.

See Figure 13.5[6] for an illustration of the larynx.

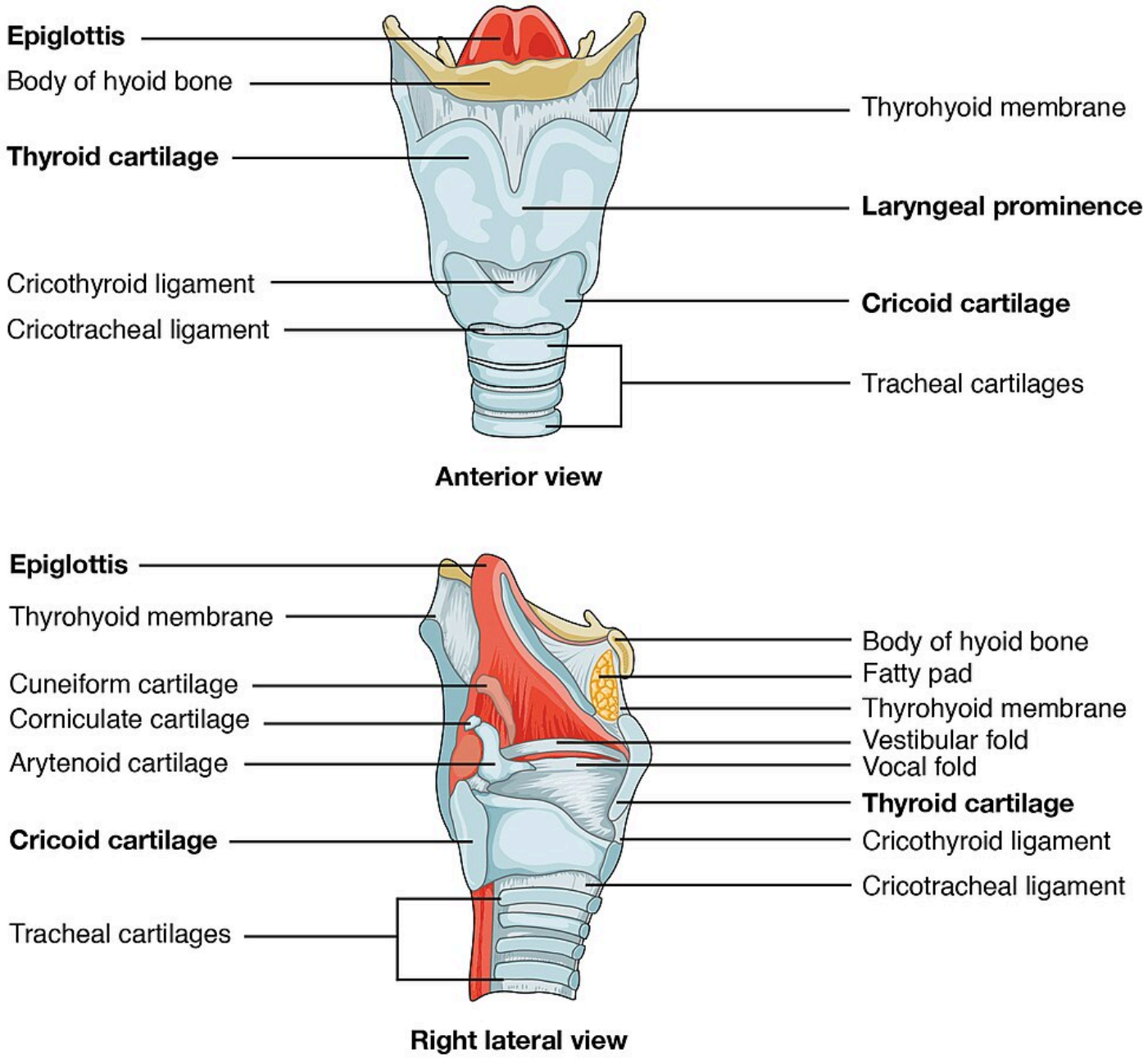


Figure 13.5 Larynx

The **true vocal cords** (also called vocal folds) are a pair of white, membranous ligaments attached to cartilage pieces of the larynx. The inner edges of the true vocal cords are free, allowing vibrations to produce sound when muscles inside the larynx

6. OpenStax College. (2013). *2306_The_Larynx* [Diagram]. Wikimedia College. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2306_The_Larynx.jpg

contract. The size of the vocal cords differs between individuals, producing voices with different pitch ranges. Folds in males tend to be larger than those in females and create a deeper voice. See Figure 13.6[7] for an illustration of the vocal cords and the glottis.

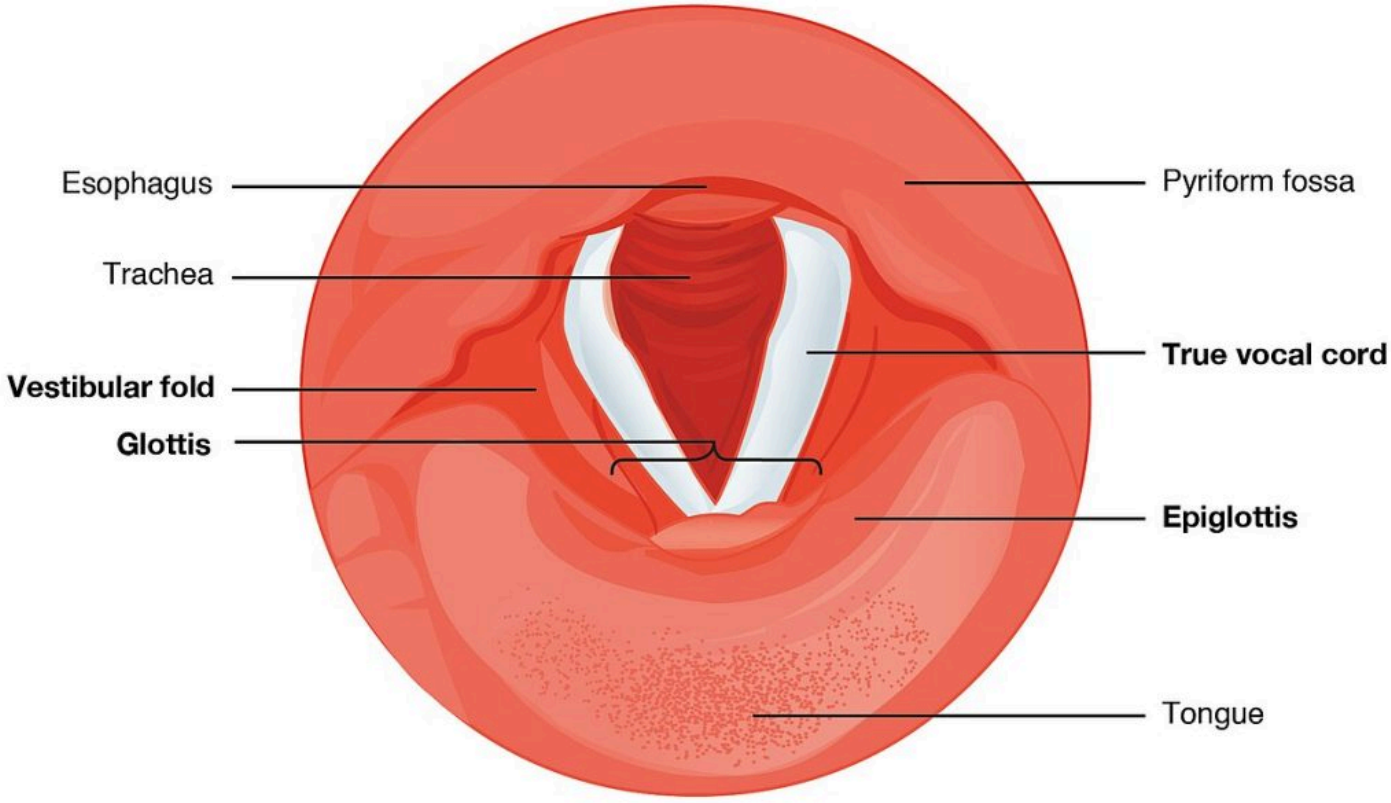


Figure 13.6 Vocal Cords and the Glottis

Trachea

The **trachea** (windpipe) is an approximately 5-inch-long tubular airway that extends from the larynx inferiorly toward the lungs. The trachea is formed by 16–20 C-shaped pieces of hyaline cartilage that are connected by dense connective tissue. The rings of cartilage provide structural support and prevent the trachea from collapsing when breathing. The esophagus borders the trachea posteriorly.

The trachea is lined with a mucous membrane containing ciliated pseudostratified columnar epithelial cells. **Cilia** help move mucus and debris with a constant beating motion, sweeping materials up towards the throat to be swallowed.

7. OpenStax College. (2013). *2307_Cartilages_of_the_Larynx* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2307_Cartilages_of_the_Larynx.jpg

See Figure 13.7[8] for an illustration of the trachea and Figure 13.8[9] for a cross section of the trachea and the esophagus, and Figure 13.9[10] for an illustration of the respiratory epithelium.

8. OpenStax College. (2013). *2308_The_Trachea* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2308_The_Trachea.jpg
9. PBrieux. (2020). *Cross_section_of_a_trachea_and_esophagus* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Cross_section_of_a_trachea_and_esophagus.svg
10. OpenStax College. (2013). *2304 Pseudostratified Epithelium* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2304_Pseudostratified_Epithelium.jpg

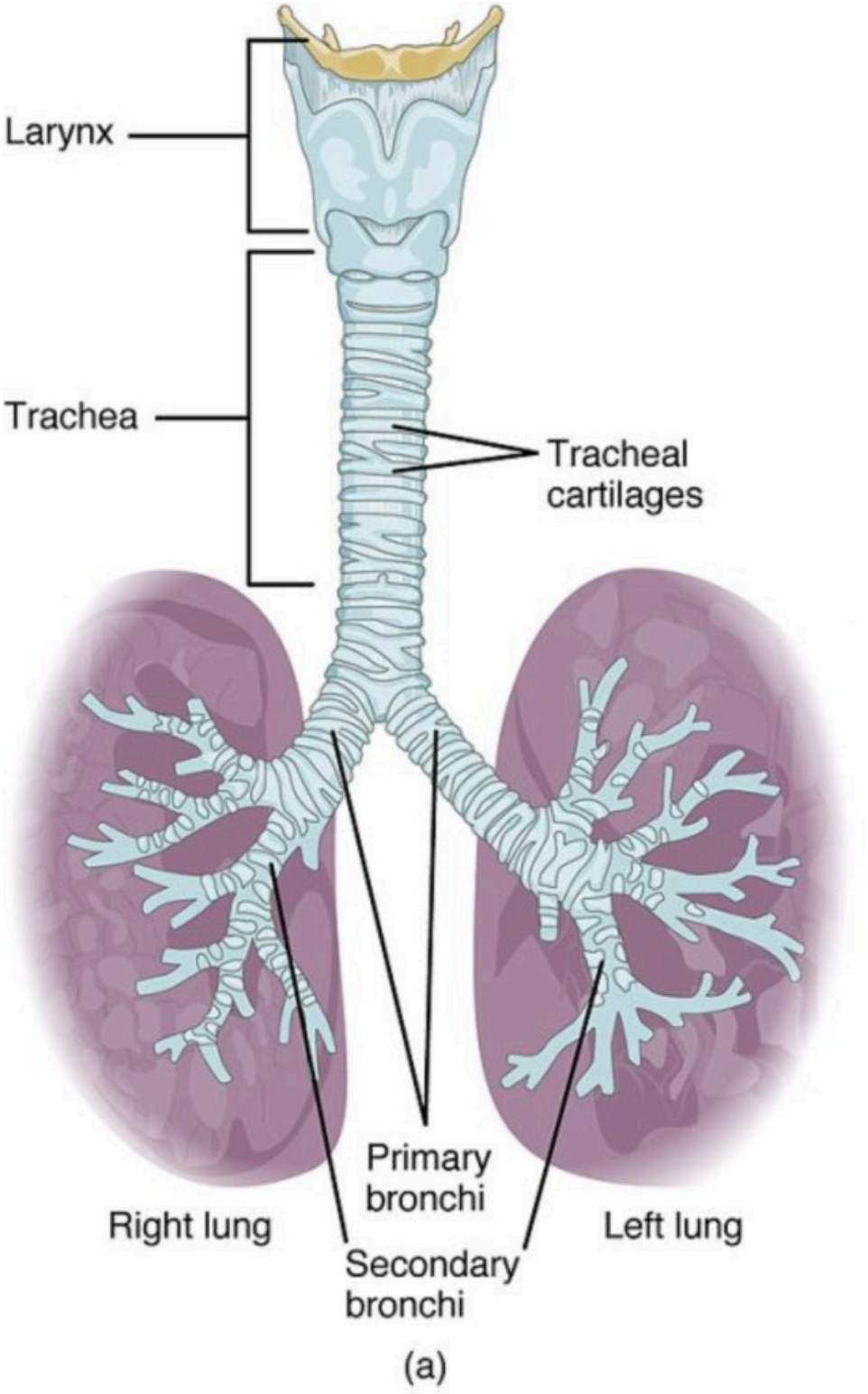


Figure 13.7 Trachea and Bronchi

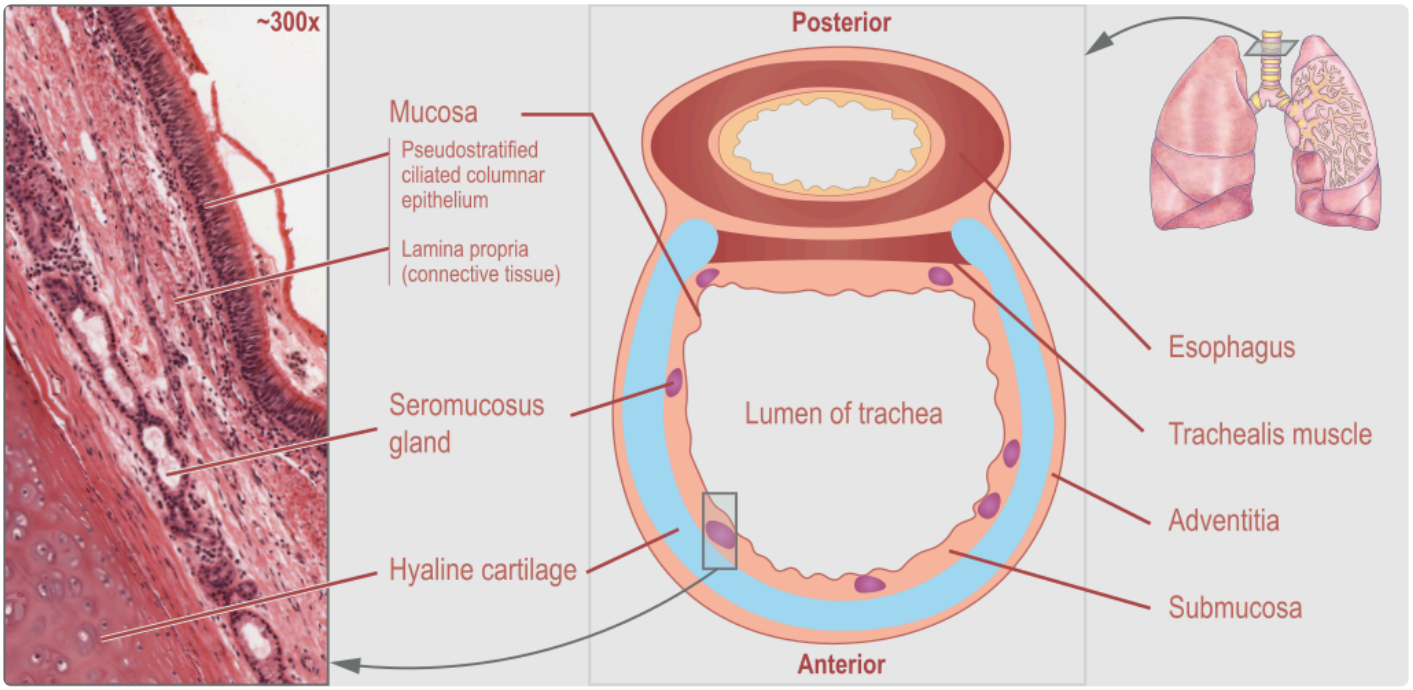


Figure 13.8 Cross Section of the Trachea and Esophagus

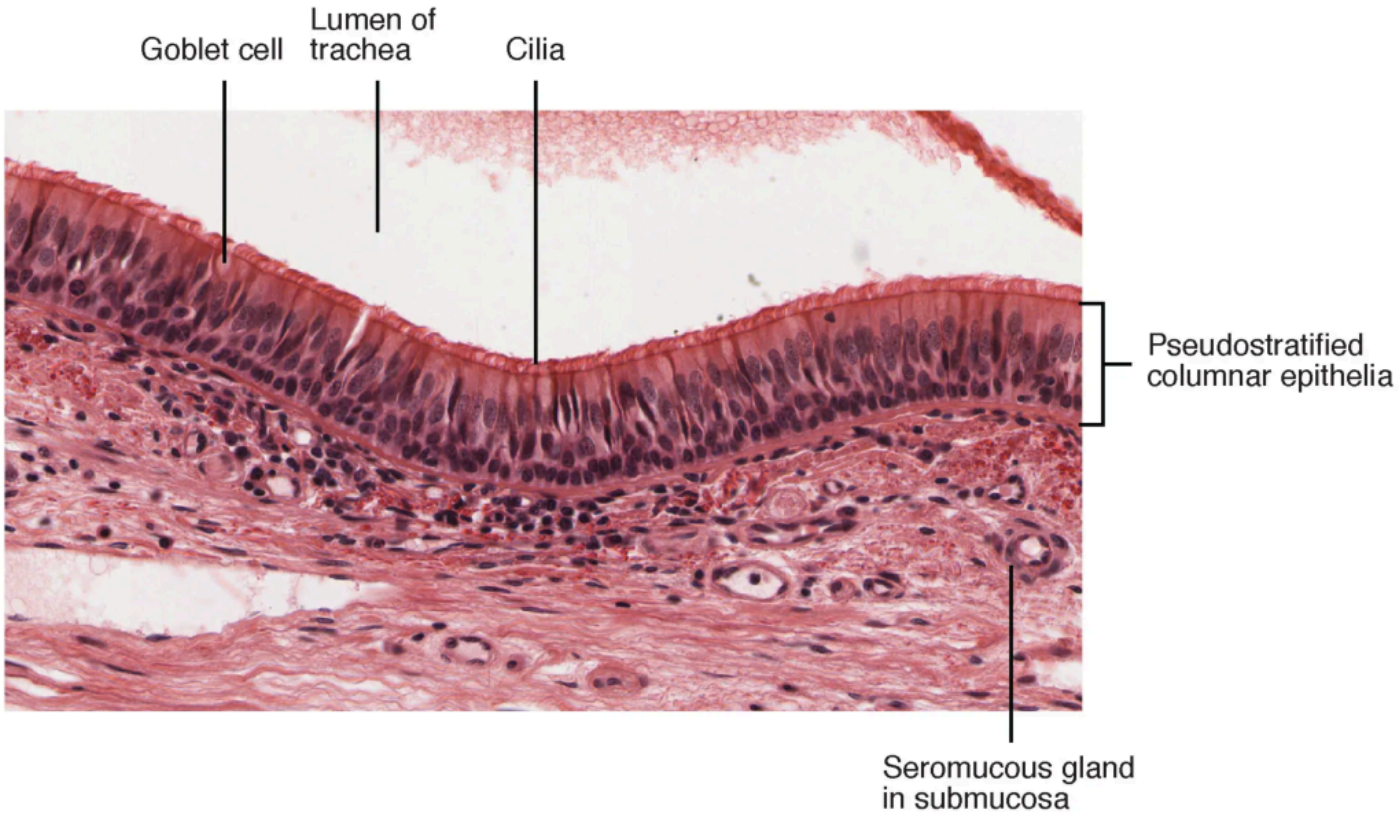


Figure 13.9 Respiratory Epithelium (Pseudostratified Ciliated Columnar Epithelium).

Lungs

The **lungs** are a pair of pyramid-shaped organs connected to the trachea by the right and left primary bronchi. The inferior surface of the lungs is bordered by the diaphragm.

The right lung is shorter and wider than the left lung, and the left lung occupies a smaller volume than the right. The **cardiac notch** is an indentation on the surface of the left lung that allows space for the heart.

Each lung is composed of smaller units called lobes. The right lung consists of three lobes: the superior, middle, and inferior lobes. The left lung consists of two lobes: the superior and inferior lobes. See Figure 13.10[11] for an illustration of the lungs.

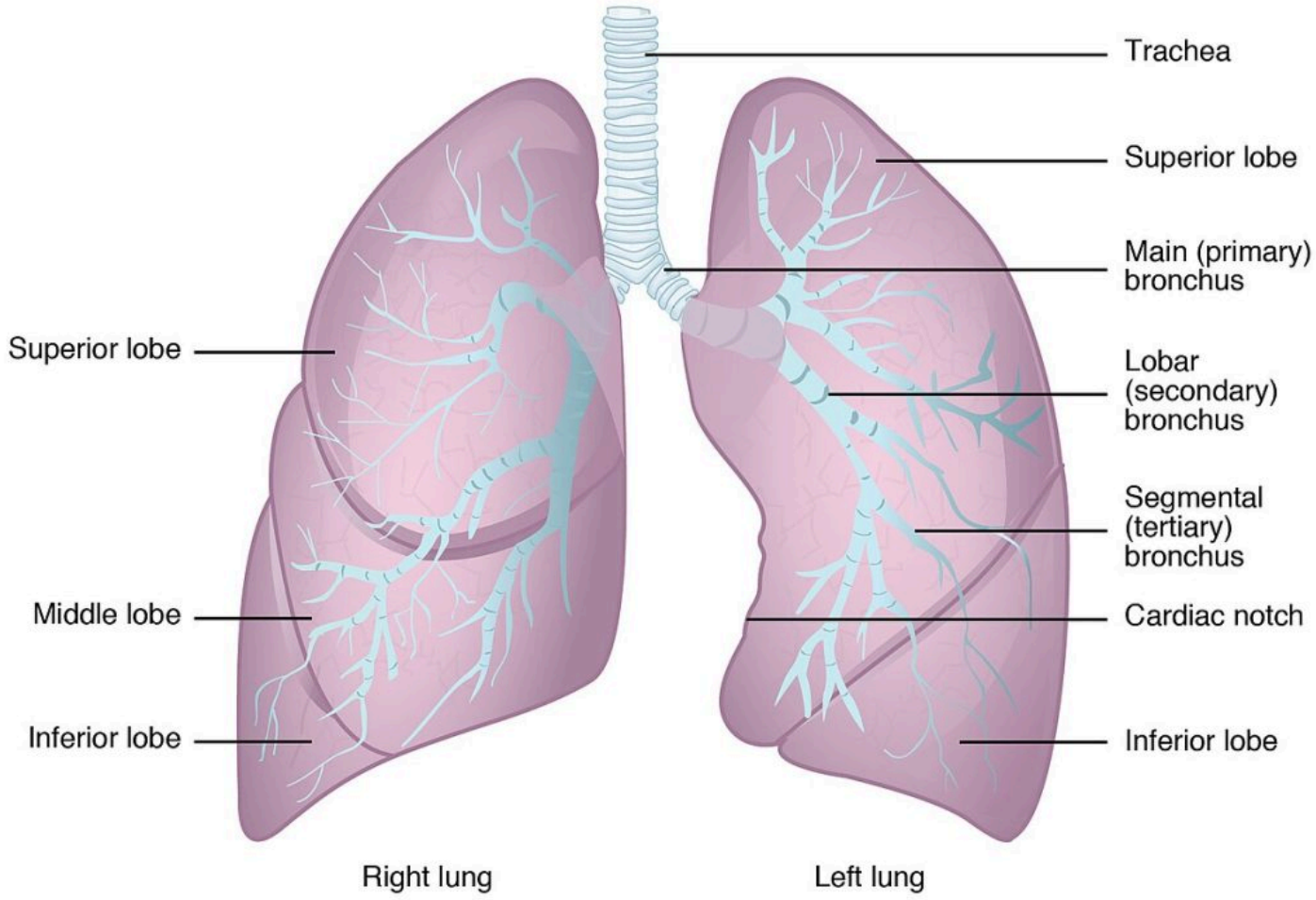


Figure 13.10 Lungs

11. OpenStax College. (2013). *2312_Gross_Anatomy_of_the_Lungs* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2312_Gross_Anatomy_of_the_Lungs.jpg

Pleural Membrane (Pleura)

Each lung is enclosed within a cavity that is surrounded by a pleural membrane (also known as the pleura). The pleura (plural = pleurae) is a serous membrane that surrounds each lung. The pleurae consist of two layers. The visceral pleura is the layer that directly covers the lungs, and the parietal pleura is the outer layer that lines the thoracic cavity, the mediastinum, and the diaphragm.

The **pleural cavity** is the space between the visceral and parietal layers that contains **pleural fluid**. Pleural fluid is secreted by both pleural layers and acts to lubricate their surfaces. This lubrication reduces friction between the two layers, and the pleura also helps keep the lungs inflated by creating a negative pressure that holds the lungs against the thoracic wall. See Figure 13.11[12] for an illustration of the pleurae and pleural cavity.

12. OpenStax College. (2013). *2313_The_Lung_Pleurea* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2313_The_Lung_Pleurea.jpg

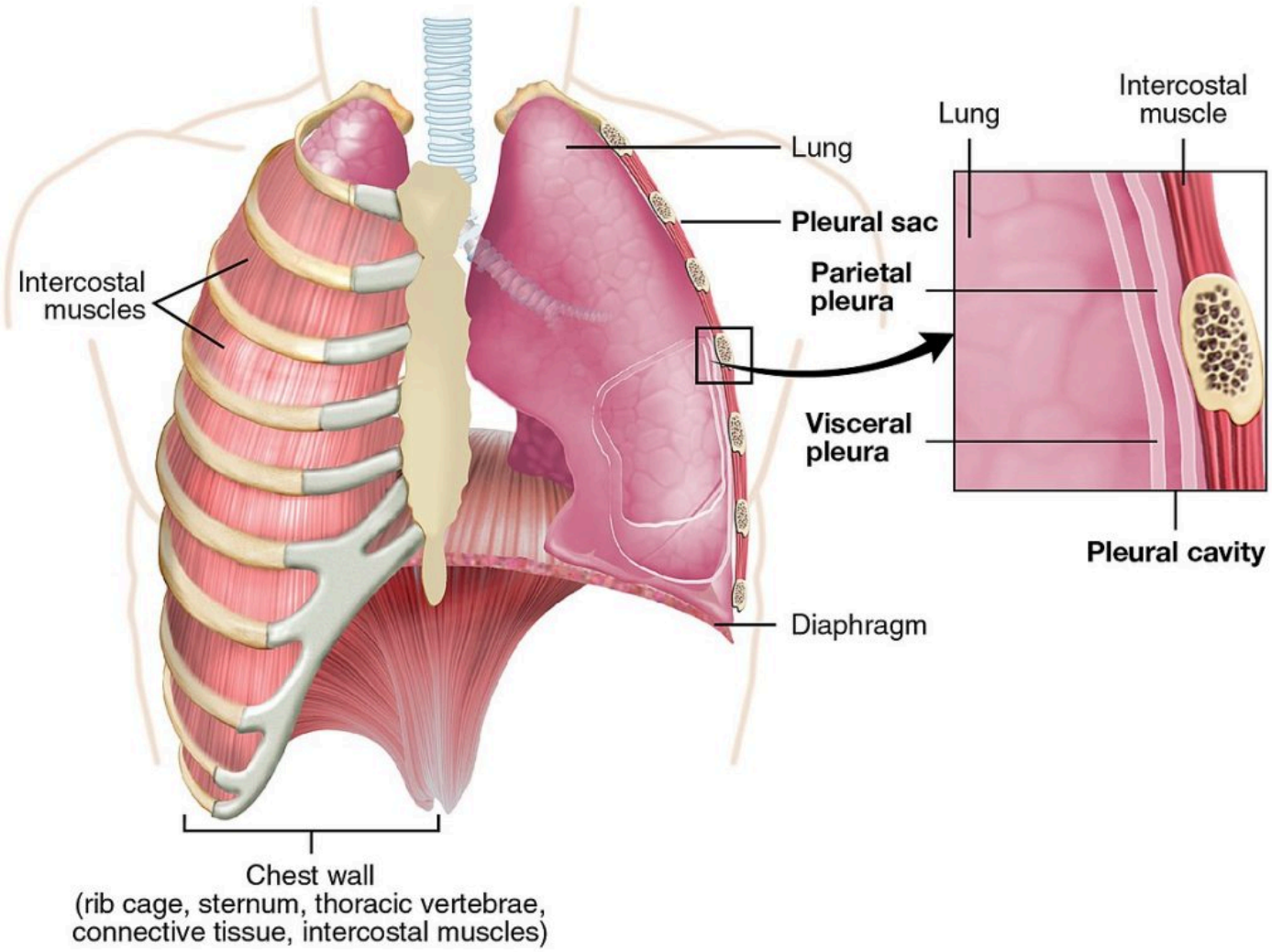


Figure 13.11 Parietal and Visceral Pleurae of the Lungs

Bronchial Tree

The trachea branches into the right and left primary bronchi (singular = bronchus) at the carina. The **carina** is a raised structure that contains specialized nervous tissue that causes violent coughing if a foreign body, such as food, is present. The right primary bronchus enters the right lung, and the left primary bronchus enters the left lung. Refer back to Figure 13.6 for an illustration of the right and left primary bronchi.

The primary bronchi enter the lungs at the hilum, a concave region where blood vessels, lymphatic vessels, and nerves also enter the lungs. The bronchi continue to branch into a bronchial tree. A **bronchial tree** (or respiratory tree) is the collective term used for these multiple-branched bronchial tubes. Rings of cartilage, similar to those of the trachea, support the structure of the bronchi and prevent their collapse.

Primary bronchi branch into secondary bronchi, which enter each lobe of the lung. The right lung typically has three lobes, so there are three secondary bronchi. The left lung typically has two lobes, so there are two secondary bronchi. The secondary bronchi then divide again into several tertiary bronchi. These bronchi branch several more times before they turn into bronchioles.

Bronchioles, which are about 1 mm in diameter, further branch until they become the tiny terminal bronchioles, which lead to the alveoli, the air sacs that perform gas exchange. In total, there are roughly 26 branches of the bronchi.

An important distinction between bronchi and bronchioles is that the walls of bronchi contain cartilage, whereas the walls of bronchioles do not. Because the bronchioles don't contain cartilage, the smooth muscle walls of the bronchioles can constrict and dilate to change the diameter of the bronchioles to increase or decrease airflow. See Figure 13.12[13] for an illustration of a terminal bronchiole and alveoli.

13. OpenStax College. (2013). *2309_The_Respiratory_Zone* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2309_The_Respiratory_Zone.jpg

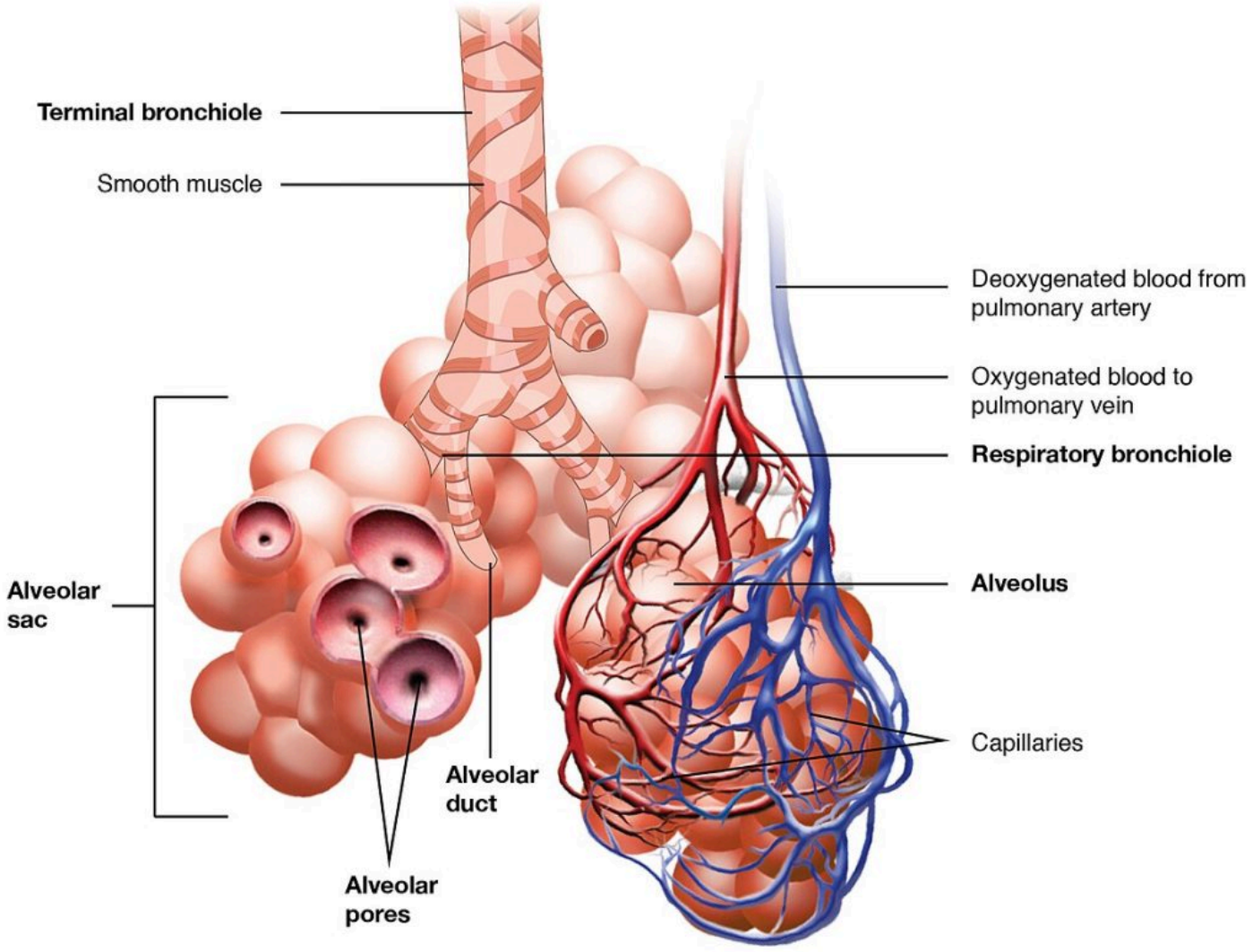


Figure 13.12 Terminal Bronchiole and Alveolus

Alveoli

Alveoli (singular = alveolus) are small, grape-like air sacs surrounded by pulmonary blood capillaries. The alveoli and capillary membranes form a very thin **respiratory membrane**. The thinness of the respiratory membrane allows for simple diffusion of oxygen and carbon dioxide. After inhalation, oxygen diffuses from the alveolus into the pulmonary capillary, and carbon dioxide diffuses from the pulmonary capillary into the alveolus to then be exhaled. Alveoli have elastic walls that allow them to stretch during inhalation, which greatly increases the surface area available for gas exchange.

The wall of each alveolus consists of three major cell types: type I alveolar cells, type II alveolar cells, and alveolar macrophages. A type I alveolar cell is a simple squamous epithelial cell of the alveoli, which constitute up to 97% of the alveolar surface area. These

cells are highly permeable to gases. Type II alveolar cells are scattered among the type I cells and secrete **pulmonary surfactant**, a slippery fluid that reduces the surface tension of the alveoli and prevents them from collapsing. Roaming around the alveolar wall are alveolar macrophages (also called dust cells), phagocytic cells of the immune system that remove inhaled debris and pathogens that have reached the alveoli.

See Figure 13.13[14] for an illustration of alveoli and their cells.

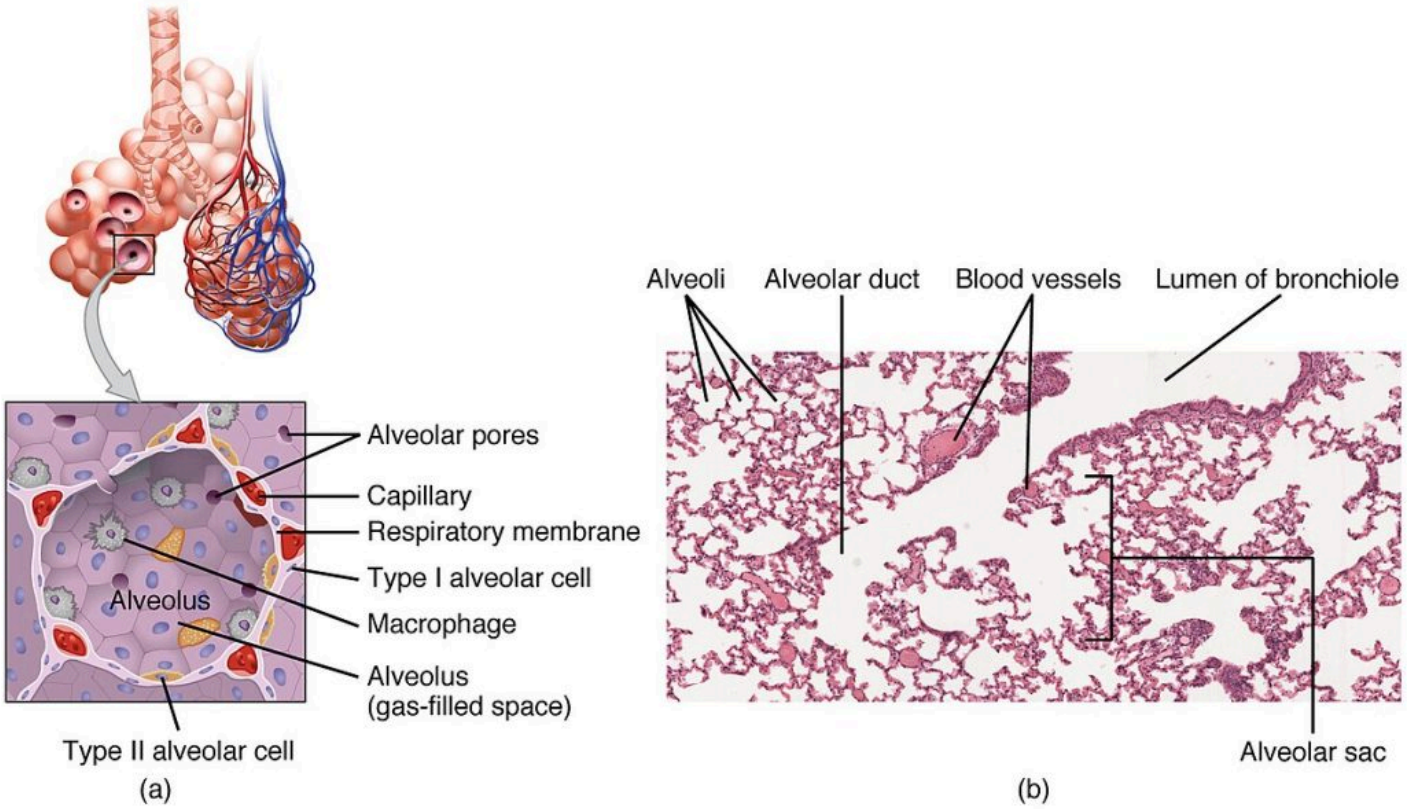


Figure 13.13 Alveoli: (a) Alveolus and Alveolar Cells and (b) Micrograph of Alveolar Structures

14. OpenStax College. (2013). *2310_Structures_of_the_Respiratory_Zone* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2310_Structures_of_the_Respiratory_Zone.jpg

13.4 Pulmonary Ventilation (Breathing)

Pulmonary ventilation is the act of breathing. It consists of **inhalation** (also called inspiration), which is the movement of air into the lungs, and **exhalation** (also called expiration) or movement of air out of the lungs.[1]

Mechanism of Breathing

The ability to breathe—to have air enter the lungs during inspiration and air leave the lungs during expiration—is dependent on the air pressure of the atmosphere and the air pressure within the lungs. Air always moves from an area of higher pressure to an area of lower pressure.

Atmospheric pressure remains constant, but the air pressure within the lungs changes with every breath. During inhalation, the body creates a pressure difference, making the air pressure inside the alveoli less than atmospheric pressure, so that air flows into the lungs. In general, two muscle groups are used during normal inspiration: the diaphragm and the external intercostal muscles. Additional muscles can be used if a bigger breath is required. When the diaphragm contracts during inspiration, it moves downward and flattens, creating a larger volume in the thoracic cavity and more space for the lungs. Contraction of the external intercostal muscles elevates the rib cage, moving the ribs upward and outward, causing the rib cage to expand, which also increases the volume of the thoracic cavity. The increasing size of the thoracic cavity forces the lungs to stretch and expand as well. This increase in volume leads to a decrease in the pressure inside the alveoli, creating a pressure lower than atmospheric pressure. As a result, air flows into the lungs. Air will flow into the lungs until the air pressure equalizes, and then the muscles will begin to relax with expiration.

Air flows out of the lungs during exhalation based on the same principle. Pressure in the lungs becomes higher than the atmospheric pressure, so air flows out. The process of normal expiration is passive; therefore, no energy is required to push air out of the

1. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

lungs. Instead, the elasticity of the lung tissue causes the lung to recoil as the diaphragm and intercostal muscles relax following inspiration. This relaxation causes the thoracic cavity and lungs to decrease in volume, causing an increase in pressure higher than atmospheric pressure. Air then flows out of the lungs. See Figure 13.14[2] for an illustration of inspiration and expiration.

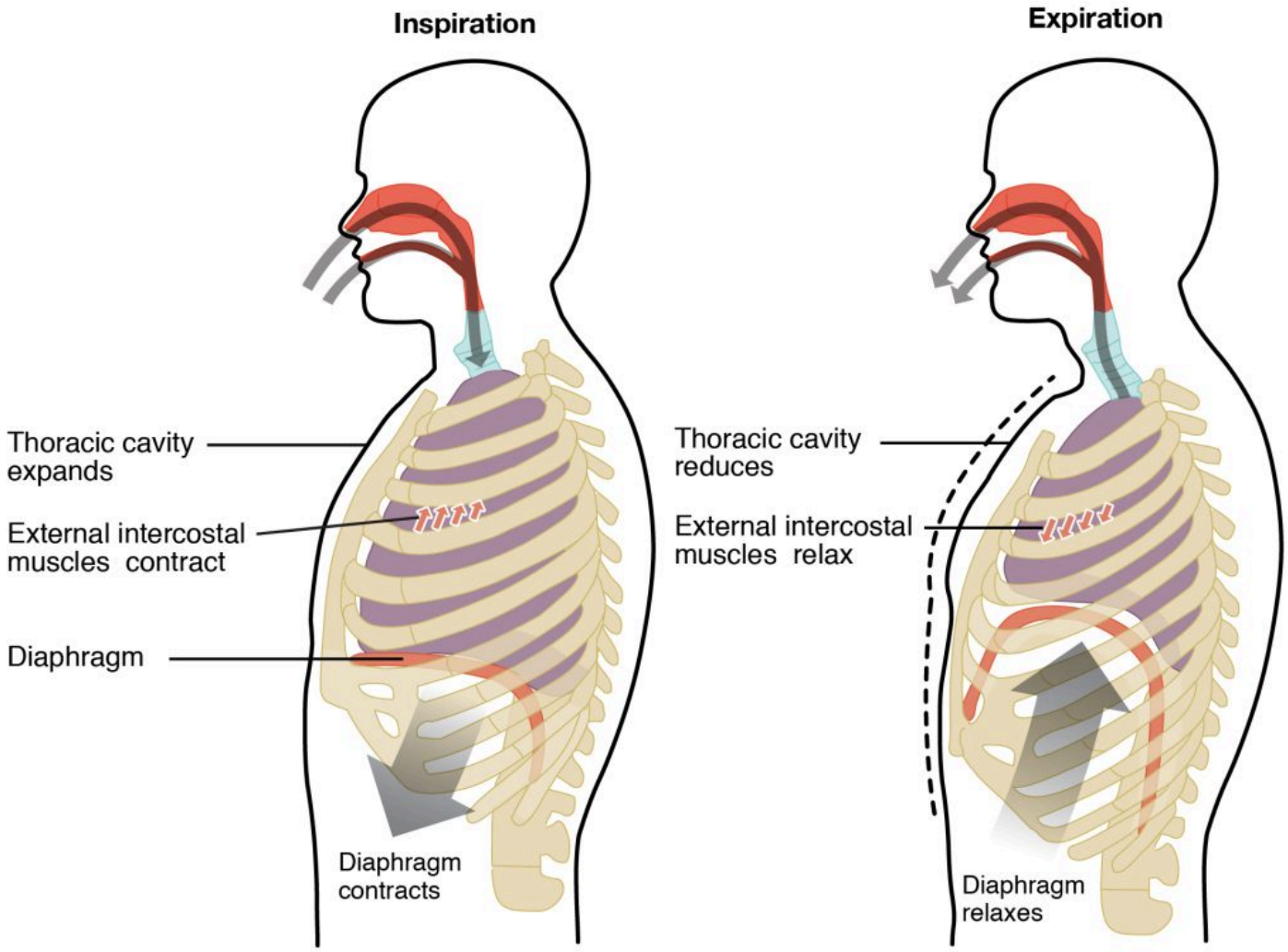


Figure 13.14 Inhalation (Inspiration) and Exhalation (Expiration)

2. OpenStax College. (2013). *Inspiration and expiration* [Diagram]. Wikimedia Commons. CC BY 4.0. https://openstax.org/books/anatomy-and-physiology/pages/22-3-the-process-of-breathing

Video

Watch the MedlinePlus health video to learn more about breathing and the respiratory system.[3]

- **Open the MedlinePlus breathing health video webpage**

Ventilation Control Centers

The control of ventilation is complex and relies on multiple regions of the brain to coordinate the activation of respiratory muscles to initiate contraction. The result is typically a rhythmic, consistent respiratory rate that provides the body with sufficient amounts of oxygen, while adequately removing carbon dioxide.

The major brain centers involved in pulmonary ventilation are the medulla oblongata and the pons. See Figure 13.15[4] for an illustration of the respiratory centers in the brain.

3. A.D.A.M. (2025, January 1). *Breathing* [Video]. MedlinePlus. All rights reserved. https://medlineplus.gov/ency/anatomyvideos/000018.htm

4. OpenStax. (2013). *2327_Respiratory centers of the brain* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2327_Respiratory_Centers_of_the_Brain.jpg

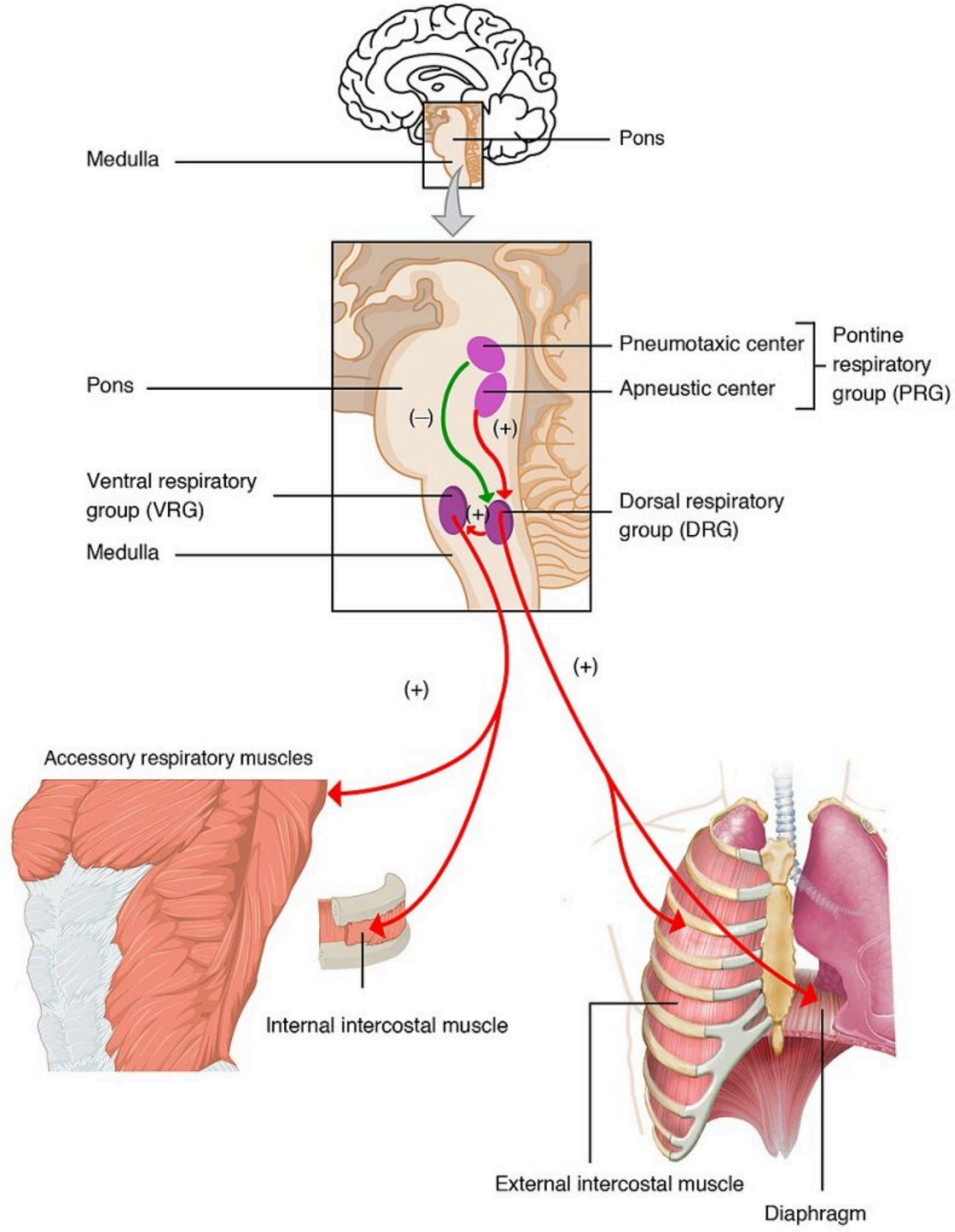


Figure 13.15 Respiratory Centers of the Brain

Respiratory Rate

The **respiratory rate** is the total number of breaths that occur each minute. The normal respiratory rate in adults is 12 to 20 breaths per minute. The normal respiratory rate for children under 1 year of age is 30 to 60 breaths per minute, but by the time a child is about 10 years old, the normal rate is closer to 18 to 30.

Respiratory rate can be an important indicator of health, as the rate may increase or decrease during illness. The respiratory rate is regulated by the respiratory center located within the medulla oblongata and pons in the brain, which responds primarily to changes in carbon dioxide and pH levels in the blood. There is also some voluntary control over breathing, such as holding one's breath or taking a big breath before diving into a pool.

Breathing Patterns

A normal breathing pattern in adults follows rhythmic inhalations and exhalations of 12–20 breaths per minute. There are several medical terms for patterns of breathing:

- Apnea: Temporary pauses in breathing
- Bradypnea: Slow breathing
- Dyspnea: Shortness of breath
- Eupnea: Normal, effortless breathing
- Tachypnea: Rapid breathing

Lung Volumes and Capacities

Lung volume is a medical term used for various volumes of air moved by the lungs at a given point of the respiratory cycle, including the following:

- **Tidal volume (TV)** is the amount of air inhaled or exhaled in a normal quiet breath, which averages about 500 milliliters (mL) for a healthy male adult and 400 mL for a healthy female adult.[5]
- **Inspiratory reserve volume (IRV)** is the extra volume of air that can be forcibly inhaled after a normal inhalation, about 3,100 mL.

- **Expiratory reserve volume (ERV)** is the extra amount of air that can be forcibly exhaled after a normal exhalation, about 1200 mL.
- **Residual volume (RV)** is the air left in the lungs after exhaling as much air as possible, averaging about 1,200 mL. Residual volume prevents alveoli from collapsing and makes breathing easier. For example, consider the effort it takes to blow up a new balloon compared to a balloon that already has some air inside it. In the second scenario, it is easier to inflate the balloon.
- **Inspiratory capacity (IC)** is the maximum amount of air that can be inhaled past a normal tidal expiration; it is the sum of the tidal volume and inspiratory reserve volume.
- **Functional reserve capacity (FRC)** is the amount of air that remains in the lung after a normal tidal expiration; it is the sum of expiratory reserve volume and residual volume.
- **Total lung capacity (TLC)** is the sum of all lung volumes (TV, ERV, IRV, RV), which represents the total amount of air a person can hold in their lungs after a forceful inhalation. TLC is about 6,000 mL of air for males, and about 4,200 mL for females.
- **Vital capacity (VC)** is the amount of air a person can move into or out of their lungs, which is the sum of all the previous volumes described except residual volume (TV ERV IRV) and is between 3,100 and 5,000 milliliters for adults.

See Figure 13.16[6] for an illustration of respiratory volumes and capacities.

5. Hallett, S., Toro, F., & Ashurst, J. V. (2025). *Physiology, tidal volume*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK482502/
6. OpenStax College. (2013). *2317_Spirometry and respiratory volumes* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2317_Spirometry_and_Respiratory_Volumes.jpg

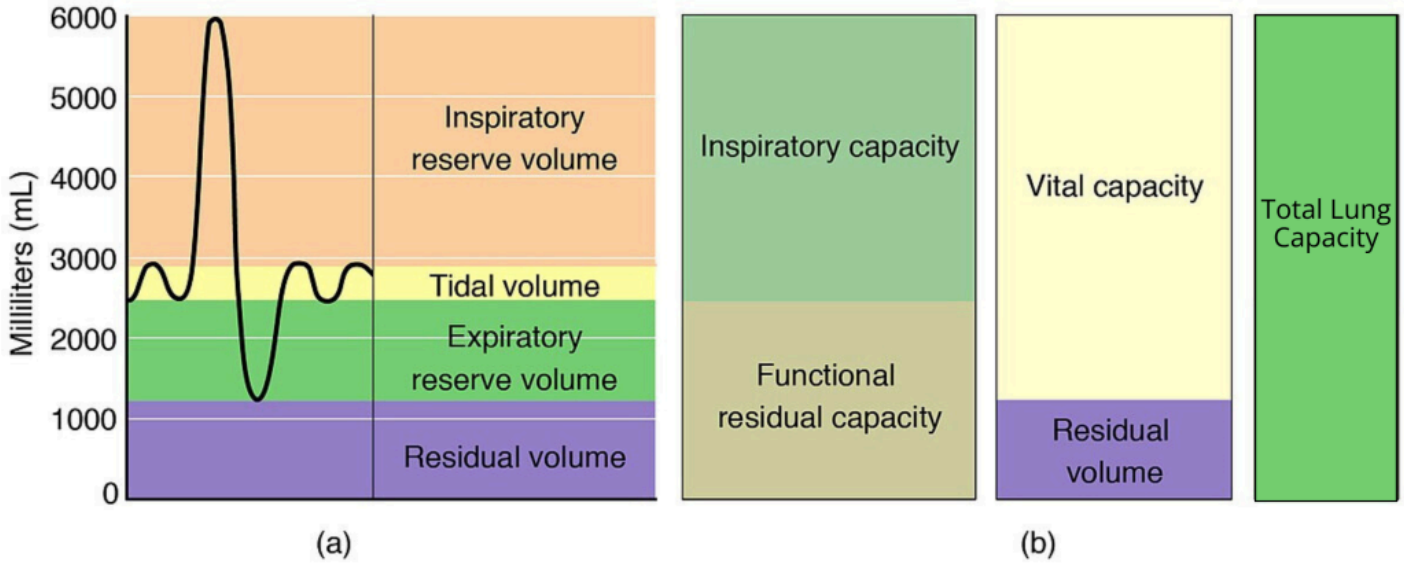


Figure 13.16 Respiratory Volumes and Capacities: (a) Lung Volumes and (b) the Combination of Volumes That Results in Lung Capacity

Gas Exchange

Gas exchange occurs in two main locations in the body: the lungs, where oxygen diffuses into the blood and carbon dioxide diffuses out of the blood and is exhaled; and in the tissues, where oxygen diffuses out of the blood into the tissues and carbon dioxide diffuses out of the tissues and into the blood. **External respiration** (or alveolar gas exchange) is the exchange of gases between the alveoli and the pulmonary capillaries, where oxygen moves from the alveoli into the blood and carbon dioxide moves from the blood into the alveoli. **Internal respiration** (or systemic gas exchange) is the exchange of gases between the systemic capillaries and the tissues, where oxygen moves from the blood into the tissues and carbon dioxide moves from the tissues into the blood.

The actual exchange of gases occurs due to simple diffusion. Energy is not required to move oxygen or carbon dioxide across membranes. Instead, these gases follow pressure gradients that allow them to diffuse from higher concentrations to lower concentrations.

Oxygen Transport in the Blood

Although oxygen is transported in the blood, it has limited solubility in plasma. A small amount of oxygen dissolves in the blood and is transported in the blood plasma,

but this amount represents only about 1.5% of the total amount. The majority of oxygen molecules are carried from the lungs to the body's tissues by hemoglobin in erythrocytes (red blood cells).

Heme is the portion of hemoglobin that contains iron and binds oxygen. Each hemoglobin molecule contains four iron-containing heme molecules, so one hemoglobin molecule can carry four molecules of oxygen. If a hemoglobin molecule is carrying four molecules of oxygen, it is considered saturated. A hemoglobin saturation of 100% means that every heme unit in all erythrocytes of the body is bound to oxygen. In a healthy individual with normal hemoglobin levels, hemoglobin saturation generally ranges from 95% to 99%.

See Figure 13.17[7] for an illustration of an erythrocyte and hemoglobin.

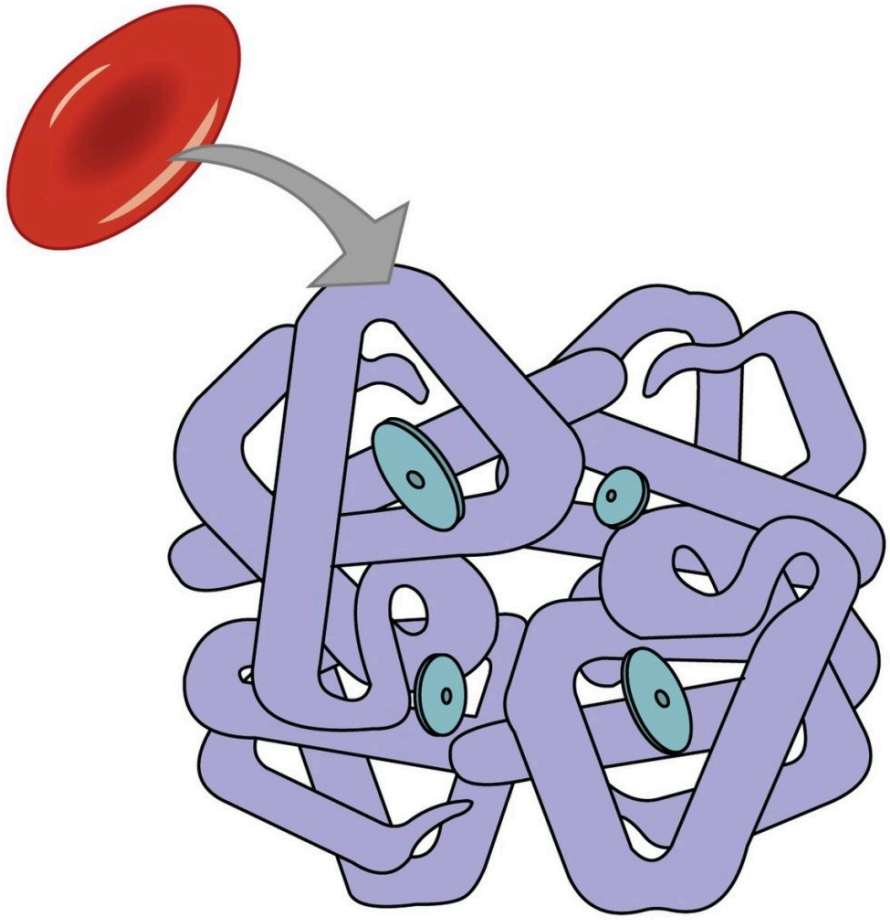
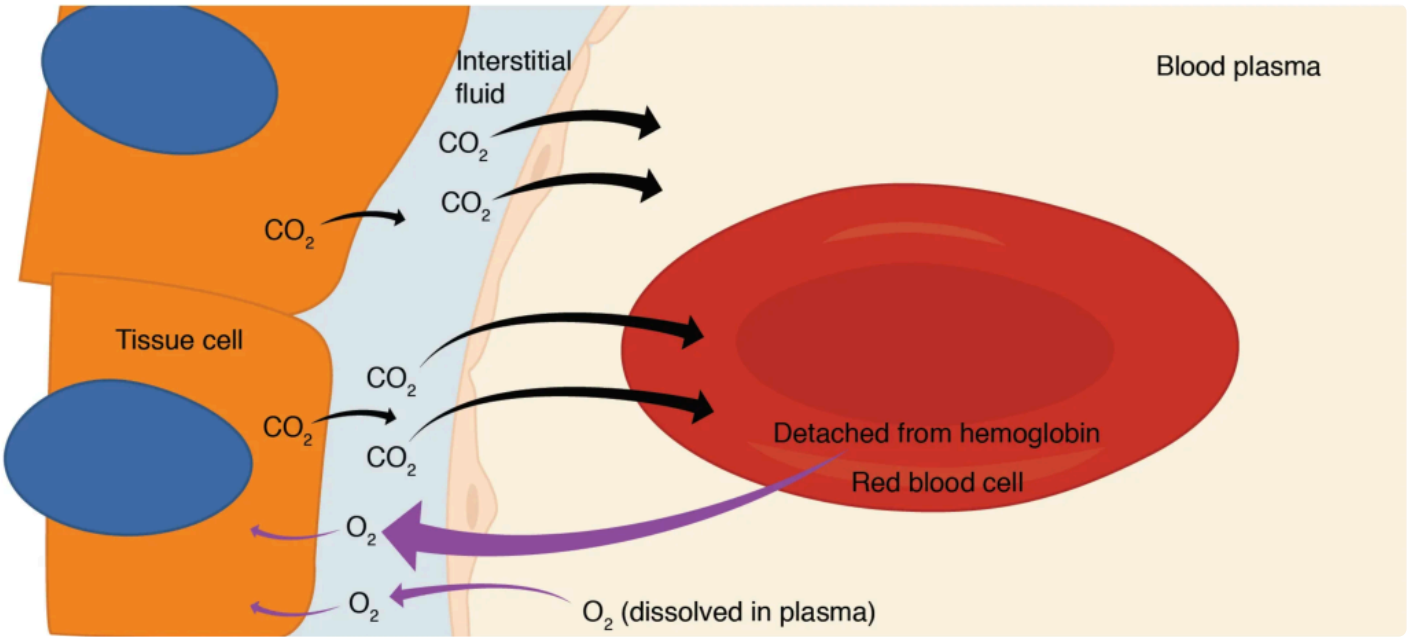


Figure 13.17 Erythrocyte and Hemoglobin

7. OpenStax. (2013). *Fig_23.22 – Anatomy and Physiology* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2322_Fig_23.22-a.jpg

When oxygen diffuses from the alveoli into the pulmonary capillaries, it diffuses into the red blood cell and binds to hemoglobin, forming **oxyhemoglobin (HbO_2)**. Oxyhemoglobin is a bright, red-colored molecule that contributes to the bright red color of oxygenated blood.

Oxygen is transported in the bloodstream and released in tissues based on their metabolic demand. For example, during exercise, more oxygen is needed by the skeletal muscles, so more oxygen is released by the hemoglobin. See Figure 13.18[8] for an illustration of this process.



13.18 Internal Respiration. Oxygen Diffuses Out of the Capillary and Into Cells, Whereas Carbon Dioxide Diffuses Out of Cells and Into the Capillary

Carbon Dioxide Transport in the Blood

Carbon dioxide (CO_2) is transported in the blood in three different ways: converted to bicarbonate ions, bound to hemoglobin as carbaminohemoglobin, and dissolved directly in the plasma.

- **Bicarbonate**: The majority of carbon dioxide (about 75%) is transported in the blood

8. OpenStax College. (2013). *Figure 23.20 – Anatomy and Physiology* [Diagram]. Wikimedia Commons. CC BY 3.0. https://openstax.org/apps/image-cdn/v1/f=webp/apps/archive/20251118.192121/resources/51782420a77f633a98451518ad50874b71d9c762

as bicarbonate (HCO_3^-) ions. CO_2 diffuses into red blood cells, where a chemical reaction converts it to bicarbonate. Bicarbonate is transported in the bloodstream to the lungs, where a reverse reaction occurs in the red blood cells, and CO_2 is exhaled.

- **Carbaminohemoglobin**: About 20% of carbon dioxide binds to hemoglobin in red blood cells, forming carbaminohemoglobin. Carbon dioxide does not bind to iron as oxygen does, but instead binds to the globin portions of hemoglobin. The red blood cells are transported in blood to the pulmonary capillaries, where carbon dioxide dissociates from hemoglobin and diffuses into the alveoli and is exhaled.
- **Dissolved in Plasma**: A small amount of carbon dioxide (about 5%) dissolves directly in the plasma and travels to the pulmonary capillaries, where it diffuses into the alveoli and is exhaled.

See Figure 13.19[9] for an illustration of the three methods of carbon dioxide transport in the blood.

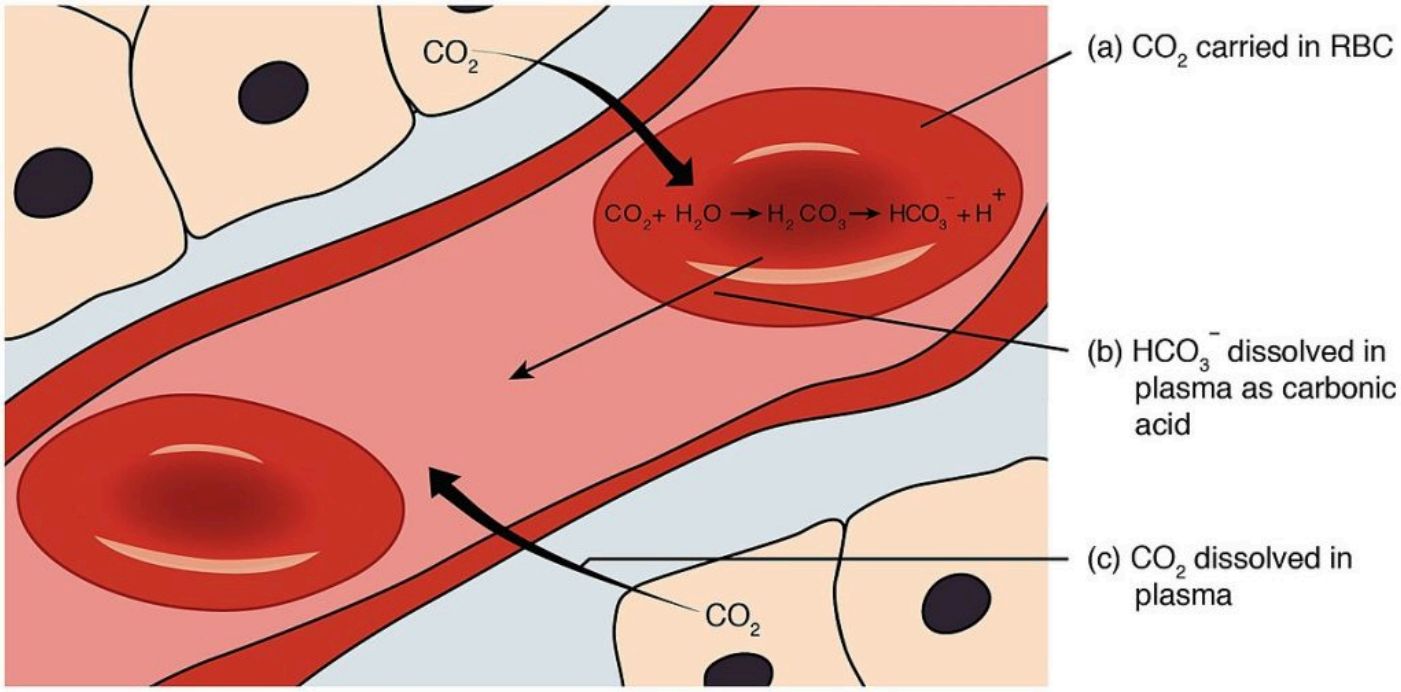


Figure 13.19 Carbon Dioxide Transport: (a) in Erythrocytes As Carbaminohemoglobin, (b) as Bicarbonate (HCO_3^-) in Plasma, and (c) CO_2 Dissolved in Plasma

9. OpenStax College. (2013). *2325_Carbon dioxide transport* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2325_Carbon_Dioxide_Transport.jpg

Video

Watch the video "Breathing Explained (Pulmonary Ventilation and Gas Exchange)" below to learn more about breathing and gas exchange in the lungs.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Watch the video "Respiratory System" below to learn about the structure and function of the respiratory system and how it facilitates gas exchange in the body.[10]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

10. Amoeba Sisters. (2022, February 28). *Respiratory system* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=v_j-LD2YEqg

13.5 Disorders of the Respiratory System

Asthma

Asthma is a common chronic respiratory disease characterized by episodes of **bronchospasms** (constriction of the bronchioles), inflammation, and edema of the airway that makes it difficult to exhale air, commonly referred to as an "asthma attack." In addition, excessive mucus secretion further contributes to airway occlusion. Approximately 8.2% of adults (18.7 million) and 9.4% of children (7 million) in the United States have asthma. In addition, asthma is the most frequent cause of hospitalization in children.

An asthma attack can be triggered by a variety of environmental factors, such as dust, pollen, pet hair, or dander, changes in the weather, mold, tobacco smoke, respiratory infections, or exercise and stress. Cells of the immune system, such as eosinophils and mononuclear cells, may be involved in an allergic response that triggers the asthma attack. See Figure 13.20[1] for an illustration comparing a normal airway to an airway during asthma symptoms.

1. National Heart, Lung and Blood Institute. (2017). *Asthma illustration* [Diagram]. National Institutes of Health. CC BY-NC 2.0. https://www.flickr.com/photos/nihgov/33173882952

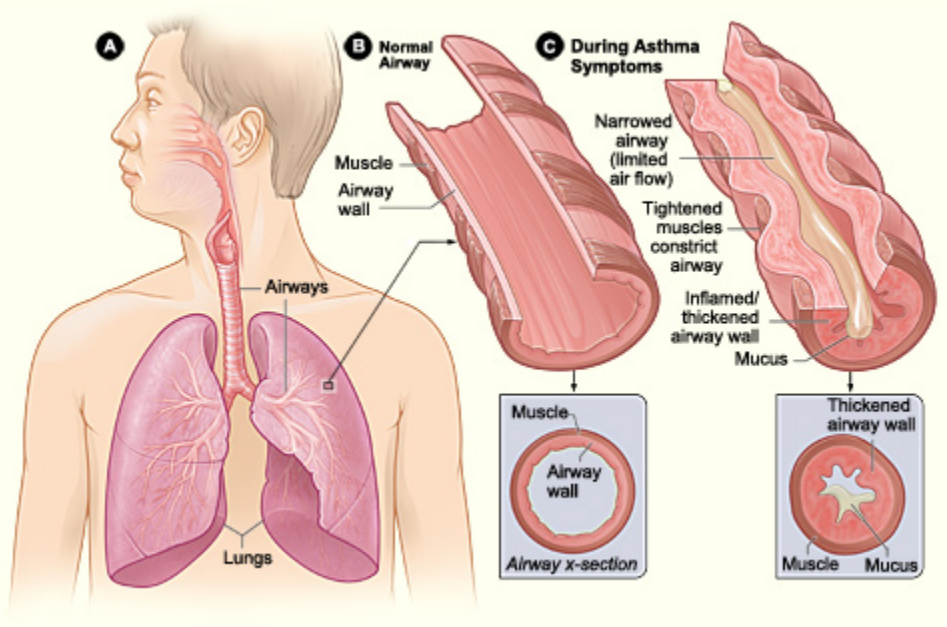


Figure 13.20 Normal Airway Compared to Airway During Asthma Symptoms

Symptoms of an asthma attack include shortness of breath, a whistling sound in the lungs called wheezing, chest tightness, and coughing. Severe asthma attacks are life-threatening and require emergency medical treatment. Symptoms of a severe asthma attack include worsening shortness of breath that results in cyanotic (blue) lips or face, confusion, drowsiness, a rapid pulse, sweating, and severe anxiety. The severity of the condition, frequency of attacks, and identified triggers influence the type of medications prescribed to manage the condition. Short-term, fast-acting medications are used to treat an asthma attack, and long-term medications are used to help prevent asthma attacks from occurring.[2,3]

Read more about asthma symptoms and treatments in the **"Asthma" section of the Open RN *Health Alterations* textbook**.

2. Centers for Disease Control. (n.d.). *Asthma*. https://www.cdc.gov/asthma/

3. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Health alterations*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthalts/



Atelectasis

Atelectasis occurs when alveoli lose air and collapse, often due to a **pneumothorax**. If left untreated, atelectasis can cause the collapse of part or all of a lung. Atelectasis is asymptomatic if only a few alveoli are affected, but as more alveoli become involved, the patient may report dyspnea, cough with or without sputum production, and pleuritic chest pain. Atelectasis is one of the most common breathing complications after surgery and can be prevented with adequate pain control, position changes, deep breathing and coughing, and walking soon after surgery.[4]

Carbon Monoxide Poisoning

Carbon monoxide poisoning occurs when carbon monoxide (CO) builds up in the blood and can lead to serious tissue damage or death. Carbon monoxide is a gas that has no odor, taste, or color and is produced from burning fuels such as gasoline, wood, propane, or charcoal. Appliances and engines that are not well-vented can cause carbon monoxide to build up to dangerous levels in the air. A tightly enclosed space makes the buildup worse. Carbon monoxide binds to hemoglobin with a much higher affinity than oxygen, displacing oxygen and reducing the blood's oxygen-carrying capacity.

Carbon monoxide poisoning significantly affects the brain and heart. Symptoms of carbon monoxide poisoning include headache, weakness, dizziness, nausea or vomiting,

4. Grott, K., Chauhan, S., Sanghavi, D.K., & Dunlap, J.D.(2024). *Atelectasis*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK545316/

shortness of breath, confusion, blurred vision, sleepiness, loss of muscle control, and loss of consciousness. Initial symptoms can be mistaken for flu symptoms without a fever. Individuals exposed to carbon monoxide should be moved to fresh air immediately and seek prompt medical attention.[5]

Chronic Obstructive Pulmonary Disease (COPD)

Chronic obstructive pulmonary disease (COPD) is a chronic, progressive lung disease caused by inflammation inside the airways, resulting in limited airflow out of the lungs, known as obstruction. COPD is often caused by long-term exposure to irritating smoke, fumes, dust, or chemicals, with the most common cause being exposure to cigarette smoke. Unlike asthma, with reversible, periodic episodes, COPD symptoms are continuous. Symptoms of COPD include shortness of breath, coughing, wheezing, and excessive mucus production. Symptoms may worsen during COPD exacerbations that are triggered by an illness or infection and typically require hospitalization.

Chronic obstructive pulmonary disease (COPD) is characterized by two main conditions: chronic bronchitis and emphysema. These two conditions may occur together and can vary in severity across individuals with COPD. Chronic bronchitis is inflammation of the lining of the bronchi, which leads to excessive mucus production. The inflammation prevents airflow into and out of the lungs. In emphysema, the alveoli are damaged and lose their elasticity, making it difficult to expel air from the lungs and affecting gas exchange. The obstructions caused by chronic bronchitis and emphysema cause decreased levels of oxygen and elevated levels of carbon dioxide in the blood. See Figure 13.21[6] for an image comparing healthy lungs to lungs affected by COPD.

5. Mayo Clinic. (2025). *Carbon monoxide poisoning.* https://www.mayoclinic.org/diseases-conditions/carbon-monoxide/symptoms-causes/syc-20370642

6. National Heart, Lung, and Blood Institute. (2017). *COPD (Chronic Obstructive Pulmonary Disease)* [Illustration]. National Institutes of Health. CC BY-NC 2.0. https://www.flickr.com/photos/nihgov/32486640184/in/photostream/

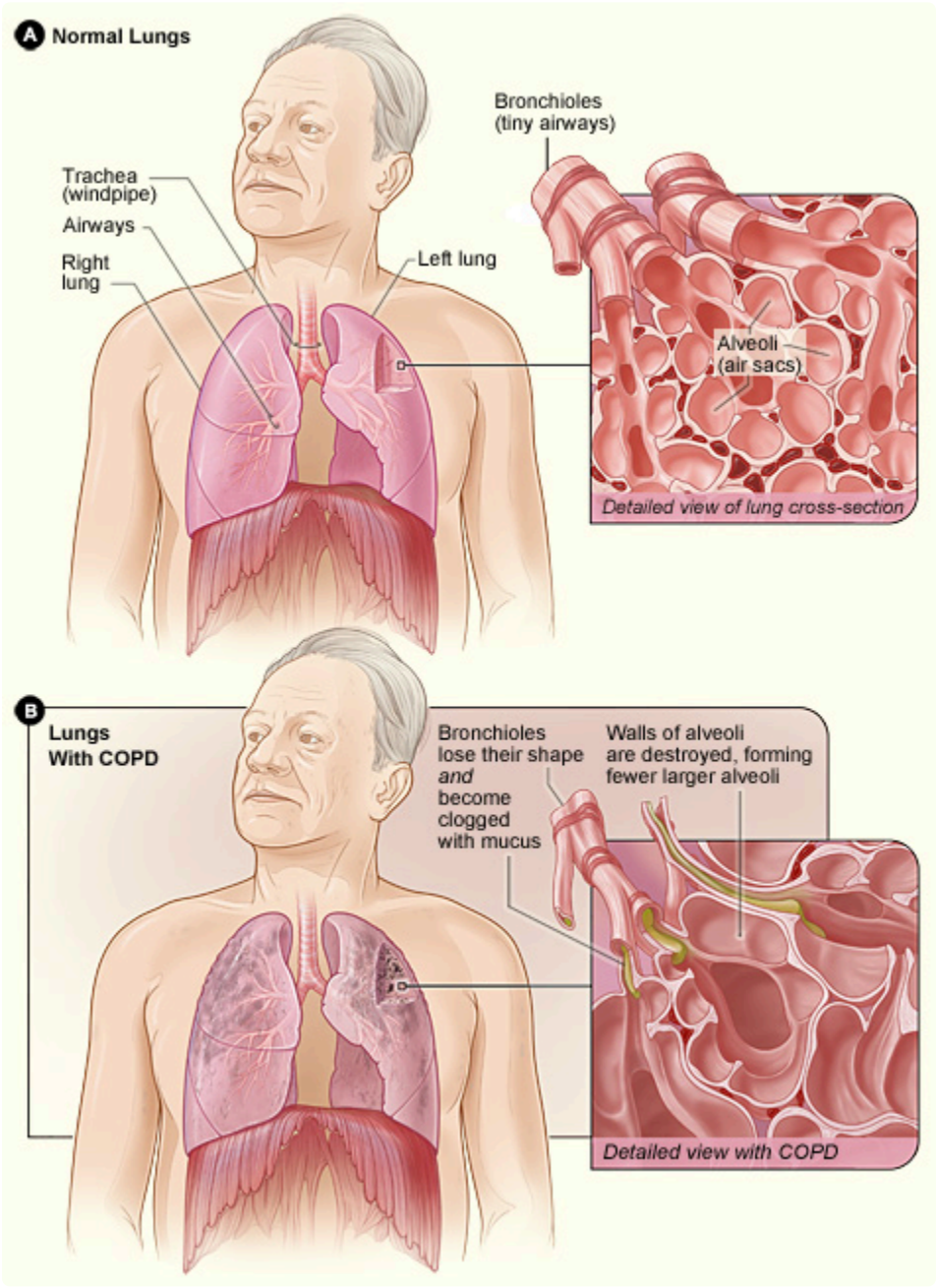


Figure 13.21 Healthy Lungs Compared to Lungs With COPD

Although COPD is a condition that worsens over time, COPD symptoms are treatable with medications, supplementary oxygen administration, and other medical treatments.

With proper management, many people with COPD can control symptoms and improve their quality of life.[7,8]

Read more about COPD symptoms and management in the "**COPD" section of the Open RN *Health Alterations* textbook**

COVID-19

COVID-19 is an infectious respiratory disease caused by a coronavirus called SARS-CoV-2. Most people infected with the virus experience mild to moderate respiratory illness. However, some individuals become seriously ill and require urgent medical attention. Older adults and those with underlying medical conditions such as cardiovascular disease, diabetes, chronic respiratory disease, obesity, or cancer are more likely to develop serious illness.

The COVID-19 virus spreads from respiratory droplets and aerosols released from an infected person's mouth or nose when they cough, sneeze, speak, sing, or breathe. These particles range from larger respiratory droplets to smaller aerosols, so respiratory etiquette is essential by covering your coughs and sneezes. Individuals infected with COVID-19 should also wash their hands or use an alcohol-based hand sanitizer frequently and stay home until they recover. Wearing a mask can also help prevent transmission of the virus by trapping the droplets that spread the disease. The best way

7. Mayo Clinic. (2024). *COPD*. https://www.mayoclinic.org/diseases-conditions/copd/symptoms-causes/syc-20353679
8. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Health alterations*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthalts/

to prevent COVID-19 is to be well-informed about how the virus spreads and stay up-to-date with CDC-recommended vaccinations.[9][10]

Cystic Fibrosis

Cystic fibrosis (CF) is a genetic condition that alters a protein in the body involved in the function of the cells, tissues, and glands responsible for producing mucus and sweat. Normal mucus is slippery and protects the airways, digestive tract, and other organs and tissues. Cystic fibrosis causes mucus to become thick and sticky. As mucus builds up, it can cause blockages, damage, or infections in affected organs. See Figure 13.22[11] for a depiction of signs and symptoms that may occur in patients with CF.

9. World Health Organization. (2024). *Coronavirus disease (COVID-19).* https://www.who.int/health-topics/coronavirus
10. Centers for Disease Control. (2025). *How to protect yourself and others.* https://www.cdc.gov/covid/prevention/index.html
11. BruceBlausen. (2013). *Cystic fibrosis* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Blausen_0286_CysticFibrosis.png

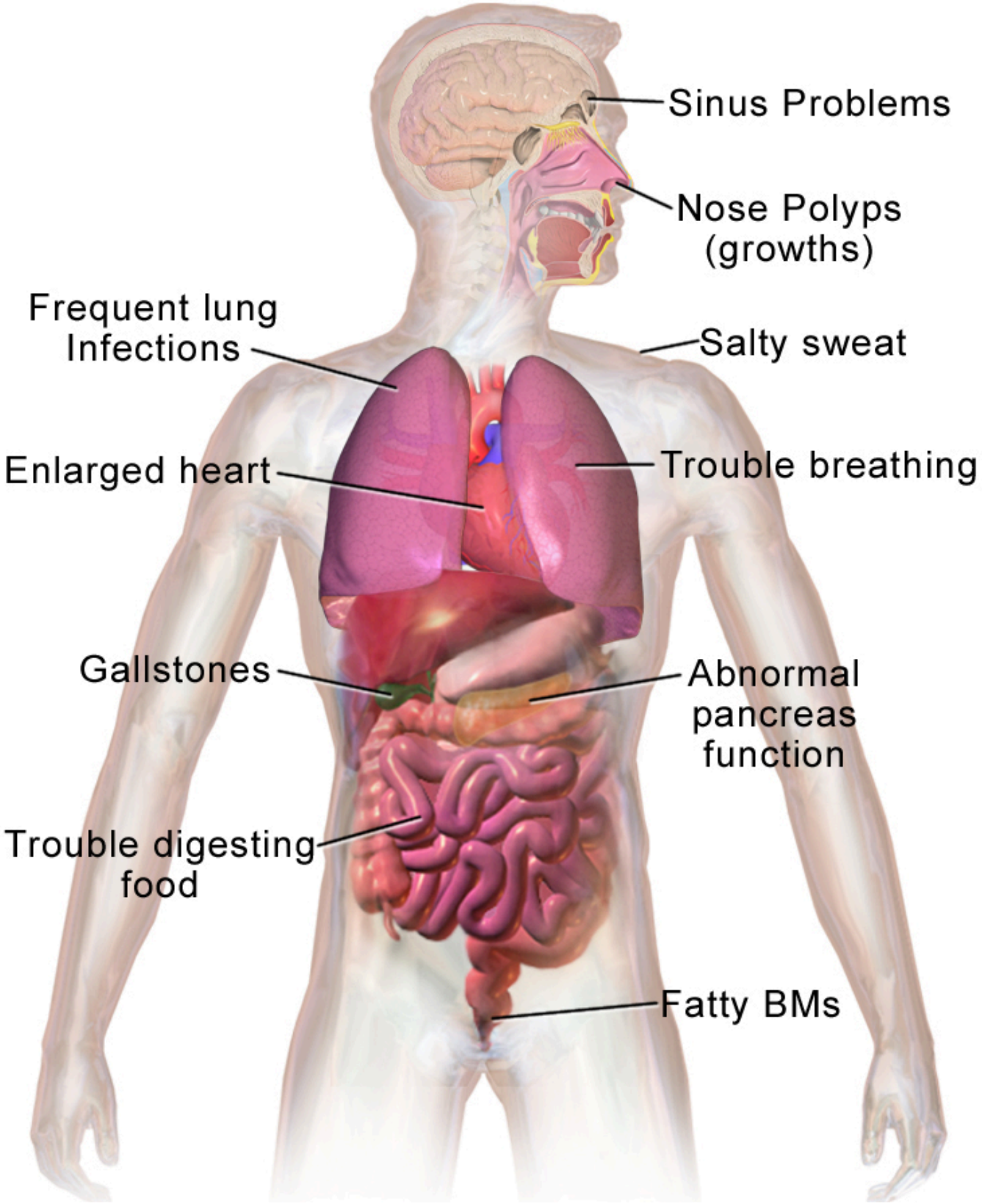


Figure 13.22 Signs and Symptoms of Cystic Fibrosis

Nearly 40,000 children and adults in the United States—and more than 100,000 worldwide—are now living with cystic fibrosis. Cystic fibrosis was historically known as a disease that caused death in childhood, but survival rates have significantly improved because of advances in newborn screening, medications, nutrition, and lung transplants. With proper treatment, children diagnosed with cystic fibrosis are now expected to reach the age of 68 or older.[12]

Influenza

Influenza, commonly called "the flu," is a viral infection that affects the epithelial cells lining the respiratory tract. Influenza viruses are different from viruses that cause the common cold. Influenza symptoms commonly include fever, headache, body aches, sore throat, nasal congestion, and cough. Some individuals, especially small children, may experience nausea and diarrhea because of the immune response to the virus, but the influenza virus is different from viruses that cause the "stomach flu." While most individuals with influenza can manage symptoms at home and recover within several days, it can be severe and even life-threatening for those at higher risk due to potential complications. Risk factors for severe illness include children under age 2 and adults aged 65 or older, women who are pregnant, and individuals with chronic illness or weakened immune systems.

Annual flu vaccines can help protect individuals from becoming infected with seasonal influenza viruses and decrease the risk of developing severe complications. Administration of the flu vaccine to health care workers and family members can also help prevent the transmission of the virus to vulnerable individuals. Other steps to help prevent infection during "flu season" include cleaning and disinfecting surfaces, frequently washing hands, and circulating fresh air indoors.[13]

Lung Cancer

Lung cancer is the leading cause of cancer death in both men and women. It forms in tissues of the lung, typically in the cells that line the air passages. There are two main

12. National Heart, Lung, and Blood Institute. (2024). *What is cystic fibrosis?* National Institutes of Health. https://www.nhlbi.nih.gov/health/cystic-fibrosis

13. Mayo Clinic. (2024). *Influenza (flu).* https://www.mayoclinic.org/diseases-conditions/flu/symptoms-causes/syc-20351719

types of lung cancer that grow differently and are treated differently: small-cell lung cancer and non–small-cell lung cancer. See Figure 13.23[14] for an image of a cancerous lung.

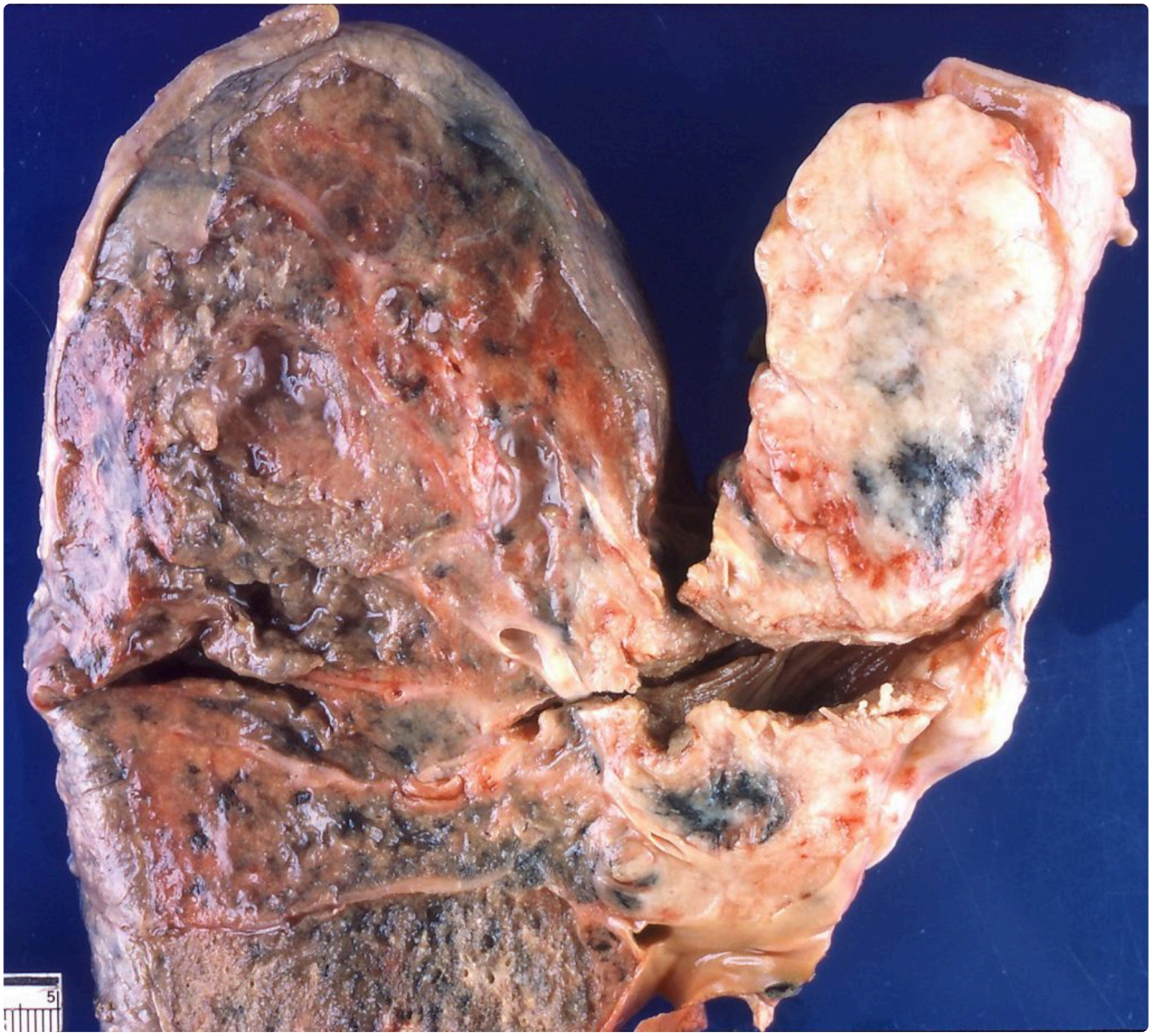


Figure 13.23 Cancerous Lung

Anyone can develop lung cancer, but factors that increase risk include the following:

14. Rose, Y. (2009). *Small cell carcinoma* [Photograph]. Flickr. CC BY-SA 2.0. https://www.flickr.com/photos/pulmonary_pathology/3922610419

- Smoking: Smoking poses the greatest risk for developing lung cancer. Tobacco smoking causes about 8 out of 10 cases of lung cancer. The number of years a person smokes and the number of cigarettes smoked each day increase the risk. Risk is also increased if a person smokes and drinks alcohol daily. If a person quits smoking, their risk is lower than if they had kept smoking, but they still have a higher risk than people who never smoked.
- Secondhand smoke: Secondhand smoke is the combination of smoke that comes from a cigarette and smoke breathed out by a smoker. People who breathe in secondhand smoke are exposed to the same cancer-causing agents as smokers, although in smaller amounts.
- Family history of lung cancer: A family history of lung cancer can increase the risk for the disease in both smokers and non-smokers.
- Exposure to toxic substances:[15, 16] Vaping, smoking cannabis; exposure to asbestos, arsenic, chromium, beryllium, nickel, soot, or tar in the workplace; exposure to air pollution; exposure to radiation to the chest from radiation therapy; and exposure to radon in the home increase the risk of lung cancer.
- Age: The risk of developing lung cancer increases with age, with the majority of people diagnosed with lung cancer aged 65 or older.

Lung cancer may not cause any signs or symptoms until the cancer is advanced. In fact, sometimes lung cancer is found during a chest X-ray performed for another condition. Symptoms of lung cancer may include chest discomfort, a persistent cough that does not go away or gets worse over time, coughing up blood, trouble breathing, wheezing, hoarseness, weight loss for no known reason, feeling very tired, and trouble swallowing.

Treatment of lung cancer depends on the type of lung cancer, whether it has metastasized, the patient's overall health, and other factors. Treatments may include surgical interventions, radiation therapy, chemotherapy, and/or immunotherapy.[17, 18]

15. Kundu, A., Sachdeva, K., Feore, A., Sanchez, S., Sutton, M., Seth, S., Schwartz, R. & Chaiton, M. (2025). Evidence update on the cancer risk of vaping e-cigarettes: A systematic review. *Tobacco Induced Diseases, 23*(January), 6. https://doi.org/10.18332/tid/192934

16. Couraud, S., Molinier, O., Sabatini, M., Thomassin, S., Haouachi, R., Levrat, V., Ghalloussi-Tebai, H., Belle, A., Mosser, L., Larive, S., Bedossa, A., Letierce, A., Morel, H., & Debieuvre, D. (2025). Outcomes of cannabis smoking in patients with lung cancer: Findings from KBP-CPHG-2020. *Respiratory Medicine and Research, 88*, 101174. https://pubmed.ncbi.nlm.nih.gov/40393352/

17. National Cancer Institute. (n.d.). *Lung cancer.* MedlinePlus [Internet]. https://medlineplus.gov/lungcancer.html

18. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Health alterations*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthalts/

Read more about lung cancer symptoms and treatments in the **"Lung Cancer" section of the Open RN *Health Alterations* textbook**.



Take a Closer Look

*]:pointer-events-auto [content-visibility:auto] supports-[content-visibility:auto]:[contain-intrinsic-size:auto_100lvh] R6Vx5W_threadScrollVars scroll-mb-[calc(var(--scroll-root-safe-area-inset-bottom,0px)+var(--thread-response-height))] scroll-mt-[calc(var(--header-height)+min(200px,max(70px,20svh)))]" dir="auto" data-turn-id="request-WEB:953b9362-436d-4e98-ba34-365751fc8512-21" data-testid="conversation-turn-44" data-scroll-anchor="false" data-turn="assistant">
Read more about the benefits of quitting commercial tobacco and e-cigarettes from national health organizations.

- Open the American Lung Association benefits of quitting smoking webpage
- Open the American Cancer Society quitting smoking or smokeless tobacco webpage
- Open the American Cancer Society quitting e-cigarettes webpage

Pharyngitis/Tonsillitis

Pharyngitis refers to inflammation of the pharynx or throat, and **tonsillitis** refers to inflammation of the tonsils. Although there is a distinction between the two disorders, they can coexist. Both disorders are commonly referred to as a "sore throat" and have

similar pathophysiologies, signs and symptoms, and treatment. Pharyngitis and tonsillitis are typically caused by bacterial or viral infections. However, pharyngitis can also be caused by allergies, acid reflux, or cancer. Common viral causes of pharyngitis and tonsillitis are rhinovirus, coronavirus, and adenovirus. Although there are a variety of bacteria that can lead to pharyngitis or tonsillitis, the most common is *Group A beta-hemolytic streptococcus* (GABHS), also called GBS. This is also known as "strep throat" and is common in school-aged children. When pharyngitis and/or tonsillitis caused by GABHS is not treated, rheumatic fever or post-streptococcal glomerulonephritis can develop. Rheumatic fever is an inflammatory disease that causes inflammation of the joints and the valves of the heart. Post-streptococcal glomerulonephritis refers to inflammation of the glomeruli of the kidneys, leading to edema, increased blood pressure, and alterations in kidney function. Medical treatment for pharyngitis and tonsillitis is based on the causative factor of the disorder. When caused by a bacterial infection such as GABHS, antibiotics are required. However, antibiotic therapy is ineffective if the causative organisms are viral or fungal. Antibiotics will not only treat the bacterial infection but also shorten the duration of the illness and prevent the development of rheumatic fever. They may also help prevent the development of post-streptococcal glomerulonephritis.[19,20,21]

Pleuritis/Pleurisy

Pleuritis, also known as pleurisy, is inflammation of the pleura, the membranes surrounding the lungs and chest wall. It is characterized by sharp chest pain that worsens with breathing, coughing, or movement and may radiate to the shoulder and back. The pain is caused by the plurae rubbing together instead of smoothly gliding. Pleuritis can be caused by a variety of conditions, but the most common cause is a viral infection. Treatment depends upon the underlying cause, but the pain is often managed with acetaminophen (Tylenol) or nonsteroidal anti-inflammatory drugs (NSAIDs).[22]

19. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Health alterations*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthalts/
20. Johns Hopkins Medicine. (n.d.). *Pharyngitis and tonsillitis.* https://www.hopkinsmedicine.org/health/conditions-and-diseases/pharyngitis-and-tonsillitis
21. Anderson, J., & Paterek, E. (2023). *Tonsillitis.* StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK544342
22. National Heart, Lung, and Blood Institute. (2022). *What are pleural disorders?* National Institutes of Health. https://www.nhlbi.nih.gov/health/pleural-disorders

Pneumonia

Pneumonia is an infection that inflames the alveoli, causing them to fill with fluid or pus. Symptoms include a productive cough with fever, chills, and difficulty breathing. A variety of organisms, including bacteria, viruses, and fungi, can cause pneumonia. See Figure 13.24[23] for an image depicting healthy alveoli compared to the alveoli of someone with pneumonia.

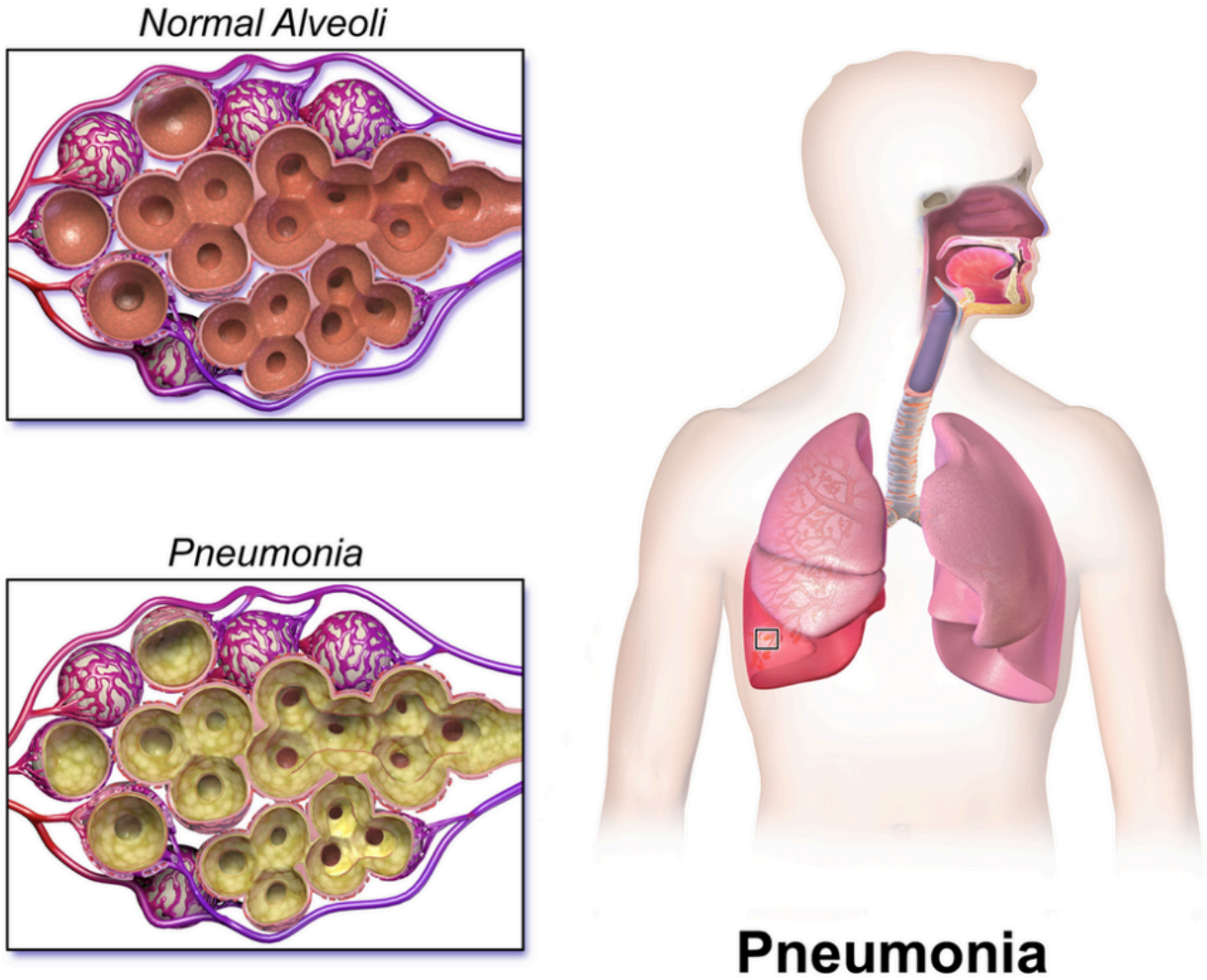


Figure 13.24 Normal Alveoli Compared to Alveoli Affected by Pneumonia

23. BruceBlaus. (2015). *Blausen_0994_Pneumonia* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Blausen_0994_Pneumonia.png

Pneumonia can range in severity from mild to life-threatening, with increased risk for infants and young children, adults aged 65 or older, and people with health problems or weakened immune systems. Vaccinations are available to prevent certain types of pneumonia for those at increased risk.

Treatment depends on the type and severity of the pneumonia. Common treatments include antibiotics for bacterial cases, antivirals for viral cases, antifungals for fungal cases, cough medications, and acetaminophen or ibuprofen to relieve pain and/or fever. Severe cases require hospitalization for intravenous antibiotics, oxygen administration, and other medical treatments.[24]

Read more about pneumonia symptoms and treatments in the **"Pneumonia" section of the Open RN *Health Alterations* textbook**.



Pneumothorax

A **pneumothorax** occurs when air leaks into the space between the lung and the chest wall, causing the lung to collapse (**atelectasis**). This can happen due to injuries such as from a car accident or stab wounds; certain medical procedures like placement of central lines or biopsies that damage the lung; or lung disorders like asthma, COPD, pneumonia, or lung cancer. In some cases, a pneumothorax occurs spontaneously without an obvious cause. A tension pneumothorax is a medical emergency that occurs when pressure builds up inside the chest as air enters and cannot escape.

Symptoms of a pneumothorax include sudden chest pain, shortness of breath, and cyanosis (bluish skin due to lack of oxygen). Treatment depends on the cause, size,

24. Mayo Clinic. (2020). *Pneumonia.* https://www.mayoclinic.org/diseases-conditions/pneumonia/symptoms-causes/syc-20354204

and severity of the pneumothorax. In severe cases, a thoracentesis is performed, where a needle is placed between the ribs to evacuate the excess air in the chest. A chest tube may be placed inside the chest for a few days or longer to reduce the amount of air in the pleural space. As the air pressure decreases, the lung re-expands and heals. To prevent the lung from collapsing again, pleurodesis may be performed, where a chemical powder is placed in the lung to help attach it to the chest cavity, eliminating extra space.[25]

Pulmonary Edema

Pulmonary edema is a serious condition where fluid accumulates in the lungs, making it difficult to breathe. This buildup of fluid interferes with the gas exchange of oxygen and carbon dioxide, potentially leading to hypoxemia (low blood oxygen levels) and respiratory failure. Acute pulmonary edema can be life-threatening and requires immediate medical attention. Pulmonary edema is often caused by heart failure of the left ventricle, where the heart's inability to pump efficiently leads to blood backing up in the lungs. It may also be caused by kidney failure, liver failure, infections, certain medications, lung injury, or exposure to high altitudes.

Symptoms of pulmonary edema include dyspnea, especially when lying down, a productive cough of pink, frothy liquid, sweating, and anxiety. It is commonly treated with medications to remove excess fluid buildup and oxygen administration. In severe cases, respiratory therapy with noninvasive ventilation or intubation and mechanical ventilation may be required.[26]

Pulmonary Embolism

A **pulmonary embolism (PE)** is a blood clot or other substance, such as fat or an air bubble, that has traveled through the bloodstream and lodged in a smaller vessel within the pulmonary circulation in the lungs and obstructs blood flow. This blockage causes a lack of oxygen delivery to the tissues supplied by that blood vessel. A PE is a medical emergency that requires rapid treatment to prevent severe damage to the lungs or

25. Cleveland Clinic. (2022). *Pneumothorax (collapsed lung).* https://my.clevelandclinic.org/health/diseases/15304-collapsed-lung-pneumothorax

26. Malek, R., & Soufi, S. (2023). *Pulmonary edema*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK557611/

heart and death. Symptoms of a PE may include sudden, severe shortness of breath; sharp pain in the chest or arm; and pale, clammy skin. Treatment includes medications to dissolve the clot or procedures to remove the clot in order to quickly restore adequate pulmonary circulation.[27]

Respiratory Distress Syndrome

Respiratory distress syndrome (RDS) is a condition that primarily affects premature babies, causing difficulty breathing. It is commonly caused by insufficient surfactant in the lungs that keep the alveoli inflated. Symptoms of RDS include rapid, shallow breathing; grunting; flaring of the nostrils; and subcostal, subxiphoid, intercostal, and suprasternal contractions. Treatment usually involves surfactant replacement therapy, oxygen administration, and respiratory treatments. In severe cases, intubation and mechanical ventilation are required. Many patients will continue to have complications during and after the acute course of RDS. RDS can be reduced by the administration of corticosteroids before a premature infant is born.[28]

Sleep Apnea

Sleep apnea is a chronic disorder that can occur in children or adults and is characterized by the cessation of breathing during sleep for several seconds. Sleep apnea leads to poor sleep, reflected in the symptoms of fatigue, morning headaches, evening napping, irritability, and memory problems. In addition, many individuals with sleep apnea experience a dry throat in the morning after waking from sleep, which may be due to excessive snoring.

There are two types of sleep apnea: obstructive sleep apnea and central sleep apnea. Obstructive sleep apnea is caused by an obstruction of the airway during sleep, which can occur at different parts of the airway, depending on the underlying cause of the obstruction. For example, the tongue and throat muscles of some individuals with obstructive sleep apnea may relax excessively, causing the muscles to push into the

27. Cleveland Clinic. (2022). *Pulmonary embolism*. https://my.clevelandclinic.org/health/diseases/17400-pulmonary-embolism

28. Yadav, S., & Lee, B. (2023). *Neonatal respiratory distress syndrome*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK560779/

airway. Another example is obesity, as excess adipose tissue in the neck region can push the soft tissues towards the lumen of the airway, causing the trachea to narrow.

In central sleep apnea, the respiratory centers of the brain do not respond properly to rising carbon dioxide levels and, therefore, do not stimulate the contraction of the diaphragm and intercostal muscles regularly. As a result, inspiration does not occur, and breathing stops for a short period. In some cases, the cause of central sleep apnea is unknown. However, some medical conditions, such as stroke and heart failure, may cause damage to the pons or medulla oblongata. In addition, some medications, such as morphine, can affect the respiratory center and decrease the respiratory rate to life-threatening levels. The symptoms of central sleep apnea are similar to those of obstructive sleep apnea.

Sleep apnea is diagnosed with a sleep study where the patient's blood oxygen levels, heart rate, respiratory rate, and blood pressure are monitored. In severe cases, brain activity and the volume of air that is inhaled and exhaled are also monitored.

Treatment of obstructive sleep apnea commonly includes the use of a device called a continuous positive airway pressure (CPAP) machine during sleep. The CPAP machine has a mask that covers the nose, or both the nose and mouth, and forces air into the airway at regular intervals. This pressurized air can help to gently force the airway to remain open, allowing more normal ventilation to occur. See Figure 13.25[29] for an image of a patient using a CPAP machine. Other treatments include lifestyle changes to lose weight, changes in sleeping position, and eliminating alcohol and medications that trigger sleep apnea. In addition to these treatments, patients with central sleep apnea may need supplemental oxygen during sleep.[30]

29. Myupchar. (2019). *Depiction of a sleep apnea patient using a CPAP machine* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Depiction_of_a_Sleep_Apnea_patient_using_a_CPAP_machine.png

30. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Health alterations*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthalts/

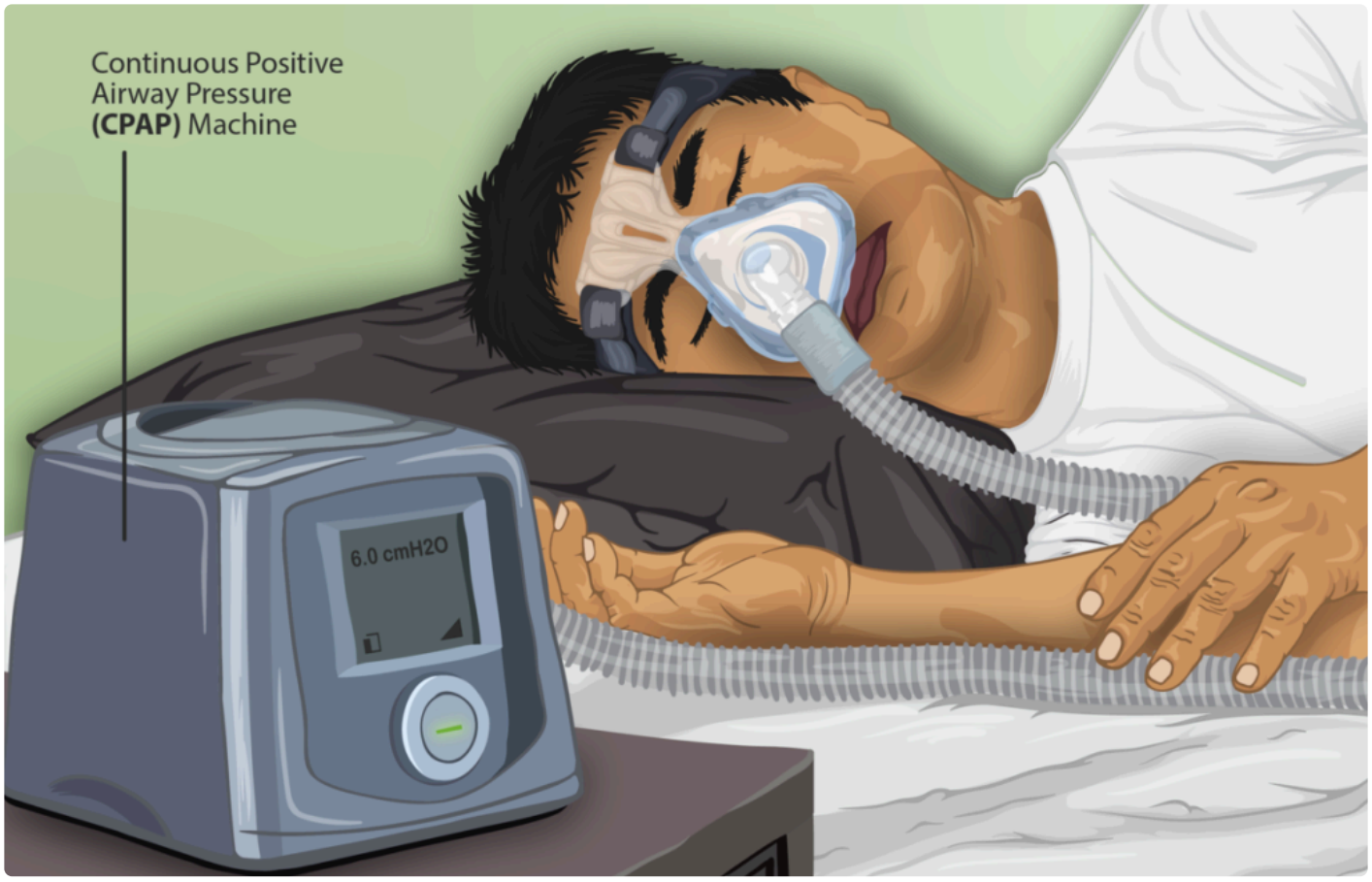


Figure 13.25 Client Using a CPAP Machine While Sleeping

Sudden Infant Death Syndrome (SIDS)

Sudden infant death syndrome (SIDS) is the sudden and unexplained death of a baby younger than one year old who otherwise appears healthy. SIDS is one of the leading causes of death in babies from ages 1 month to 1 year and happens most often between 2 and 4 months old. The cause of SIDS is unknown, but there are multiple factors related to SIDS. SIDS may be caused by problems in the area of an infant's brain that controls breathing and waking up from sleep. SIDS can happen to any infant, but premature infants and those with low birth weight are at higher risk. Exposure to secondhand smoke and a recent upper respiratory infection also increase the risk for SIDS. Other risk factors for SIDS include the following:

- Sleeping on their stomach or side: Babies placed in these positions to sleep may have more trouble breathing than those placed on their backs, especially premature infants.
- Sleeping on a soft surface: Lying face down on a fluffy comforter, a soft mattress, or a

waterbed can block an infant's airway.

- Sharing a bed: The risk of SIDS rises if a baby sleeps in the same bed with parents, siblings, or pets, but sleeping in a separate bed in the same room with parents lowers the risk of SIDS.
- Overheating: Being too warm while sleeping can increase a baby's risk of SIDS.

Safe sleep practices play a large role in preventing SIDS. Infants should be placed on their back to sleep in a crib with a firm mattress and without toys, blankets, crib bumpers, or pillows. Infants should not be placed in a bed with other children or adults, and overheating should be avoided. Mothers are encouraged to breastfeed because this has been shown to reduce the risk of SIDS. Vaccinations should be kept up-to-date, especially to prevent respiratory illnesses that increase the risk of SIDS.[31,32]

See Figure 13.26[33] for tips on safe sleep practices for infants.

31. Stanford Medicine Children's Health. (n.d.). *Sudden infant death syndrome (SIDS)*. https://www.stanfordchildrens.org/en/topic/default?id=sudden-infant-death-syndrome-sids-90-P02412&sid=33192
32. Mayo Clinic. (2024). *Sudden infant death syndrome (SIDS).* https://www.mayoclinic.org/diseases-conditions/sudden-infant-death-syndrome/symptoms-causes/syc-20352800
33. NICHD. (2018). *Safe sleep for your baby* [Infographic]. National Institutes of Health. CC BY-ND 2.0. https://www.flickr.com/photos/nichd/44168292205



Figure 13.26 Safe Sleep Practices for Infants

Tuberculosis

Tuberculosis (TB) is a leading cause of death worldwide due to infectious disease. TB usually affects the lungs, but can also affect multiple parts of the body, such as the brain, the kidneys, or the spine. In the United States, the majority of TB cases are caused by *Mycobacterium tuberculosis*. Other mycobacteria (such as *Mycobacterium bovis*) can also cause TB disease in people.

Primary risk factors include close contact with a TB-infected person, HIV infection, an otherwise weakened immune system, and substance misuse. TB is a common disease around the world, so individuals who travel or live in regions with high TB prevalence, such as Africa, Asia, or parts of Latin America, have an increased risk. Individuals who emigrate from high-incidence countries or experience homelessness are also at

increased risk. Additionally, individuals who live in overcrowded environments are at increased risk for TB transmission, including individuals who work or live in long-term health care settings or prisons.

Not everyone exposed to TB bacteria becomes sick. There are two types of TB: latent TB (or inactive TB infection) and active TB disease. When the TB bacillus enters the lung, it replicates over the course of 2-12 weeks, and the immune response becomes activated. The immune response involves macrophages and lymphocytes migrating to the site of inflammation and walling off the bacillus, forming a tubercle. Individuals with healthy immune systems may heal this initial lesion and develop latent TB before any signs or symptoms of the illness occur. However, the tubercle may calcify and remain dormant for many years, but over time, or in immunocompromised states, spread to other areas of the lung or to other organs. The CDC estimates up to 13 million people in the United States live with inactive TB. These individuals do not feel sick or have symptoms and cannot spread TB to others.

Active TB disease occurs if an individual's immune system cannot stop the TB bacilli from multiplying. People with active TB disease feel sick. Common symptoms of active TB are a cough (that may or may not contain blood), weight loss, night sweats, fatigue, chills, and fever. The TB infection can spread to people through respiratory droplets that are coughed into the air. Without treatment, active TB disease is typically fatal. See Figure 13.27[34] for a depiction of a patient with active TB disease.

34. Myupchar. (2019). *Depiction of a tuberculosis patient* [Illustration]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Depiction_of_a_tuberculosis_patient.png

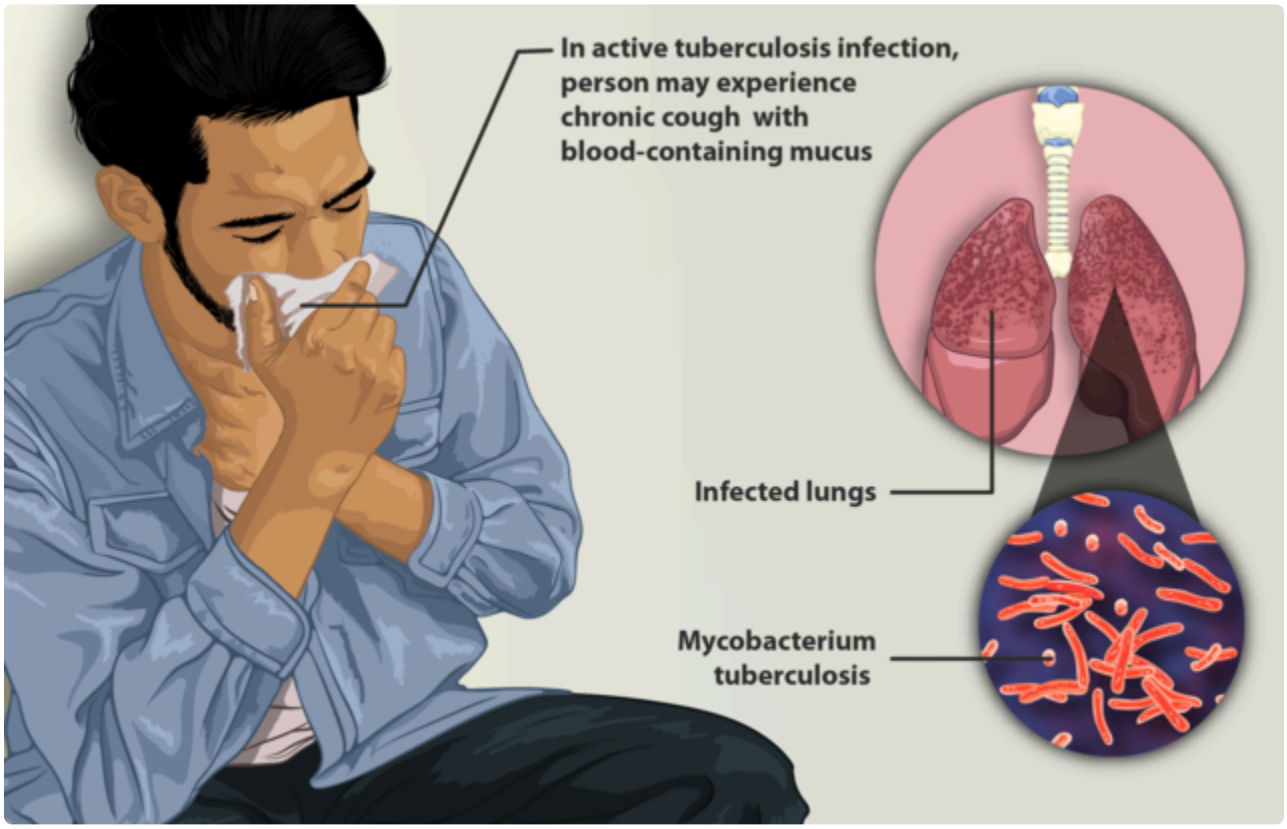


Figure 13.27 Active TB Disease

The CDC recommends that people who are at increased risk of TB should be tested regularly. There are two types of tests that can detect TB infection, but these tests cannot distinguish between active and latent TB:

- Tuberculin Skin Test (Mantoux Test): A small amount of tuberculin protein is injected just beneath the skin, usually in the forearm. The test is read 48 to 72 hours later. A positive reaction indicates exposure to TB or the BCG vaccine, but it does not confirm active disease. In regions of the world with high TB prevalence, a Bacillus Calmette-Guérin (BCG) vaccine is commonly administered. Receiving a BCG vaccine has a substantial effect on tuberculin skin tests, with individuals who received BCG after infancy having tuberculin skin test reactions up to 55 years post-immunization.
- TB blood test: The TB blood test is also called an interferon-gamma release assay (IGRA). The TB blood test measures how the immune system reacts to the bacteria that cause TB. (If an individual received a BCG vaccine, they should be tested using the TB blood test. Unlike the TB skin test, TB blood tests are not affected by the BCG vaccine.)

If a patient has a positive TB skin or blood test, further testing is needed to determine

if they have a latent or active infection. These tests include a chest X-ray, as well as sputum cultures.

TB is treated with multiple antibiotics for one year or longer. *Mycobacterium* tuberculosis has developed drug resistance in many areas of the world, causing a significant treatment problem. After medication therapy has been initiated, sputum cultures are obtained to assess treatment response. Patients are considered infectious until three negative sputum samples have been obtained, typically after approximately three months of treatment.[35,36]

Read more about tuberculosis symptoms and treatments in the **"Tuberculosis" section of the Open RN *Health Alterations* textbook**.



Upper Respiratory Infection

An **upper respiratory tract infection (URI)**, also known as the common cold, can be described as the swelling and irritation of the upper airways, including the nose, sinuses, throat, larynx, and larger airways. Although a variety of infectious organisms can lead to a URI, the most common causative organism is rhinovirus. Risk factors for a URI include contact with school-aged children, underlying respiratory issues, exposure to smoke, and immunodeficiency.

A URI results when a client inhales infected respiratory droplets that then invade the mucosa of the upper respiratory tract. Once deposited in the mucosa, the infectious organism begins to replicate. The infected individual will then mount an inflammatory

35. Centers for Disease Control. (n.d.). *About tuberculosis*. https://www.cdc.gov/tb/about/index.html[

36. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Health alterations*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthalts/

response, which leads to dilation and increased permeability of blood vessels, ultimately contributing to the symptoms of the URI. Common symptoms include cough, sore throat, runny nose, stuffy nose, headache, fever, sneezing, and a general feeling of illness, weakness, or discomfort. Symptoms begin one to three days after exposure to the infectious organism and usually last seven to ten days. However, symptoms can sometimes last up to three weeks. Potential complications of a URI caused by rhinovirus are exacerbations of asthma, ear infections, sinus infections, bronchitis, or pneumonia.

There is no cure for the common cold. Treatment focuses on symptomatic relief with the use of over-the-counter medications.[37,38]

37. Thomas, M., & Bomar, P. A. (2023). *Upper respiratory tract infection*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK532961/

38. Ernstmeyer, K., & Christman, E. (Eds.). (2025). *Nursing health promotion*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/healthpromo/

13.6 Career Connections Related to the Respiratory System

The respiratory system includes the lungs, airways, and other structures that help move oxygen into the body and remove carbon dioxide. When a person has difficulty breathing because of illness, injury, surgery, or a chronic condition, many professionals may help with testing, treatment, monitoring, rehabilitation, and patient care. Careers related to the respiratory system can include respiratory therapists, medical assistants, nursing assistants, registered nurses, and diagnostic medical sonographers.

Respiratory Therapist

Respiratory therapists are health care professionals who assess, treat, and care for patients who have breathing or cardiopulmonary disorders. They may provide oxygen therapy, aerosol therapy, breathing treatments, airway management, mechanical ventilation, cardiopulmonary resuscitation, pulmonary function testing, smoking cessation support, and pulmonary rehabilitation. Respiratory therapists may care for patients of all ages, from newborns to older adults.

Medical Assistant

Medical assistants work in clinics and other health care settings where they support patient care and office procedures. In pulmonology, primary care, allergy, or urgent care settings, medical assistants may help room patients, collect health information, record symptoms, check vital signs, prepare patients for examinations, assist with basic procedures, support documentation, and communicate follow-up instructions.

Nursing Assistant

Nursing assistants provide basic care and help patients with daily activities under the supervision of licensed nursing staff. This career connects to the respiratory system because nursing assistants may help care for patients who have pneumonia, chronic obstructive pulmonary disease, asthma, shortness of breath, weakness, or limited mobility. They may assist with positioning, comfort measures, activity, vital signs, and reporting changes in breathing or oxygen needs.

Registered Nurse

Registered nurses provide patient care, education, and support in hospitals, clinics, long-term care facilities, home health, and community settings. This career connects to the respiratory system because nurses may care for patients with asthma, chronic obstructive pulmonary disease, pneumonia, respiratory infections, lung cancer, or breathing problems after surgery. They may monitor symptoms, administer medications, provide oxygen-related care, support patient education, and coordinate care with other health professionals.

Diagnostic Medical Sonographer

Diagnostic medical sonographers use ultrasound equipment to create images of structures inside the body. Although sonography is not limited to the respiratory system, sonographers may help evaluate areas of the chest, blood vessels, or related conditions that affect breathing and circulation. They use knowledge of anatomy, imaging equipment, patient positioning, safety practices, and communication while performing exams.

Take a Closer Look

Explore careers related to the human body's respiratory system on these websites.

- Respiratory therapist from the American Association for Respiratory Care

- Respiratory therapists from the U.S. Bureau of Labor Statistics
- Respiratory therapists from O*NET OnLine
- Medical assistant from the American Association of Medical Assistants
- Registered nurse from the American Nurses Association
- Nursing assistant and orderly careers from the U.S. Bureau of Labor Statistics

13.7 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

13.8 Glossary

Alveoli: Small, grape-like air sacs surrounded by pulmonary blood capillaries. (Chapter 13.3)

Asthma: A common chronic respiratory disease characterized by episodes of bronchospasms (constriction of the bronchioles), inflammation, and edema of the airway that makes it difficult to exhale air. (Chapter 13.5)

Atelectasis: Occurs when alveoli lose air and collapse. (Chapter 13.5)

Bicarbonate: The majority of carbon dioxide (about 75%) is transported in the blood as bicarbonate (HCO_3^-) ions. (Chapter 13.4)

Bronchial tree: The collective term used for multiple-branched bronchial tubes. (Chapter 13.3)

Bronchioles: Small airways about 1 mm in diameter that branch extensively and lead to terminal bronchioles and alveoli, where gas exchange occurs. (Chapter 13.3)

Bronchospasms: Constriction of the bronchioles. (Chapter 13.5)

Carbaminohemoglobin: A compound formed when carbon dioxide binds to hemoglobin in red blood cells, accounting for about 20% of CO_2 transport in the blood. (Chapter 13.4)

Carbon monoxide poisoning: Occurs when carbon monoxide (CO) builds up in the blood and can lead to serious tissue damage or death. (Chapter 13.5)

Cardiac notch: An indentation on the surface of the left lung that allows space for the heart. (Chapter 13.3)

Carina: A raised structure that contains specialized nervous tissue that causes violent coughing if a foreign body, such as food, is present. (Chapter 13.3)

Chronic obstructive pulmonary disease (COPD): A chronic, progressive lung disease caused by inflammation inside the airways, resulting in limited airflow out of the lungs; known as obstruction. (Chapter 13.5)

Cilia: Short, hair-like projections from the cell surface that are involved in the movement of the cell or the movement of substances along the cell surface. (Chapter 13.3)

Conducting zone: The parts of the respiratory system through which air passes, but do not participate directly in gas exchange. (**Chapter 13.2**)

Coronavirus disease (COVID-19): An infectious respiratory disease caused by the SARS-CoV-2 virus. (**Chapter 13.5**)

Cystic fibrosis (CF): A genetic condition that alters a protein in the body involved in the function of the cells, tissues, and glands responsible for producing mucus and sweat. (**Chapter 13.5**)

Dissolved in plasma: About 5% of carbon dioxide is transported directly in the blood plasma and diffuses into the alveoli for exhalation. (**Chapter 13.4**)

Epiglottis: A flap of cartilage that closes over the windpipe during swallowing to prevent food and liquids from entering the airway. (**Chapter 13.3**)

Exhalation: Movement of air out of the lungs; also called expiration. (**Chapter 13.4**)

Expiratory reserve volume (ERV): The extra amount of air that can be forcibly exhaled after a normal exhalation, about 12 mL. (**Chapter 13.4**)

External respiration: The exchange of gases between the alveoli and pulmonary capillaries. (**Chapter 13.4**)

Functional reserve capacity (FRC): The amount of air that remains in the lung after a normal tidal expiration; it is the sum of expiratory reserve volume and residual volume. (**Chapter 13.4**)

Influenza: A viral infection that affects the epithelial cells lining the respiratory tract; commonly called “the flu.” (**Chapter 13.5**)

Inhalation: The movement of air into the lungs; also called inspiration. (**Chapter 13.4**)

Inspiratory capacity (IC): The maximum amount of air that can be inhaled past a normal tidal expiration; it is the sum of the tidal volume and inspiratory reserve volume. (**Chapter 13.4**)

Inspiratory reserve volume (IRV): The extra volume of air that can be forcibly inhaled after a normal inhalation, about 3,100 mL. (**Chapter 13.4**)

Internal nares: The openings between the nasal cavity and the nasopharynx. (**Chapter 13.3**)

Internal respiration: The exchange of gases between the systemic capillaries and the tissues. (**Chapter 13.4**)

Larynx: A cartilaginous structure that connects the pharynx to the trachea and helps

regulate the volume of air that enters and leaves the lungs; also known as the voice box. (Chapter 13.3)

Laryngopharynx: The lower part of the throat that directs air to the voice box and food to the swallowing tube, serving as a pathway for both respiration and digestion; also known as the hypopharynx. (Chapter 13.3)

Lung cancer: The leading cause of cancer death in both men and women. (Chapter 13.5)

Lungs: A pair of pyramid-shaped organs connected to the trachea by the right and left primary bronchi. (Chapter 13.3)

Lung volume: A medical term used for various volumes of air moved by the lungs at a given point of the respiratory cycle. (Chapter 13.4)

Nares: Allow air into the nasal cavity. (Chapter 13.3)

Nasal conchae: Three bony projections on each lateral wall of the nasal cavity that increase surface area and create turbulence, helping warm, humidify, and filter incoming air. (Chapter 13.3)

Nasopharynx: The upper section of the throat behind the nasal cavity that allows air to pass from the nose to the lungs. (Chapter 13.3)

Oropharynx: The middle section of the throat located behind the mouth, which serves as a passageway for both food and air. (Chapter 13.3)

Oxyhemoglobin (HbO_2): A bright, red-colored molecule that contributes to the bright red color of oxygenated blood. (Chapter 13.4)

Paranasal sinuses: Air-filled spaces in the bones surrounding the nasal cavity that help warm and humidify incoming air. (Chapter 13.3)

Pharyngitis: Inflammation of the pharynx or throat. (Chapter 13.5)

Pharynx: Involved in both digestion and respiration, receiving food and air from the mouth and air from the nasal cavity. (Chapter 13.3)

Pleural cavity: The space between the visceral and parietal layers that contains pleural fluid. (Chapter 13.3)

Pleural fluid: Secreted by both lung pleural layers and acts to lubricate their surfaces, which reduces friction between the two layers. (Chapter 13.3)

Pleuritis (Pleurisy): Inflammation of the pleura, the membranes surrounding the lungs and chest wall. (Chapter 13.5)

Pneumonia: An infection that inflames the alveoli, causing them to fill with fluid or pus. (**Chapter 13.5**)

Pneumothorax: Occurs when air leaks into the space between the lung and the chest wall, causing the lung to collapse. (**Chapter 13.5**)

Pulmonary edema: A serious condition where fluid accumulates in the lungs, making it difficult to breathe. (**Chapter 13.5**)

Pulmonary embolism (PE): A blood clot or other substance, such as fat or an air bubble, that has traveled through the bloodstream and lodged in a smaller vessel within the pulmonary circulation in the lungs and obstructed blood flow. (**Chapter 13.5**)

Pulmonary surfactant: A slippery fluid that reduces the surface tension of the alveoli and prevents them from collapsing. (**Chapter 13.3**)

Pulmonary ventilation: The act of breathing. (**Chapter 13.4**)

Pulmonologist: A physician who specializes in diagnosing and treating respiratory system diseases. (**Chapter 13.6**)

Pulmonology: The study of the lungs and their functions. (**Chapter 13.1**)

Residual volume (RV): The air left in the lungs after exhaling as much air as possible, averaging about 1,200 mL. (**Chapter 13.4**)

Respiratory distress syndrome (RDS): A condition that primarily affects premature babies, causing difficulty breathing. (**Chapter 13.5**)

Respiratory membrane: A thin barrier formed by alveolar and capillary walls that allows efficient gas exchange by simple diffusion of oxygen and carbon dioxide. (**Chapter 13.3**)

Respiratory rate: The total number of breaths that occur each minute. (**Chapter 13.4**)

Respiratory therapists (RTs): Health care professionals who monitor, assess, and treat people who are having problems breathing. (**Chapter 13.6**)

Respiratory zone: The parts of the respiratory system where gas exchange between air and blood occurs. (**Chapter 13.2**)

Sleep apnea: A chronic disorder that can occur in children or adults and is characterized by the cessation of breathing during sleep for several seconds. (**Chapter 13.5**)

Sudden infant death syndrome (SIDS): Sudden and unexplained death of a baby younger than one year old who otherwise appears healthy. (**Chapter 13.5**)

Thoracic surgeon: A surgeon who has specialized in either thoracic (chest) surgery or cardiothoracic (heart and chest) surgery. (**Chapter 13.6**)

Tidal volume (TV): The amount of air inhaled or exhaled in a normal quiet breath, which averages about 500 milliliters (mL) for a healthy male adult and 400 mL for a healthy female adult. (**Chapter 13.4**)

Tonsillitis: Inflammation of the tonsils (**Chapter 13.5**)

Total lung capacity (TLC): The sum of all lung volumes (TV+ ERV+ IRV+ RV), which represents the total amount of air a person can hold in their lungs after a forceful inhalation. (**Chapter 13.4**)

Trachea: An approximately 5-inch-long tubular airway that extends from the larynx inferiorly toward the lungs; also called the windpipe. (**Chapter 13.3**)

True vocal cords: A pair of white, membranous ligaments attached to cartilage pieces of the larynx; also called vocal folds. (**Chapter 13.3**)

Tuberculosis (TB): A potentially fatal infectious disease, primarily affecting the lungs but capable of spreading to other organs; caused by *Mycobacterium* tuberculosis in most U.S. cases. (**Chapter 13.5**)

Upper respiratory tract infection (URI): The swelling and irritation of the upper airways, including the nose, sinuses, throat, larynx, and larger airways; known as the common cold. (**Chapter 13.5**)

Uvula: Small, conical projection that hangs from the posterior edge of the soft palate and helps prevent food from entering the nasal cavity during swallowing. (**Chapter 13.3**)

Vital capacity (VC): The amount of air a person can move into or out of their lungs, which is the sum of all volumes except residual volume (TV+ ERV+ IRV) and is between 4,000 and 5,000 milliliters for adults. (**Chapter 13.4**)

PART XIV

CHAPTER 14 DIGESTIVE SYSTEM

14.1 Introduction to the Digestive System

Chapter Competency

Analyze how components of the digestive system function in the body.

Learning Objectives

- Identify the gross and microscopic structural components of the digestive system.
- Correlate the structural components of the digestive system with their functions.
- Describe the functions of major digestive enzymes.
- Summarize the functions of the digestive system.

Imagine you are working as a dental hygienist educating a patient about oral health and its connection to overall health. As you assess the patient's teeth, gums, tongue, and oral cavity, you recognize that the mouth is the first part of the digestive system. Chewing mechanically breaks down food, saliva begins chemical digestion, and swallowing moves food toward the rest of the gastrointestinal tract. To support patient education and prevention, you must understand how the structures of the digestive system work together to process food, absorb nutrients, and eliminate waste.

The digestive system includes the gastrointestinal tract and accessory organs that work together to break food into smaller components the body can use. Digestion includes mechanical processes, such as chewing and mixing, and chemical processes, such as enzyme activity and acid secretion. Once nutrients are broken down, they are absorbed into the blood or lymph and transported to body cells. Materials that cannot be digested or absorbed are eliminated from the body.

In this chapter, you will explore **gastroenterology**, the study of the normal function

and diseases of the gastrointestinal (GI) system. You will learn about the structure and function of the digestive system, including the organs of the **gastrointestinal tract**, also called the **alimentary canal**. These organs include the mouth, pharynx, esophagus, stomach, small intestine, large intestine, rectum, and anus. You will also study accessory organs, including the teeth, tongue, salivary glands, liver, gallbladder, and pancreas. In addition, you will examine digestion, absorption, metabolism, nutrition, and common digestive system disorders.

By mastering these concepts, you will gain a deeper understanding of how the digestive system supports nutrition, energy production, fluid balance, and elimination. This foundation will help you connect digestive structure and function to oral health, nutrition, patient education, metabolism, gastrointestinal assessment, and disorders affecting digestion and absorption.

The digestive system works continuously, whether you are eating a meal or you are between meals. Consider what happens when you eat an apple. You probably enjoy tasting the apple as you chew it, but in the hours that follow, unless something goes amiss and you get a stomachache, you don't notice that your digestive system is working, digesting the apple and absorbing its vitamins and other nutrients. By the time any waste material is excreted, the body has removed all nutrients that can be used from the apple to fuel your body.

See Figure 14.1[1] for an illustration of the components of the digestive system.

1. OpenStax. (2013). *2429 Digestion of Proteins (Physiology)* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:2429_Digestion_of_Proteins_(Physiology).jpg

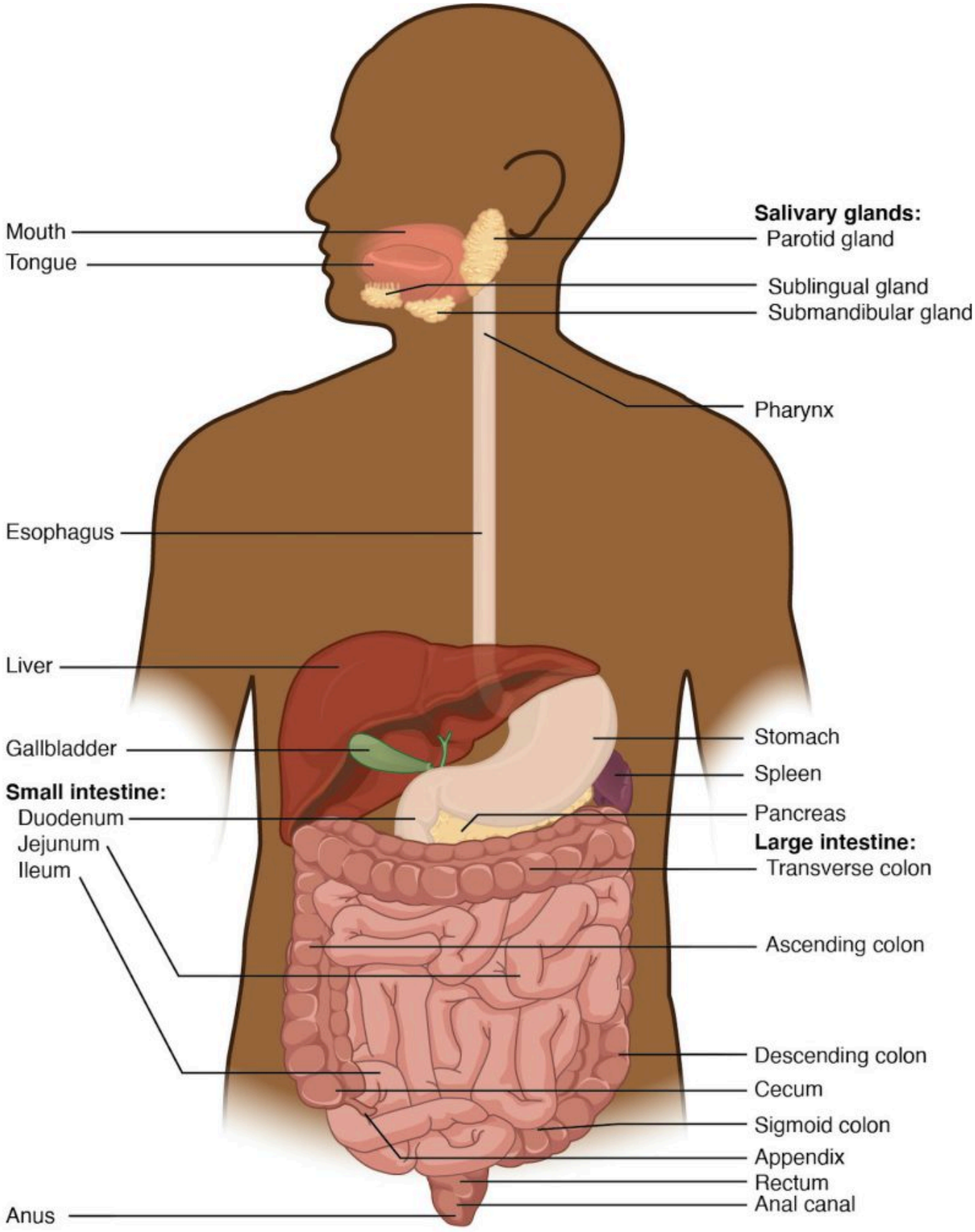


Figure 14.1 Components of the Digestive System

14.2 Functions of the Digestive System

The functions of the digestive system are to bring food into the body (ingestion), move it through the gastrointestinal tract (propulsion), break down the foods you eat (digestion), absorb those nutrients (absorption), and eliminate wastes from the body (defecation). These functions are further described in the following subsections.[1]

Ingestion

Ingestion refers to eating or bringing food into the GI tract through the mouth. In the mouth, food is chewed and mixed with saliva that contains enzymes that begin breaking down carbohydrates in the food. Chewing increases the surface area of the food and allows an appropriately sized **bolus** (mass of chewed food) to be produced.

Propulsion

Food leaves the mouth when the muscles of the tongue and pharynx (throat) move it into the esophagus. This act of swallowing is one of the few voluntary actions in the digestive process and serves as an example of **propulsion**, the movement of food through the digestive tract. The next time voluntary muscles are used is during defecation.

Peristalsis consists of involuntary, alternating wave-like contraction and relaxation of smooth muscles. In the GI system, peristalsis moves food along the length of the digestive tract. See Figure 14.2[2] for an illustration of peristalsis.

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

2. OpenStax. (2013). *2404 PeristalsisN* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2404_PeristalsisN.jpg

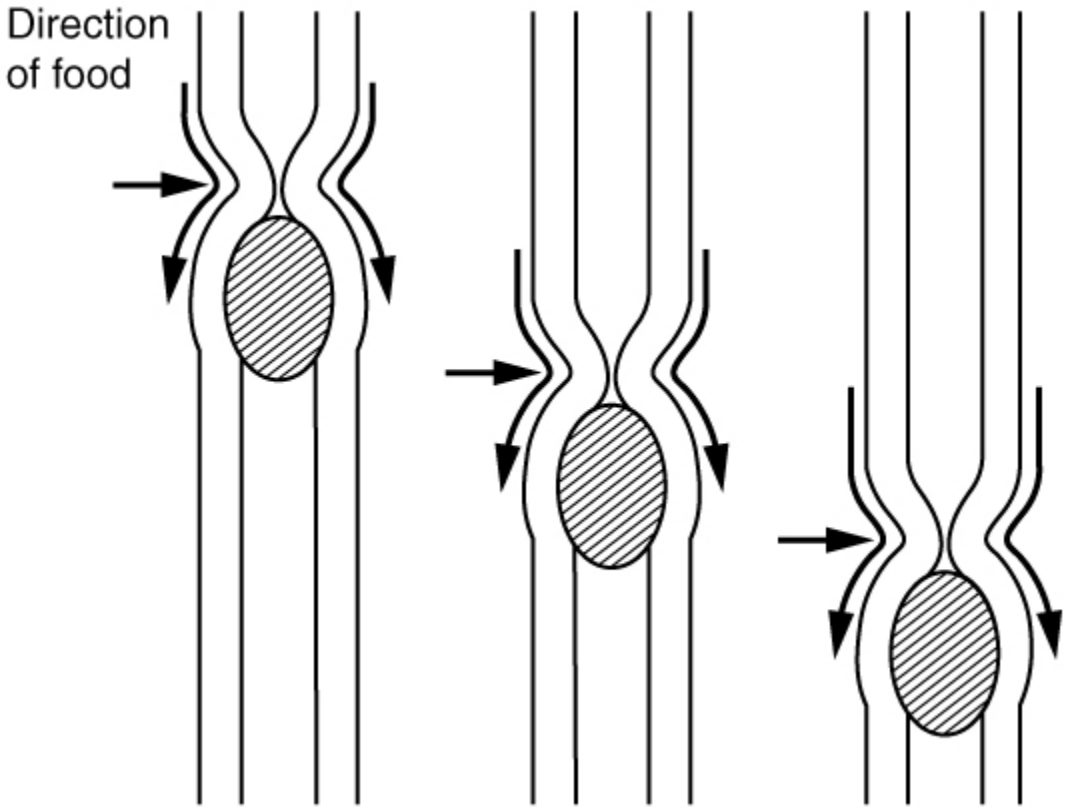


Figure 14.2 Peristalsis

Digestion includes both mechanical and chemical processes. **Mechanical digestion** is a physical process that does not change the chemical nature of the food but makes it smaller to increase surface area and mobility. It includes **mastication** (chewing), as well as tongue movements that help break food into smaller bits and mix food with saliva. The mechanical churning of food in the stomach serves to further break it apart and expose more of its surface area to digestive juices, creating an acidic "soup" called **chyme**. **Segmentation**, which occurs mainly in the small intestine, consists of localized contractions of the smooth muscle wall. These contractions isolate small sections of the intestine, moving their contents back and forth while continuously subdividing, breaking up, and mixing the contents. By moving food back and forth in the intestinal lumen, segmentation mixes food with digestive juices and facilitates absorption.

Chemical digestion utilizes enzymes to break down food. It begins in the mouth, continues in the stomach, and ends in the small intestine. Digestive secretions break down complex food molecules into their chemical building blocks (for example, proteins are broken down into amino acids). These digestive secretions vary in composition, but typically contain water, enzymes, acids, and salts.

Absorption

For nutrients to be used by the body, they must enter the bloodstream and travel to our cells. This occurs through the process of absorption, which takes place primarily in the small intestine. There, most nutrients are absorbed directly into the bloodstream through the epithelial cells that make up the **mucosa**. Lipids, however, are absorbed into lacteals and are transported via the lymphatic vessels to the bloodstream. The details of these processes are discussed later in this chapter.

Defecation

Defecation is the final step in digestion as undigested materials are removed from the body as feces. See Figure 14.3[3] for an illustration of the functions of the digestive system.

3. OpenStax. (2013). *2405 Digestive process* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2405_Digestive_Process.jpg

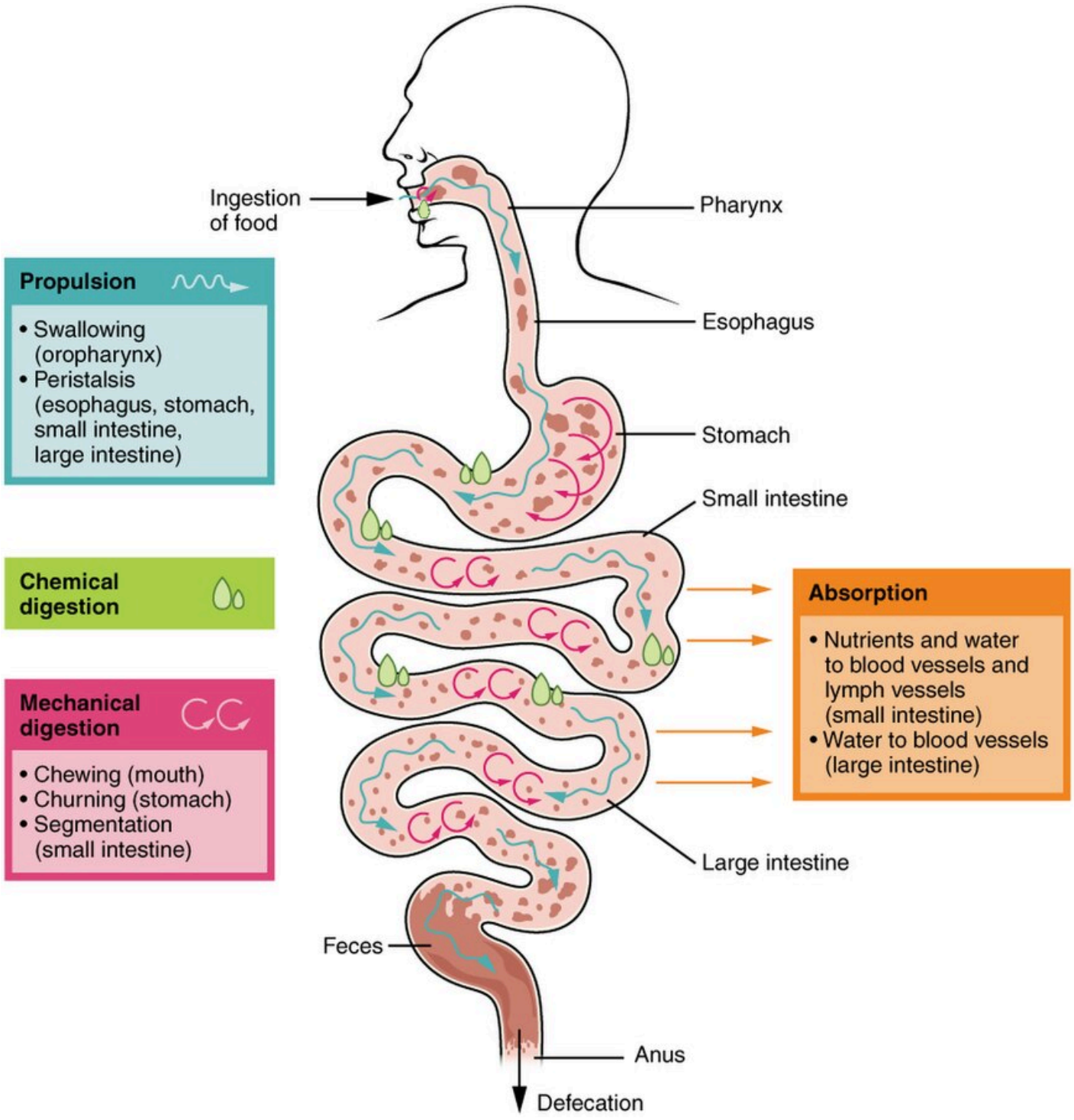


Figure 14.3 Digestive Functions

14.3 Anatomy of the Gastrointestinal System

Layers of the Gastrointestinal Tract

The entire length of the gastrointestinal (GI) tract is composed of the same four tissue layers. Starting from the deep inside the lumen (the hollow, tubular portion of the GI tract) and moving out to the superficial layer, these layers are the mucosa, submucosa, muscularis, and serosa, which is continuous with the mesentery. The mesentery is the membrane that connects the intestines to the abdominal wall. See Figure 14.4[1] for an illustration of the layers of the GI tract.

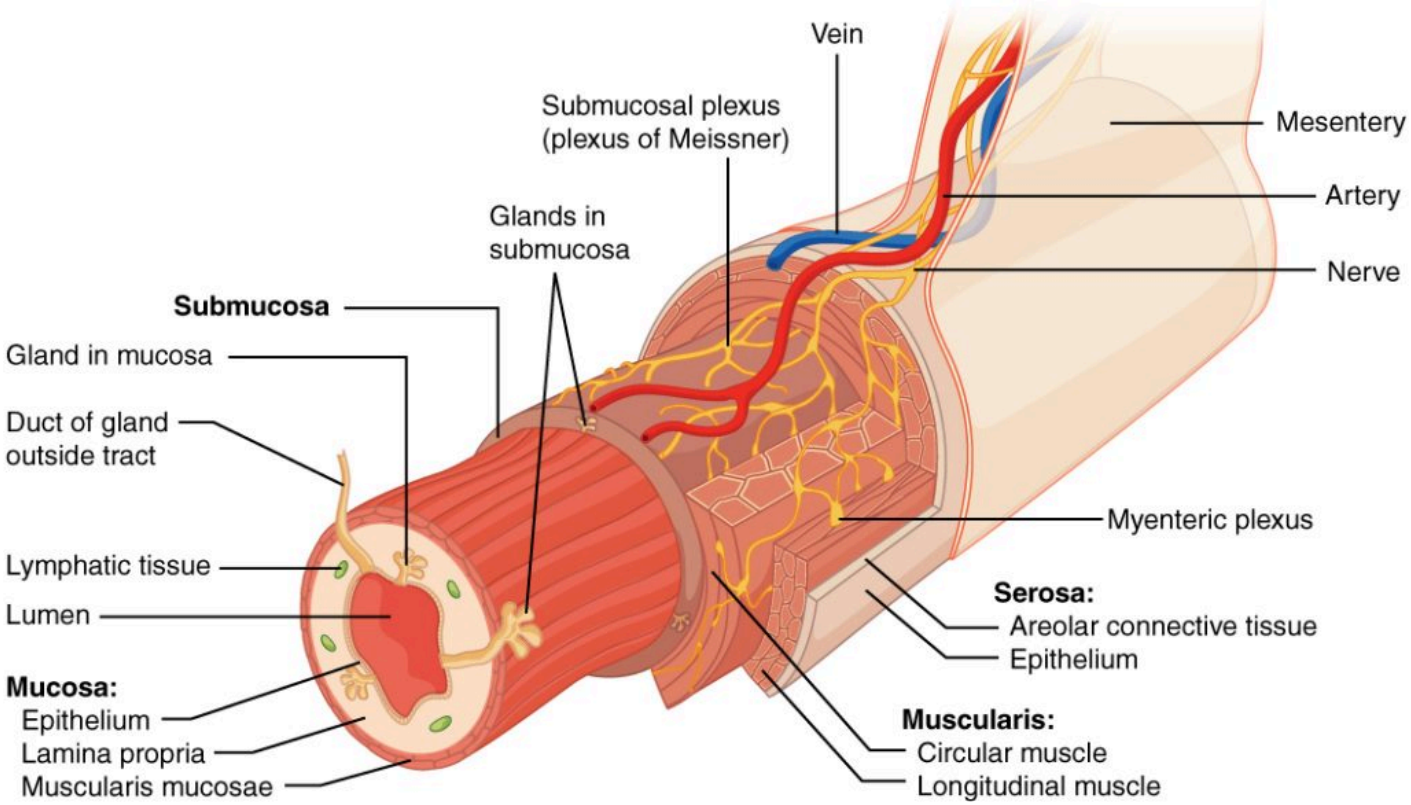


Figure 14.4 Layers of the Gastrointestinal Tract

1. OpenStax. (2013). *2402 Layers of the gastrointestinal tract* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2402_Layers_of_the_Gastrointestinal_Tract.jpg

Mucosa

The **mucosa** is referred to as a mucous membrane because mucus production is a characteristic feature. The membrane consists of epithelial cells, which are in direct contact with ingested food. Located among these epithelial cells are **goblet cells**, which secrete mucus and fluid into the lumen. In the mouth, pharynx, esophagus, and anal canal, the epithelium is primarily a non-keratinized stratified squamous epithelium. In the stomach and intestines, it is a simple columnar epithelium.

Epithelial cells have a very brief life span, averaging only a couple of days in the mouth to about a week in the gut. This process of rapid renewal helps preserve the health of the GI tract, despite the wear and tear resulting from continued contact with food.

The **lamina propria**is a layer of connective tissue similar to the dermis that makes up the middle layer of the mucosa. It contains numerous blood and lymphatic vessels that transport nutrients absorbed through the GI tract to other parts of the body. The lamina propria also houses clusters of lymphocytes, making up the mucosa-associated lymphoid tissue (MALT). These lymphocyte clusters are substantial in the distal small intestine where they are known as Peyer's patches. When considering the gastrointestinal tract is exposed to foodborne bacteria and other pathogens, it is easy to understand why the immune system has evolved a means of defending it.

The most superficial layer of the mucosa is a thin, smooth muscle layer, called the muscularis mucosae (not to be confused with the muscularis layer, as described below), The **muscularis mucosae** is in a constant state of tension, pulling the mucosa of the stomach and small intestine into rippling folds. These folds dramatically increase the surface area available for digestion and absorption.[2]

Submucosa

The **submucosa** is deep to the mucosa. It is composed of a broad layer of dense connective tissue that connects the overlying mucosa to the underlying muscularis. It includes blood and lymphatic vessels that transport absorbed nutrients and a scattering of submucosal glands that release digestive secretions.

2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Muscularis

The third layer of the GI tract is the **muscularis** (also called the muscularis externa). In the mouth, pharynx, anterior part of the esophagus, and external anal sphincter, the muscularis is made up of skeletal muscle, giving voluntary control over swallowing and defecation. The smooth muscle of the stomach is equipped for its churning function by the addition of a third layer, the oblique muscle. The muscularis in the small intestine is made up of a double layer of smooth muscle: an inner circular layer and an outer longitudinal layer. The contractions of these layers promote mechanical digestion, expose more of the food to digestive chemicals, and move the food along the canal. While the colon has two layers like the small intestine, its longitudinal layer is segregated into three narrow parallel bands, the tenia coli, which make it look like a series of pouches rather than a simple tube.

Serosa

The **serosa** is the portion of the alimentary canal superficial to the muscularis. Present only in the region of the GI tract within the abdominal cavity, it consists of a layer of visceral peritoneum overlying a layer of loose connective tissue.

Instead of serosa, the mouth, pharynx, and esophagus have a dense sheath of collagen fibers called the adventitia to hold them in place.

The Peritoneum

The digestive organs in the abdominal cavity are held in place by the **peritoneum**, a broad serous membrane made up of squamous epithelial tissue surrounded by connective tissue. It is composed of two different regions: the parietal peritoneum, which lines the abdominal wall, and the visceral peritoneum, which covers the abdominal organs.

The visceral peritoneum includes multiple large folds that envelop various abdominal organs, holding them to the dorsal surface of the body wall. Within these folds are blood vessels, lymphatic vessels, and nerves that innervate the organs with which they are in contact, supplying their adjacent organs. The five major peritoneal folds are described in Table 14.3. Note that during fetal development, certain digestive structures, including the first portion of the small intestine (called the duodenum), the pancreas, and portions of the large intestine (the ascending and descending colon, and the rectum) remain

completely or partially posterior to the peritoneum.[3] Thus, the location of these organs is described as **retroperitoneal**. See Table 14.3 for an overview of the five major peritoneal folds.

Table 14.3. Major Peritoneal Folds[4]

3. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

4. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Fold	Description
Greater Omentum	Apron-like structure that lies superficial to the small intestine and transverse colon; a site of fat deposition in people who are overweight
Falciform Ligament	Anchors the liver to the anterior abdominal wall and the inferior border of the diaphragm
Lesser Omentum	Suspends the stomach from the inferior border of the liver; provides a pathway for structures connecting to the liver
Mesentery	Vertical band of tissue anterior to the lumbar vertebrae and anchoring all of the small intestine except the initial portion (the duodenum)
Mesocolon	Attaches two portions of the large intestine (the transverse and sigmoid colon) to the posterior abdominal wall

The **peritoneal cavity** is the space between the visceral and parietal peritoneal layers. A few milliliters of watery fluid called **peritoneal fluid** act as a lubricant to minimize friction between the layers of the peritoneum.

See Figure 14.5[5] for an illustration of the peritoneal cavity colored in pink.

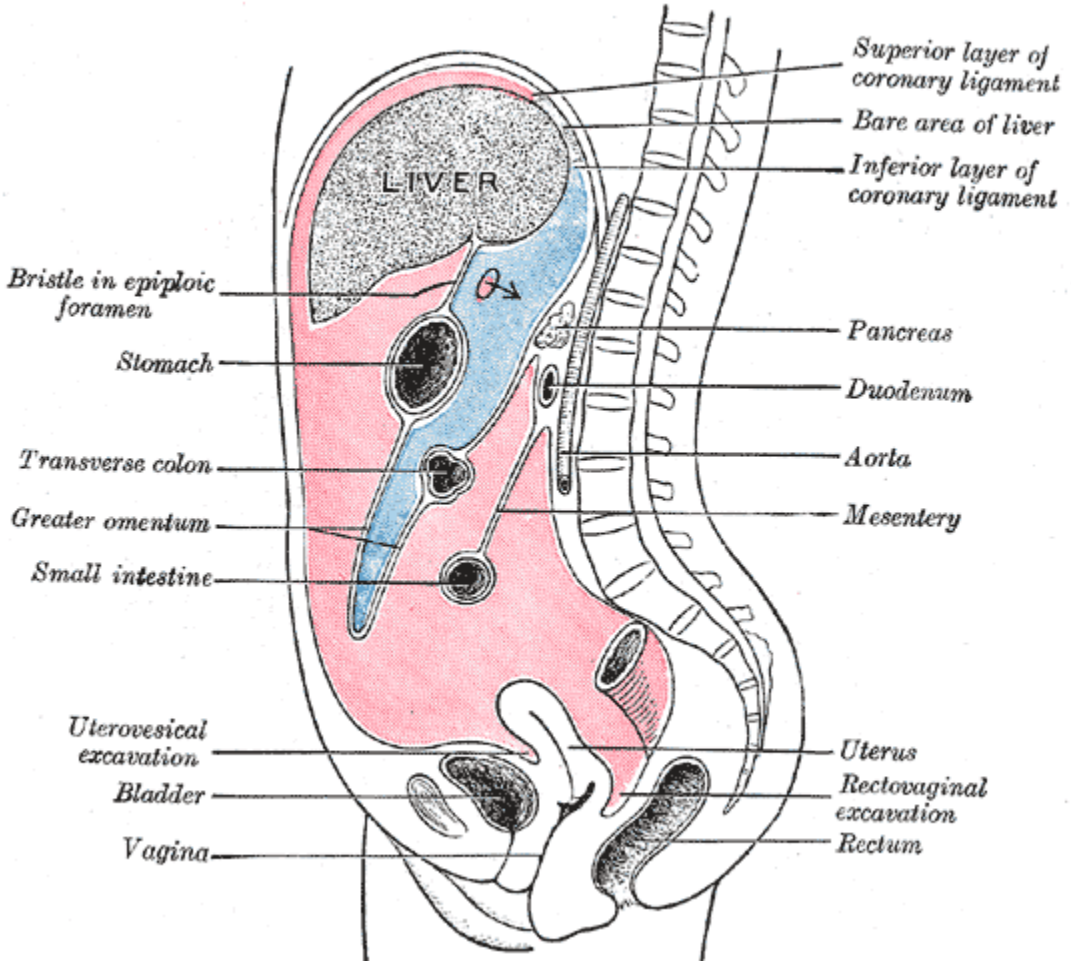


Figure 14.5 Peritoneal Cavity

Digestive System Organs

The easiest way to understand the digestive system is to divide its organs into two main categories. The first group is the organs that make up the GI tract or alimentary canal. The second group includes accessory digestive organs that are important for the

5. Henry Gray. (1918). *Anatomy of the human body – Gray1035* [Illustration]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Gray1035.png

breakdown of food and the absorption and digestion of nutrients into the body. Food does not travel through accessory organs.[6]

Gastrointestinal Tract Organs

The Mouth

The cheeks, tongue, and palate frame the mouth, which is also called the oral cavity (or buccal cavity). The structures of the mouth are illustrated in Figure 14.6.[7] See the subsection on "Accessory Organs of the Digestive System" for information on the teeth, tongue, and salivary glands.

6. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

7. OpenStax. (2013). *2406 Structures of the mouth* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2406_Structures_of_the_Mouth.jpg

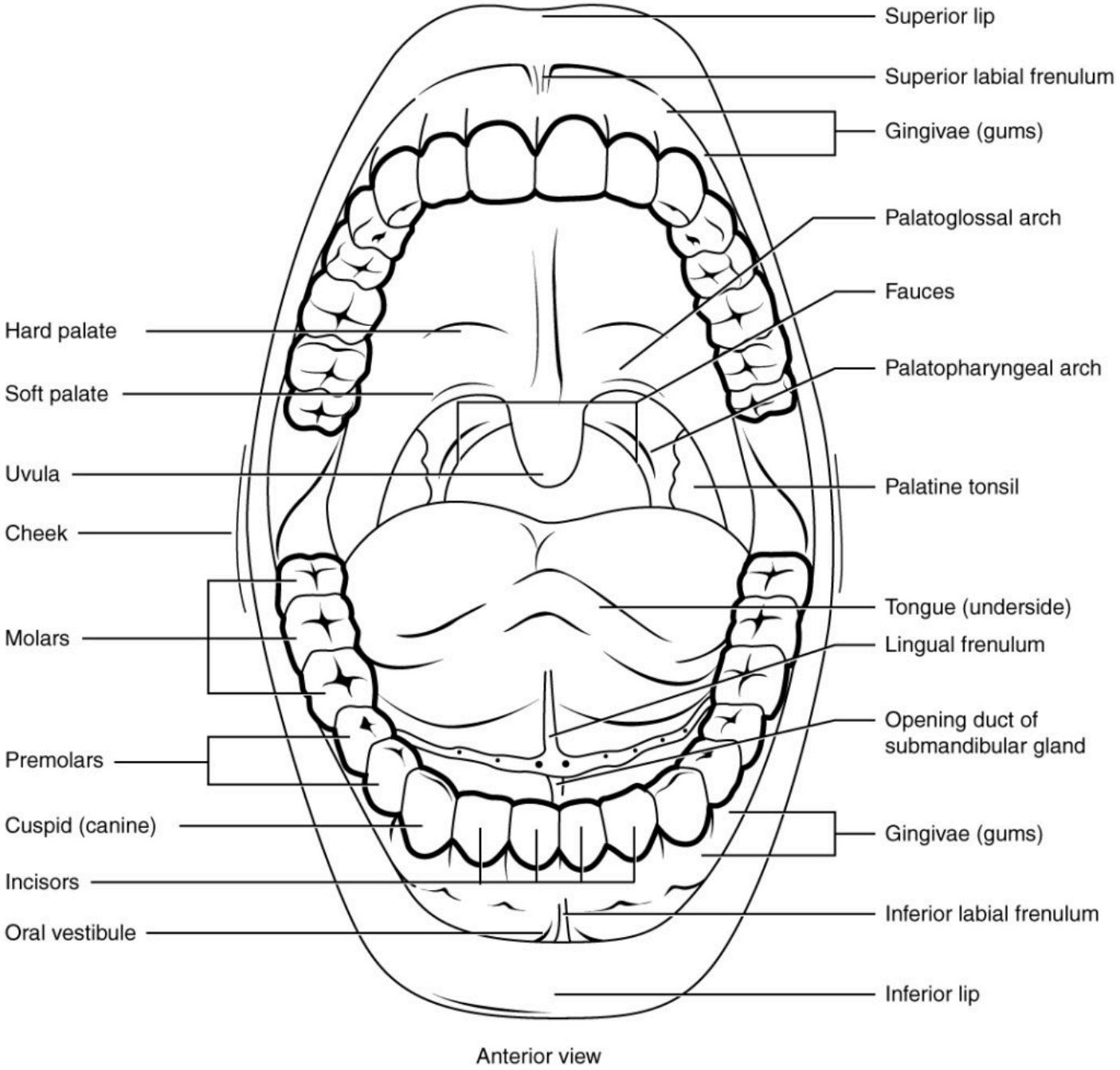


Figure 14.6 Mouth

At the entrance to the mouth are the lips, also called the labia (singular = labium). Their outer covering is skin, which transitions to a mucous membrane inside the mouth. Lips are very vascular with a thin layer of keratin, which is the reason they are "red." The lips cover the orbicularis oris muscle, which functions to control the opening and closing of the mouth, playing a key role in regulating what enters or exits the oral cavity.

The cheeks make up the lateral walls of the oral cavity. While their outer covering is

skin, their inner covering is a mucous membrane. This membrane is made up of non-keratinized stratified squamous epithelium. Between the skin and mucous membranes are connective tissue and buccinator muscles.

Chewing and breathing can occur simultaneously due to the arched shape of the **palate**, which allows the mouth to support both digestion and respiration. This arch is called the palate and is divided into an anterior portion made of bone (hard palate) and a posterior portion made of muscle (soft palate).

The anterior region, or **hard palate**, serves as a wall (septum) between the oral and nasal cavities, as well as a rigid surface against which the tongue can push food. It is formed by the maxillary and palatine bones of the skull.

If you run your tongue along the roof of your mouth, you'll notice that the hard palate ends in the posterior oral cavity, and the tissue becomes fleshier. This part of the palate, known as the **soft palate**, is composed mainly of skeletal muscle. During swallowing, the soft palate pushes superiorly so food cannot go into the nasal cavity.

A fleshy mass of tissue called the **uvula** hangs down from the center of the posterior edge of the soft palate. When you swallow, the uvula moves upward, helping to keep food and liquid from entering the nasal cavity. Unfortunately, it can also contribute to the sound produced by snoring.

The Pharynx

The **pharynx** (throat) is involved in both digestion and respiration. It receives food and air from the mouth and air from the nasal cavity.

The pharynx is a short tube of skeletal muscle lined with a mucous membrane. It runs from the posterior nasal and oral cavities to the opening of the esophagus and larynx. It has three subdivisions: the nasopharynx, oropharynx, and laryngopharynx.

The most superior portion of the pharynx, the **nasopharynx**, is involved only in breathing and speech. It is located posterior to the nasal cavity. During swallowing, the entrance to the nasopharynx is closed off by the soft palate and uvula to prevent food and liquids from moving upward and into the nasal cavity.

The **oropharynx** is used for both breathing and digestion and is located posterior to the oral cavity. It is inferior to the nasopharynx and superior to the laryngopharynx. Histologically, the wall of the oropharynx is similar to the oral cavity, with a continuation of nonkeratinized stratified squamous epithelium containing mucus-producing glands for protection from the abrasion of food.

The **laryngopharynx** is also used for both breathing and digestion. It is inferior to the oropharynx and posterior to the larynx. It continues the route for ingested food and air until its inferior end, where the digestive and respiratory systems separate. The anterior portion connects to the larynx, allowing air to flow into the bronchial tree. The inferior border of the laryngopharynx is continuous with the esophagus. The mucus-producing nonkeratinized stratified squamous epithelium continues throughout the laryngopharynx and into the esophagus

During swallowing, the larynx is pulled up and the **epiglottis**, a cartilaginous structure, covers the **glottis** (the opening to the larynx) to prevent food and liquids from going into the trachea and bronchi, which are located inferior to the larynx. If food somehow does enter the trachea, the reaction is to cough, which usually forces the food up and out of the trachea, and back into the pharynx. See Figure 14.7[8] for an illustration of the subdivisions of the pharynx and the epiglottis.

8. OpenStax. (2013). *2411_Pharynx* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2411_Pharynx.jpg

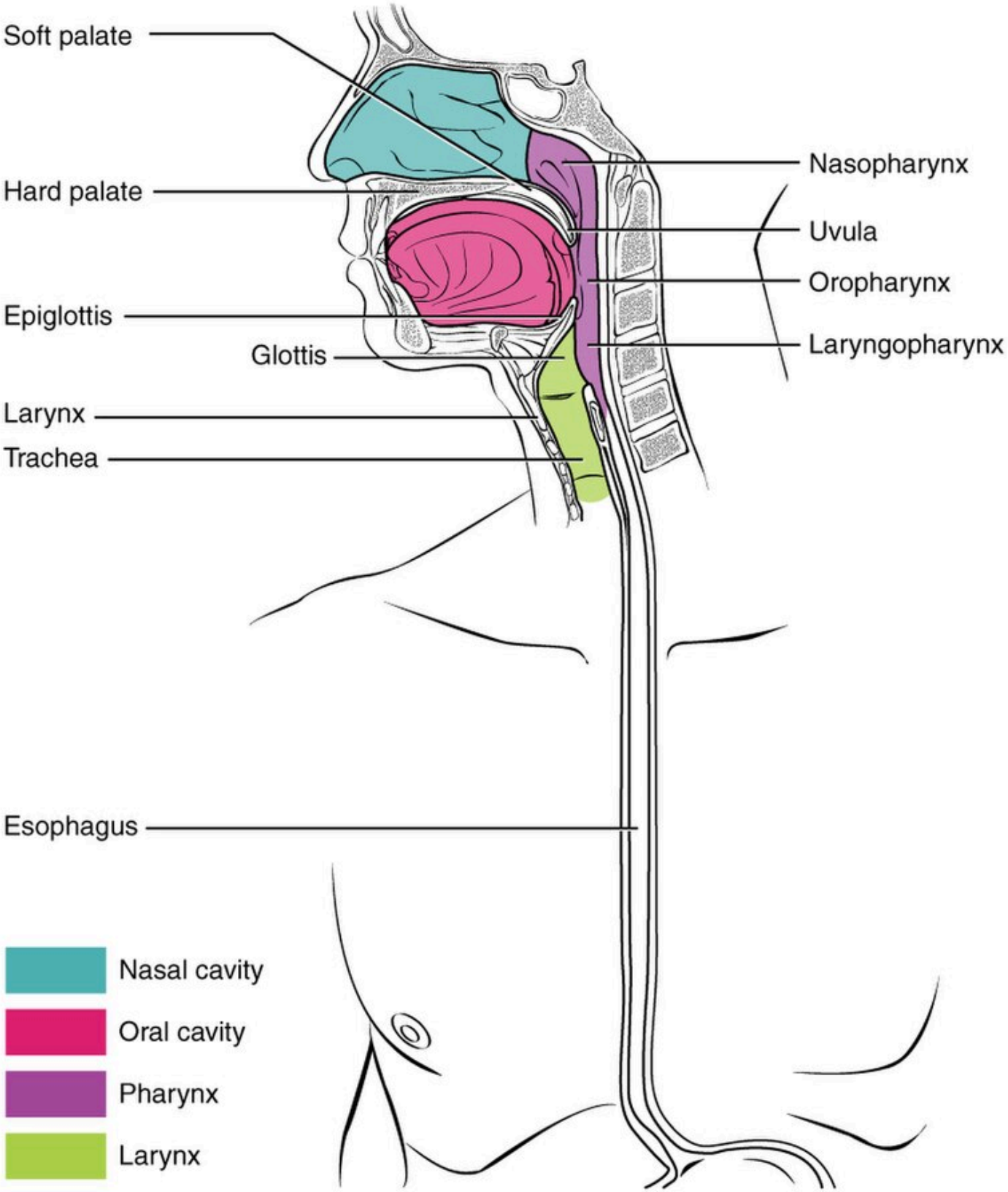


Figure 14.7 Subdivisions of the Pharynx and the Epiglottis

The Esophagus

The **esophagus** is a muscular tube that connects the pharynx to the stomach. It is approximately ten inches in length, located posterior to the trachea, and remains in a collapsed form when not swallowing.

The **upper esophageal sphincter (UES)** controls the movement of food from the pharynx into the esophagus. **Sphincters** are circular muscles that surround openings to tubes and regulate the movement of materials, closing the tube when the sphincters contract and opening it when they relax.

The upper two-thirds of the esophagus consists of both smooth and skeletal muscle, with the amount of skeletal muscle decreasing in the bottom third of the esophagus. Rhythmic waves of peristalsis, which begin in the upper esophagus, move the bolus toward the stomach. At the same time, secretions from the esophageal mucosa lubricate the esophagus and food. To enter the abdomen, the esophagus goes through an opening in the diaphragm called the **esophageal hiatus**.

Food passes from the esophagus into the stomach at the **lower esophageal sphincter (LES)** (also called the gastroesophageal or cardiac sphincter). The lower esophageal sphincter relaxes to let food pass into the stomach and then contracts to prevent stomach acid from backing up into the esophagus.

Surrounding the lower esophageal sphincter is the **muscular diaphragm**, which helps close the sphincter when no food is being swallowed. When the lower esophageal sphincter does not completely close, stomach contents can reflux (back up into the esophagus), causing heartburn or **gastroesophageal reflux disease (GERD)**. Read more about GERD in the "Digestive Systems Disorders" section.

See Figure 14.8[9] for an illustration of the esophagus.

9. OpenStax. (2013). *2412_The esophagus* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2412_The_Esophagus.jpg

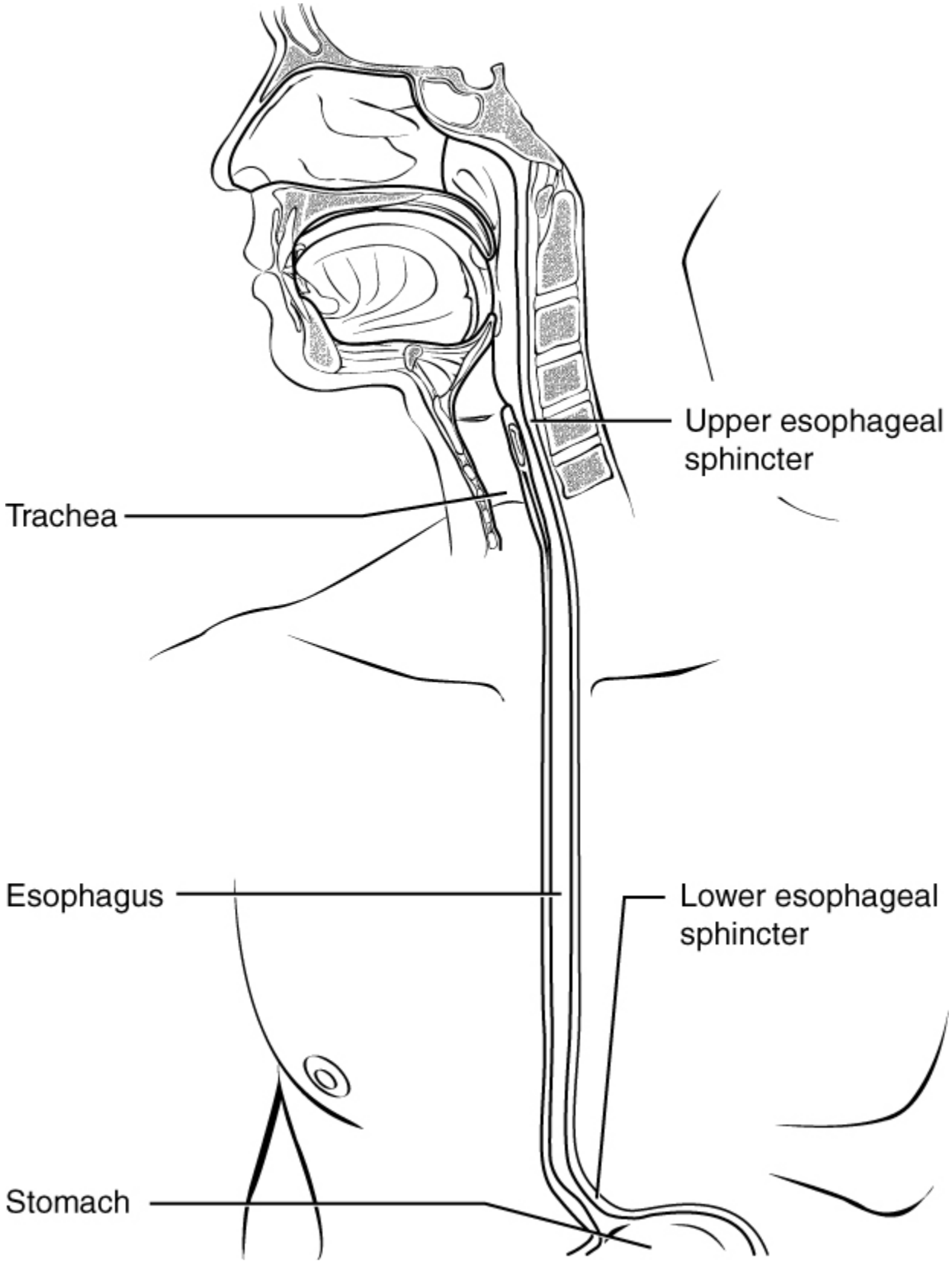


Figure 14.8 Esophagus

Stomach

The stomach is an expansion of the gastrointestinal tract located inferior to the esophagus. The stomach links the esophagus to the first part of the small intestine (the duodenum) and is relatively fixed in place.

The stomach can be a highly active structure, contracting and continually changing position and size. These muscular contractions provide mechanical assistance to digestion. The stomach, normally about the size of a fist when empty, can expand to hold up to 4 liters of food and fluid – over 75 times its resting volume – then shrink back after emptying. Although one might think that the size of a person's stomach is related to how much food that individual consumes, body weight does not correlate with stomach size. Rather, when greater quantities of food are eaten—such as at a holiday dinner—the stomach stretches more than when less is eaten.

An important function of the stomach is to serve as a temporary holding chamber. Eating a meal happens much more quickly than it can be digested and absorbed by the small intestine. The stomach holds food and passes only small amounts into the small intestine at a time. Food is mixed together with digestive juices in the stomach until they are converted into a soupy liquid called **chyme**, which is released into the small intestine.

There are four main regions in the stomach: the cardia, fundus, body, and pylorus.

The **cardia** (or cardiac region) is the point where the esophagus connects to and through which food passes into the stomach. Located inferior to the diaphragm, superior and to the left of the cardia, is the dome-shaped **fundus**. Below the fundus is the body, the main part of the stomach. The funnel-shaped **pylorus** connects the stomach to the duodenum.

The smooth muscle pyloric sphincter is located between the pylorus and the duodenum (the first part of the small intestine) and controls stomach emptying.

In the absence of food, the stomach deflates inward, and its mucosa and submucosa form large folds called **rugae** (singular = ruga).

See Figure 14.9[10] for an illustration of the regions of the stomach.

10. OpenStax. (2013). *2414_Stomach* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2414_Stomach.jpg

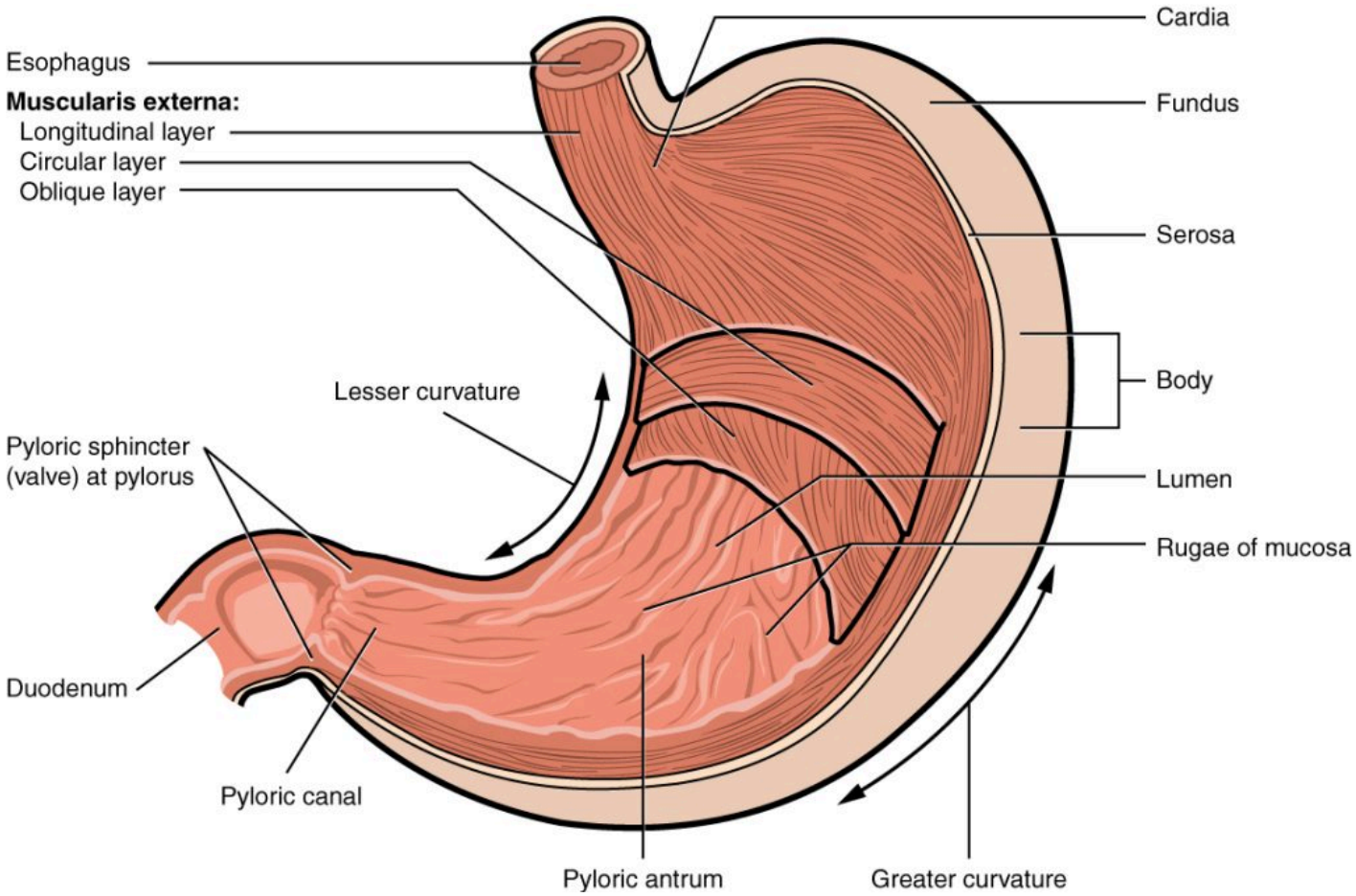


Figure 14.9 Stomach

The stomach plays several important roles in chemical digestion, including the initial digestion of proteins and triglycerides. Salivary amylase, an enzyme in saliva that begins carbohydrate digestion in the mouth, is deactivated in the acidic environment of the stomach. Little, if any, absorption occurs in the stomach, with the exception of alcohol and some medications such as aspirin.

Within a few minutes after food enters your stomach, mixing waves begin to occur at intervals of approximately 20 seconds. A mixing wave is a unique type of peristalsis that mixes and softens the food with gastric juices to create a soupy mixture called chyme.

The pylorus acts as a filter, permitting only liquids and small food particles to pass through the mostly, but not fully, closed pyloric sphincter. In a process called **gastric emptying**, rhythmic mixing waves force only about 3 mL of chyme at a time through the pyloric sphincter and into the duodenum. Release of a greater amount of chyme at one time would overwhelm the capacity of the small intestine to handle it. The rest of the chyme is pushed back into the body of the stomach, where it continues mixing. This process is repeated when the next mixing waves force more chyme into the duodenum.

The fundus of the stomach plays an important role because it stores both undigested food and gases that are released during the process of chemical digestion. Food may sit in the fundus of the stomach for a while before being mixed with the chyme. While the food is in the fundus, the digestive activities of salivary amylase continue until the food begins mixing with the acidic chyme. Ultimately, mixing waves incorporate this food with the chyme, the acidity of which inactivates salivary amylase and activates **lingual lipase**, an enzyme released from the glands of the tongue. Lingual lipase then begins breaking down triglycerides. The breakdown of protein begins in the stomach through the actions of HCl and the enzyme pepsin.

In addition to its numerous digestive functions, the stomach also produces intrinsic factor that is essential for the intestinal absorption of **vitamin B12**. This vitamin is necessary for both the production of mature red blood cells and normal neurological functioning. People who have their stomach removed (gastrectomy), such as for advanced stomach cancer, can survive with minimal digestive issues if they receive vitamin B12 injections.

Most contents of the stomach are completely emptied into the duodenum within two to four hours after eating a meal. Different types of food take different amounts of time to process. Foods high in carbohydrates empty fastest, followed by high-protein foods. Meals with a high-fat content remain in the stomach the longest. Because enzymes in the small intestine digest fats slowly, food can stay in the stomach for six hours or longer when the duodenum is processing fatty chyme. However, note that this is still a fraction of the 24 to 72 hours that full digestion typically takes from start to finish.

Histology of the Stomach

The wall of the stomach is made of the same layers as most of the rest of the gastrointestinal tract, but with some adaptations. In addition to the typical circular and longitudinal smooth muscle layers, the muscularis has an inner oblique smooth muscle layer. As a result, the stomach can vigorously churn food, mechanically breaking it down into smaller pieces.

The stomach mucosa's epithelial lining consists of surface mucus cells, which secrete a protective coat of alkaline mucus. Gastric pits cover the surface of the epithelium, giving it the appearance of a well-used pincushion, and mark the entry to each gastric

gland, which secretes gastric juice. See Figure 14.10[11] for an illustration of histology of the stomach.

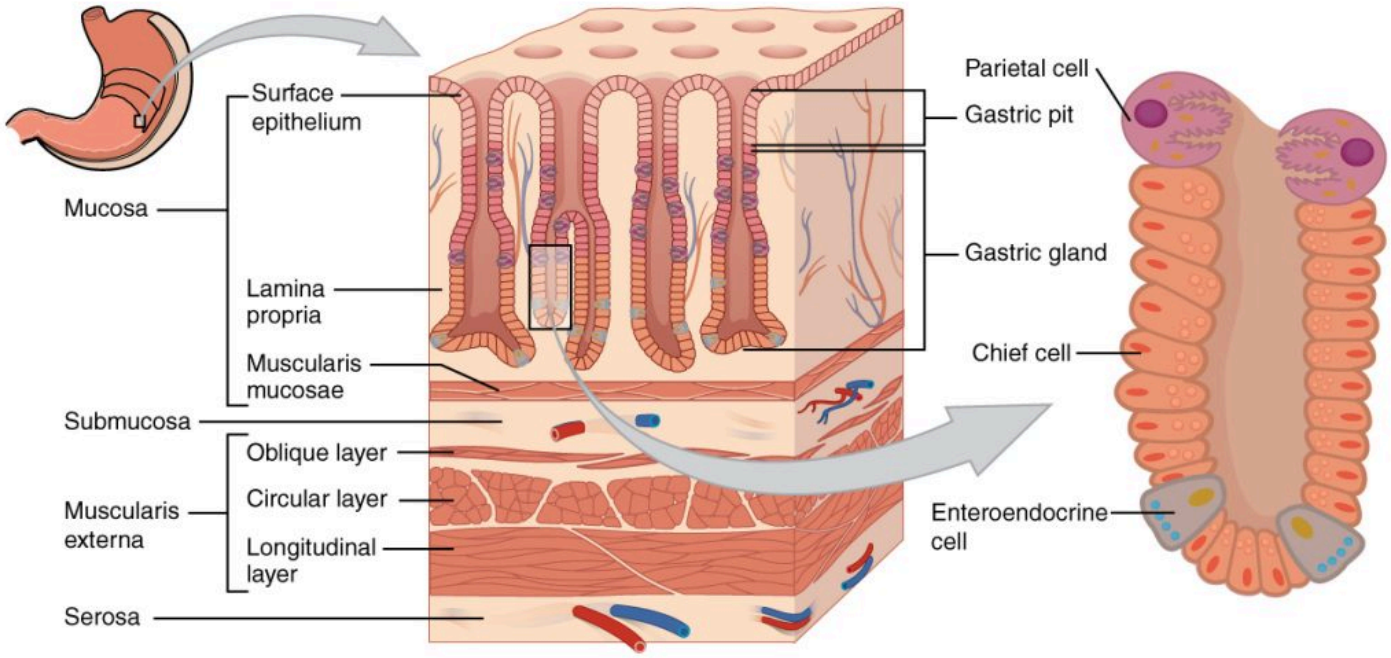


Figure 14.10 Histology of the Stomach. The stomach wall is adapted for the functions of the stomach. In the epithelium, gastric pits lead to gastric glands that secrete gastric juice. The gastric glands (one gland is shown enlarged on the right) contain different types of cells that secrete a variety of enzymes, including hydrochloric acid, which activates the protein-digesting enzyme pepsin.

Although the walls of the gastric pits are made up primarily of mucus cells, the gastric glands are made up of different types of cells. The glands of the cardia and pylorus are composed primarily of mucus-secreting cells. Cells that make up the pyloric antrum secrete mucus and a number of hormones, including the hormone gastrin. The much larger glands of the fundus and body of the stomach, the site of most chemical digestion, produce most of the gastric secretions. These glands are made up of a variety of secretory cells. These include parietal cells, chief cells, mucous neck cells, and enteroendocrine cells.

Parietal cells—These relatively large cells produce both hydrochloric acid (HCl) and intrinsic factor. HCl is responsible for the high acidity (pH 1.5 to 3.5) of the stomach contents and is needed to activate the protein-digesting enzyme, pepsin. The

11. OpenStax. (2013). *2415 Histology of the stomach* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2415_Histology_of_StomachN.jpg

acidity also kills many of the bacteria ingested with food and helps to denature proteins. Intrinsic factor is necessary for the absorption of vitamin B_{12} in the small intestine.

Chief cells—Secrete pepsinogen, an inactive enzyme that is converted into pepsin by hydrochloric acid (HCl). Pepsin breaks down proteins in the stomach.

Mucous neck cells—Secrete a thin, acidic mucus that is much different from the mucus secreted by the goblet cells of the surface epithelium. The role of this mucus is not currently known.

Enteroendocrine cells—Enteroendocrine cells secrete various hormones, including gastrin, which is released mainly by enteroendocrine G cells.

The Small Intestine

Chyme released from the stomach enters the small intestine, which is the primary digestive organ in the body. Additionally, the small intestine is the site of most nutrient absorption.

The longest part of the gastrointestinal tract, the small intestine, is about 3.05 meters (10 feet) long in a living person. Despite being significantly longer than the large intestine, the small intestine is named for its narrower diameter, approximately 1 inch compared with the 3-inch diameter of the large intestine.

In addition to length, the folds and projections of the small intestine's lining work to give it an enormous surface area, which is approximately 200 square meters (m^2), more than 100 times the surface area of your skin. This large surface area is necessary for the complex processes of digestion and absorption that occur within it. See Figure 14.11[12] for an illustration of the small intestine.

12. OpenStax. (2013). *2417_Small intestineN* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2417_Small_IntestineN.jpg

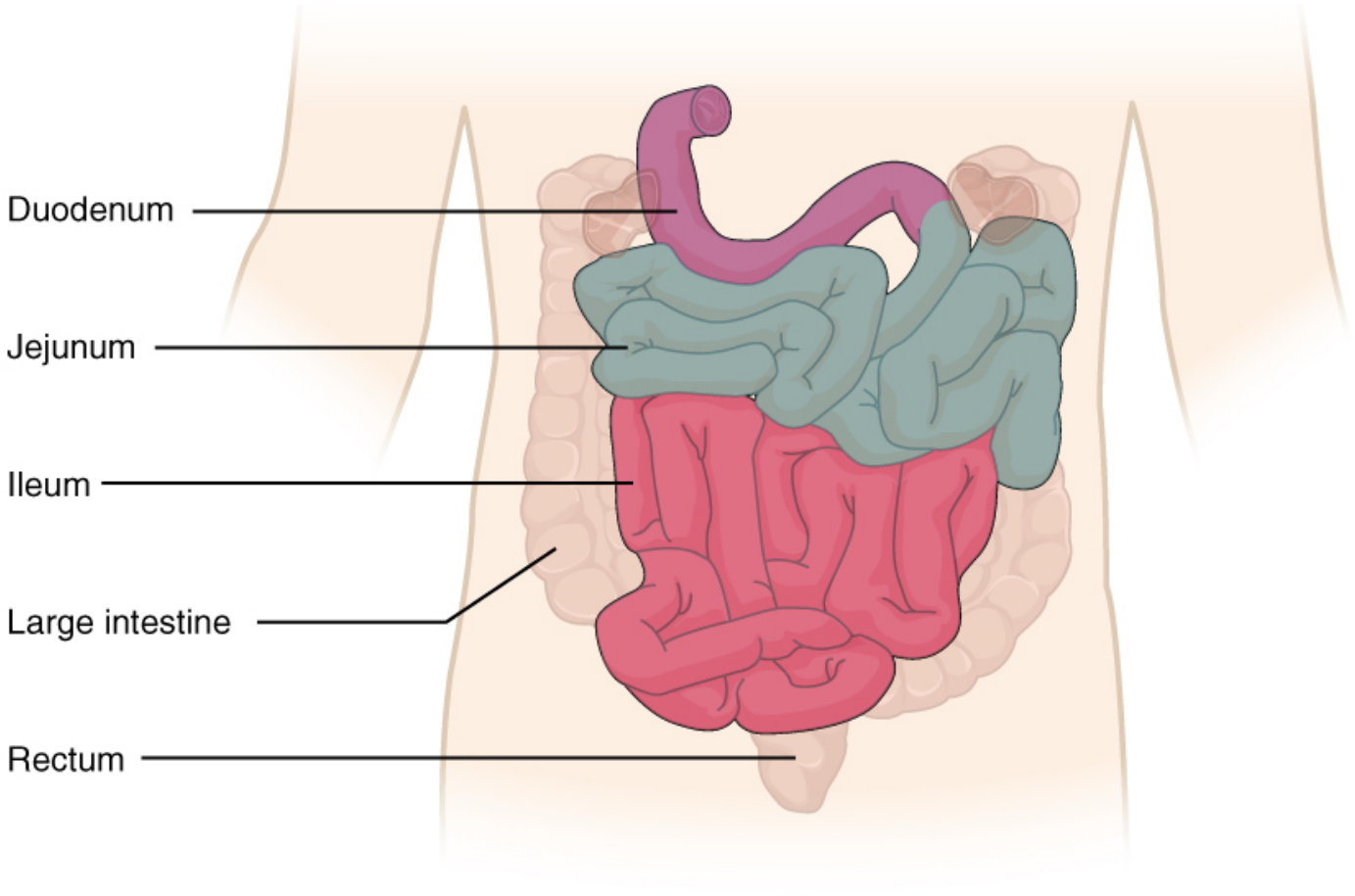


Figure 14.11 Small Intestine

The small intestine is subdivided into three regions: the duodenum, jejunum, and ileum (proximal to distal, starting at the stomach). The **duodenum** is the shortest part of the small intestine. It is 25.4 cm (10 inches) long and begins at the pyloric sphincter. Located in the duodenal wall is the **hepatopancreatic ampulla** (ampulla of Vater). The ampulla is where the **bile duct** (through which bile passes from the liver) and the main **pancreatic duct** (through which pancreatic juice passes from the pancreas) join. This ampulla opens into the duodenum. The **hepatopancreatic sphincter** (sphincter of Oddi) regulates the one-way flow of both bile and pancreatic juice from the ampulla into the duodenum. See Figure 14.12[13] for an illustration of the ducts.

13. Vishnu2011. (2009). *Biliary system new* [Diagram]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Biliary_system_new.svg

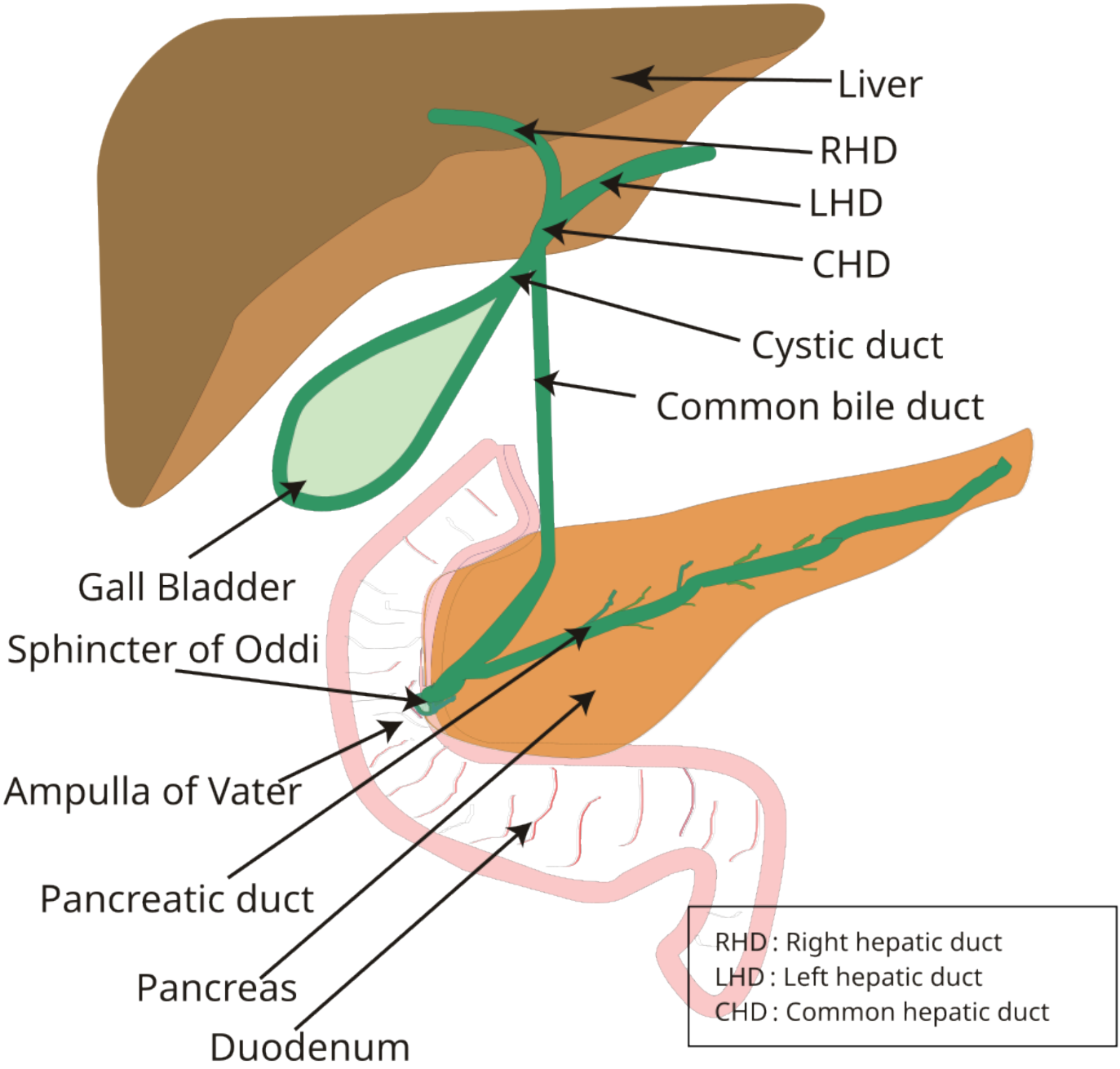


Figure 14.12 Ducts Entering the Small Intestine

The **jejunum** is about 3 feet long and runs from the duodenum to the ileum. *Jejunum* means "empty" in Latin and supposedly was so named by the ancient Greeks, who noticed it was always empty at death. No clear line exists between the jejunum and the final segment of the small intestine, the ileum.

The **ileum** is the longest part of the small intestine, measuring about 6 feet in length. It is thicker, more vascular, and has more developed mucosal folds than the jejunum. The

ileum joins the cecum, the first portion of the large intestine, at the ileocecal sphincter (or valve).

Recall the four layers present in the walls of the gastrointestinal tract. The small intestine has structural modifications in these layers that increase the surface area for absorption more than 600-fold. These special features include circular folds, villi, and microvilli. These adaptations are most abundant in the proximal two-thirds of the small intestine, where the majority of absorption occurs.

Circular folds (also called plicae circulares) are deep ridges in the mucosa and submucosa that facilitate absorption. Their shape causes the chyme to spiral rather than move in a straight line through the small intestine. Spiraling slows the movement of chyme and provides the time needed for nutrients to be fully absorbed.

Within the circular folds are small (0.5–1 mm long) hairlike projections called villi (singular = villus) that give the mucosa a fuzzy appearance. There are about 20 to 40 villi per square millimeter, greatly increasing the surface area of the epithelium. The mucosal epithelium, primarily composed of absorptive cells, covers the villi. In addition to muscle and connective tissue to support its structure, each villus contains a capillary bed composed of one arteriole and one venule, as well as a lymphatic capillary called a lacteal. The breakdown products of carbohydrates and proteins (monosaccharides and amino acids) can enter the bloodstream directly, but lipid breakdown products are absorbed by the lacteals and transported to the bloodstream via the lymphatic system.

As their name suggests, microvilli (singular = microvillus) are much smaller (1 μm) than villi. They are surface extensions of the plasma membrane of the mucosa's epithelial cells. Although their small size makes it difficult to see each microvillus, their combined microscopic appearance suggests a mass of bristles, which is termed the brush border. Fixed to the surface of the microvilli membranes are enzymes that finish digesting carbohydrates and proteins. There are an estimated 200 million microvilli per square millimeter of small intestine, greatly expanding the surface area of the plasma membrane and, therefore, enhancing absorption.

See Figure 14.13[14] for an illustration of the small intestine with the circular folds, villi, and microvilli.

14. OpenStax. (2013). *2418_Histology small intestinesN* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2418_Histology_Small_IntestinesN.jpg

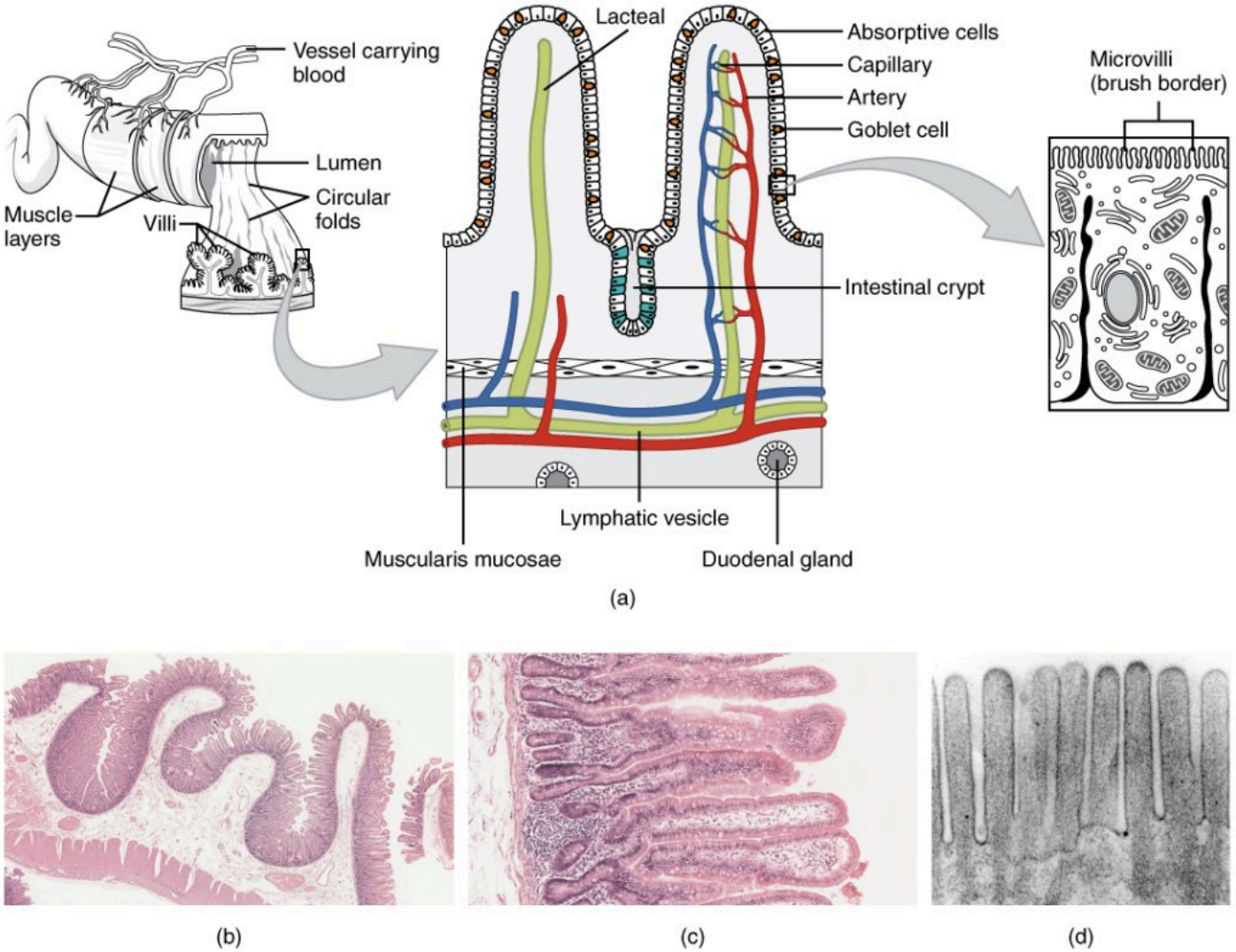


Figure 14.13 Small Intestine (a) The absorptive surface of the small intestine is vastly enlarged by the presence of circular folds, villi, and microvilli. (b) Micrograph of the circular folds. (c) Micrograph of the villi. (d) Electron micrograph of the microvilli.

In addition to the three specialized absorptive features, the mucosa between the villi has deep crevices that lead to intestinal glands. These intestinal glands produce intestinal juice, a slightly alkaline (pH 7.4 to 7.8) mixture of water and mucus. Each day, about 0.95 to 1.9 liters (1 to 2 quarts) are secreted in response to the distention of the small intestine or the irritating effects of chyme on the intestinal mucosa.

Intestinal juice combines with pancreatic juice to facilitate absorption. The small intestine is also where most water is absorbed via osmosis.

Digestion begins in the mouth and is completed in the small intestine. Intestinal and pancreatic juice continue to digest proteins into peptides and then amino acids and carbohydrates into disaccharides and then monosaccharides.

Lipids arrive in the small intestine largely undigested. Bile and the enzyme pancreatic lipase are added to the small intestine, which is primarily responsible for digesting lipids.

The Large Intestine

The large intestine is the last part of the gastrointestinal tract. The primary function of this organ is to finish the absorption of water, synthesize certain vitamins, form feces, and eliminate feces from the body.

The large intestine runs from the appendix to the anus and frames the small intestine on three sides. The large intestine is subdivided into four main regions: the cecum, the colon, the rectum, and the anus. The **ileocecal valve**, located at the opening between the ileum and the large intestine, regulates the one-way flow of chyme from the small intestine to the large intestine.

The first part of the large intestine is the **cecum**, a pouch-like structure that is suspended below the ileocecal valve. It is about 2.4 inches long. The cecum receives the contents of the ileum and continues the absorption of water and salts.

The **appendix** (or vermiform appendix) is a winding tube that attaches to the cecum and is about 3 inches long. The appendix contains lymphatic tissue, suggesting an immune function, but this organ is generally considered vestigial or no longer functional. However, at least one recent report proposes a survival advantage provided by the appendix: in diarrheal illness, the appendix may serve as a bacterial reservoir to repopulate the intestinal bacteria for those surviving the initial phases of the illness.

Upon entering the colon, the food residue first travels superiorly through the ascending colon on the right side of the abdomen. At the inferior surface of the liver, the colon bends to form the right colic flexure (hepatic flexure) and becomes the transverse colon. Food residue passing through the transverse colon travels across to the left side of the abdomen, where the colon angles sharply immediately inferior to the spleen, at the left colic flexure (splenic flexure). From there, food residue passes through the descending colon, which runs inferiorly on the left side of the posterior abdominal wall. After entering the pelvis inferiorly, it becomes the S-shaped sigmoid colon. See Figure 14.14[15] for an illustration of the parts of the colon.

15. OpenStax. (2013). *2420 large intestine* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2420_Large_Intestine.jpg

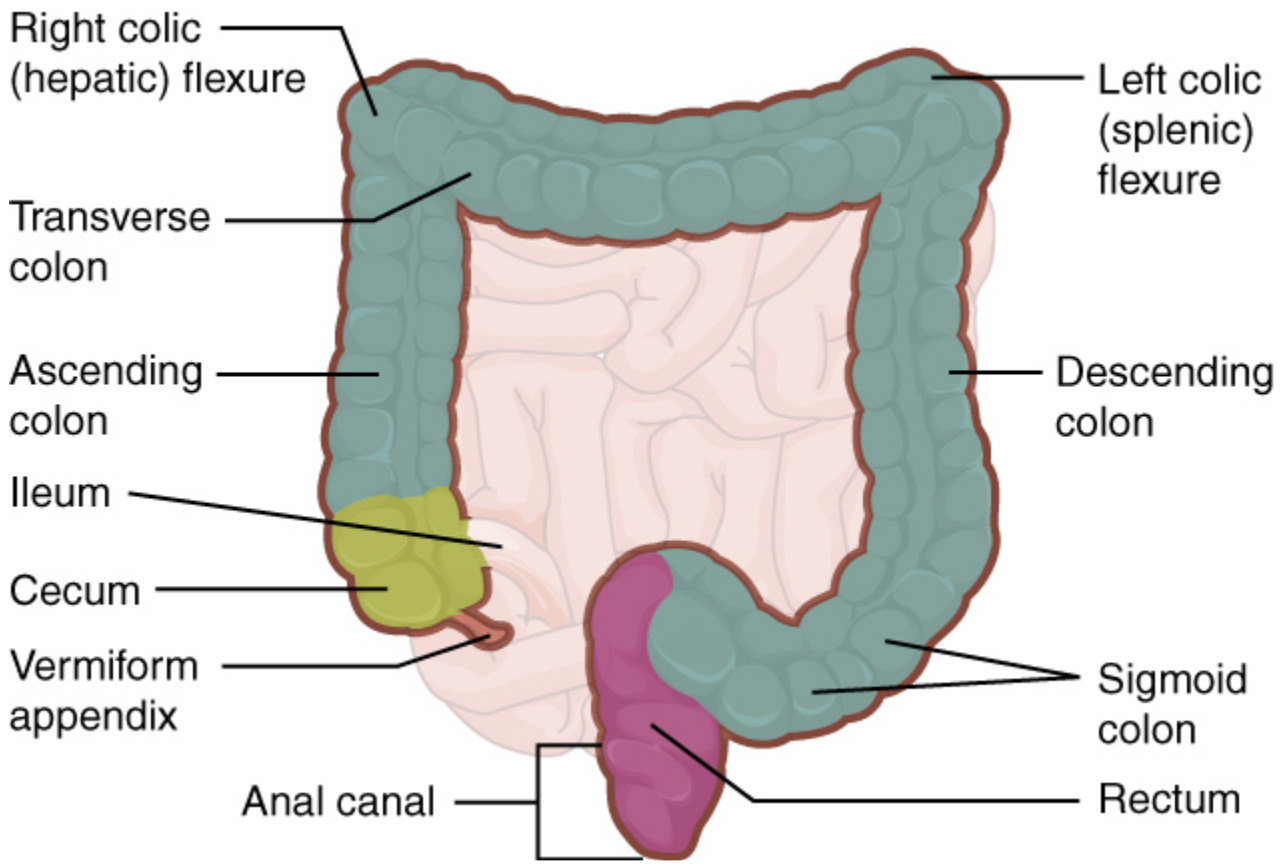


Figure 14.14 Large Intestine

Food residue leaving the sigmoid colon enters the **rectum**, the final eight inches of the gastrointestinal tract. Even though *rectum* is Latin for "straight," this structure follows the curved contour of the sacrum and has three lateral bends that create a trio of internal transverse folds called the rectal valves. These valves help separate the feces from gas to prevent the simultaneous passage of feces and gas.

Finally, food residue reaches the last part of the large intestine, the **anal canal**. This structure is about 1.5–2 inches long and opens to the exterior of the body at the anus. The anal canal includes two sphincters, the internal anal sphincter and the external anal sphincter. The internal anal sphincter is made of smooth muscle, and its contractions are involuntary. The external anal sphincter is made of skeletal muscle, which is under voluntary control after a child is potty-trained. Except when defecating, both usually remain closed.

Three features are unique to the large intestine: teniae coli, haustra, and epiploic appendages. The **teniae coli** are three bands of smooth muscle that make up the longitudinal muscle layer of the muscularis of the large intestine, except at its terminal end. Contractions of the teniae coli bunch up the colon into a succession of pouches

called **haustra** (singular = haustrum), which are responsible for the wrinkled appearance of the colon. Attached to the teniae coli are small, fat-filled sacs of visceral peritoneum called **epiploic appendages**. The purpose of these is unknown. The rectum and anal canal have neither teniae coli nor haustra, but they do have well-developed layers of muscularis that create the strong contractions needed for defecation.

See Figure 14.15[16] for an illustration of these features of the large intestine.

16. OpenStax. (2013). *2433_Teniae coli haustra epiploic appendage* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2433_Teniae_Coli_Haustra_Epiploic_Appendage.jpg

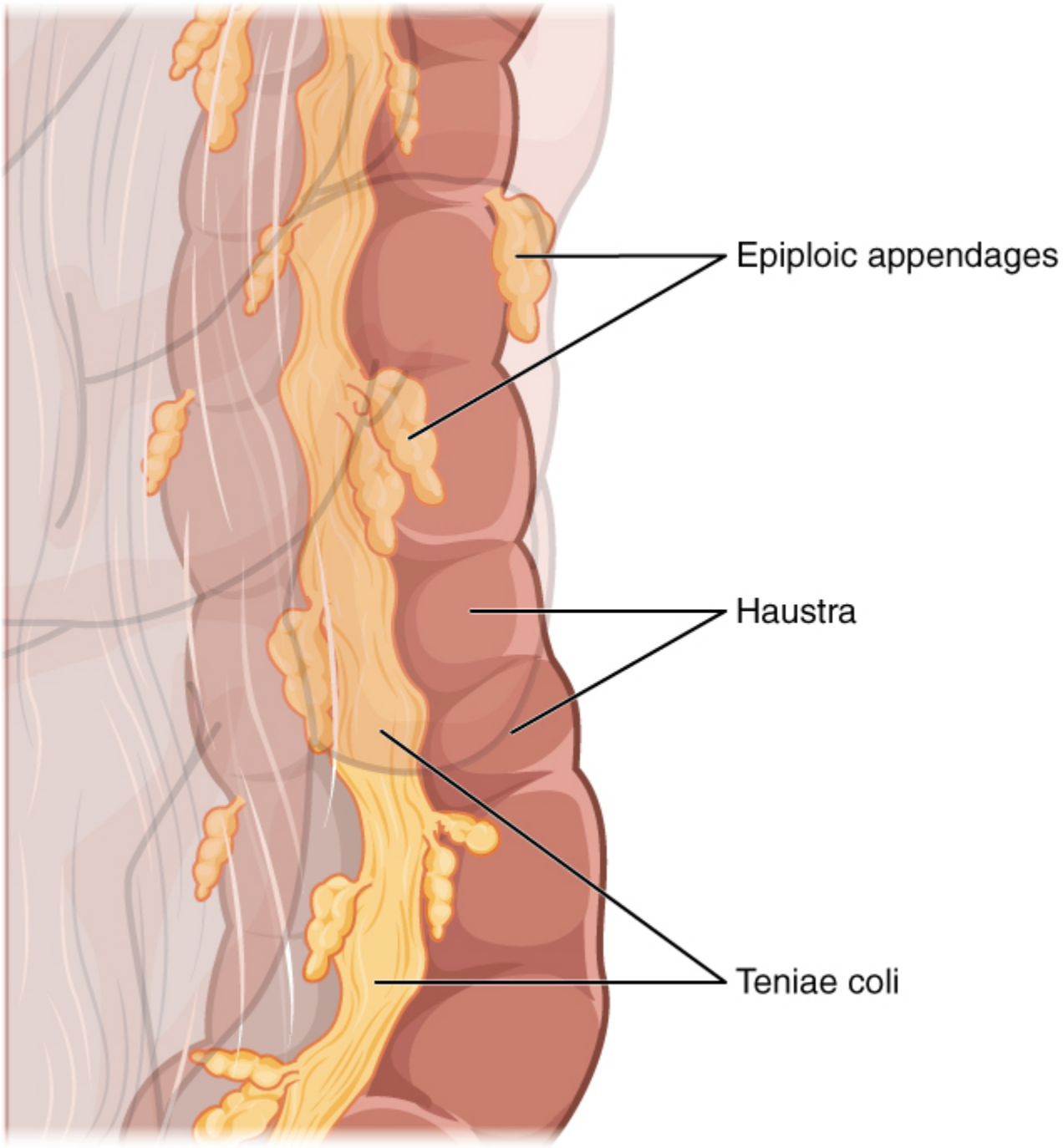


Figure 14.15 Teniae Coli, Haustra, and Epiploic Appendages of the Large Intestine

Most bacteria that enter the GI tract are killed by lysozyme, hydrochloric acid (HCl), or protein-digesting enzymes. However, trillions of bacteria live within the large intestine that are referred to as normal flora. Most of the 700 species of these bacteria are nonpathogenic organisms that cause no harm as long as they stay inside the gut lumen. In fact, many facilitate chemical digestion and absorption, and some make certain

vitamins, mainly biotin, pantothenic acid, and vitamin K. Some are linked to the immune response.

The chyme entering the large intestine contains few nutrients aside from water, which is gradually reabsorbed as the residue remains there for 12 to 24 hours. Because of this, the large intestine can be completely removed without significantly affecting digestive functioning. For example, in severe cases of inflammatory bowel disease, the large intestine can be removed by a procedure known as a **colectomy**. Often, a new fecal pouch can be crafted from the small intestine and sutured to the anus, but if not, an ileostomy can be created by bringing the distal ileum through the abdominal wall, allowing the watery chyme to be collected in an adhesive pouch.

Although the glands of the large intestine secrete mucus, they do not secrete digestive enzymes. Therefore, chemical digestion in the large intestine occurs exclusively from bacteria in the lumen of the colon. Bacteria break down some of the remaining carbohydrates, resulting in the discharge of hydrogen, carbon dioxide, and methane gases that create flatus (gas) in the colon; flatulence is excessive flatus. Each day, up to 1500 mL of gas is produced in the colon. More is produced when you eat foods such as beans, which are rich in otherwise indigestible sugars and complex carbohydrates like soluble dietary fiber.

Feces Formation and Defecation

The small intestine absorbs about 90 percent of the water ingested (either as liquid or within solid food). The large intestine absorbs most of the remaining water, a process that converts the liquid chyme residue into semi-solid feces (“stool”).

Feces is composed of undigested food residues, unabsorbed digested substances, millions of bacteria, old epithelial cells from the GI mucosa, inorganic salts, and enough water to let it pass smoothly out of the body. Of every 500 mL (17 ounces) of food residue that enters the cecum each day, about 150 mL (5 ounces) becomes feces.

Feces are eliminated through contractions of the rectal muscles. You help this process by a voluntary procedure called **Valsalva’s maneuver**, in which you increase intra-abdominal pressure by contracting your diaphragm and abdominal wall muscles and closing your glottis.

The process of defecation begins when mass movements force feces from the colon into the rectum, stretching the rectal wall and provoking the defecation reflex, which eliminates feces from the rectum. It contracts the sigmoid colon and rectum, relaxes the internal anal sphincter, and initially contracts the external anal sphincter.

The presence of feces in the anal canal sends a signal to the brain, which gives you the choice of voluntarily opening the external anal sphincter (defecating) or keeping it temporarily closed. If you decide to delay defecation, it takes a few seconds for the reflex contractions to stop and the rectal walls to relax. The next mass movement will trigger additional defecation reflexes until you defecate.

If defecation is delayed for an extended time, additional water is absorbed, making the feces firmer and potentially leading to **constipation**. On the other hand, if the waste matter moves too quickly through the intestines, not enough water is absorbed, and **diarrhea** can result. Diarrhea can also be caused by the ingestion of foodborne pathogens. In general, diet, exercise, health, and stress determine the frequency of bowel movements. The number of bowel movements varies greatly between individuals, ranging from two or three per day to three or four per week.

See Figure 14.16[17] for an illustration of digestion and absorption through the digestive tract.

17. OpenStax. (2013). *2426_Mechanical and chemical digestionN* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2426_Mechanical_and_Chemical_DigestionN.jpg

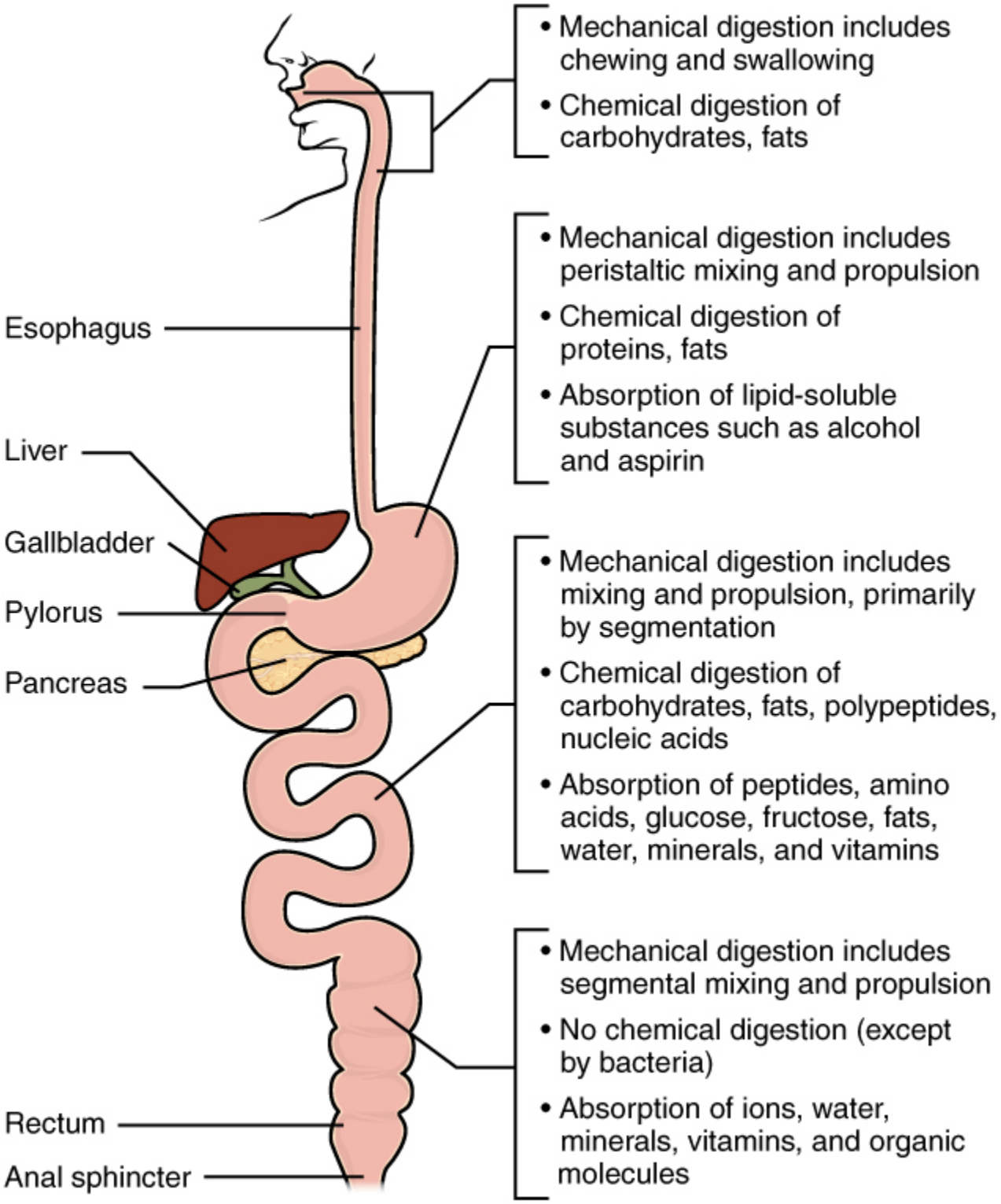


Figure 14.16 Digestion and Absorption

Accessory Organs of the Digestive System

While food travels through the GI tract, each accessory digestive organ also aids in the breakdown of food. Within the mouth, the teeth and tongue begin mechanical digestion, whereas the salivary glands begin chemical digestion. Once food products enter the small intestine, the gallbladder, liver, and pancreas release secretions—such as bile and enzymes—essential for digestion to continue.

Salivary Glands

Many small **salivary glands** are located in the mucous membranes of the mouth and tongue. These exocrine glands are constantly secreting saliva, either directly into the oral cavity or indirectly through ducts, even while you sleep. An average of 1 to 1.5 liters of saliva is secreted each day. Usually, just enough saliva is present to moisten the mouth and teeth.

Saliva secretion increases when you eat because saliva is necessary to moisten food and start the chemical breakdown of carbohydrates. Small amounts of saliva are also secreted by glands in the lips. In addition, the buccal glands in the cheeks, palatal glands in the palate, and lingual glands in the tongue help make sure that all areas of the mouth are supplied with adequate saliva.

There are three pairs of major salivary glands that secrete the majority of saliva into ducts that open into the mouth: the parotid glands, the sublingual glands, and the submandibular glands:

- The **parotid glands** lie between the skin and the masseter muscle anterior to the ears. They secrete saliva into the mouth through the parotid duct, which is located near the second upper molar tooth.
- The **sublingual glands**, which lie inferior to the tongue, use the lesser sublingual ducts to secrete saliva.
- The **submandibular glands**, which are in the floor of the mouth inferior to the mandible, secrete saliva into the mouth through the submandibular ducts.

See Figure 14.17[18] for an illustration of the major salivary glands.

18. OpenStax. (2013). *2408 Salivary glands* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2408_Salivary_Glands.jpg

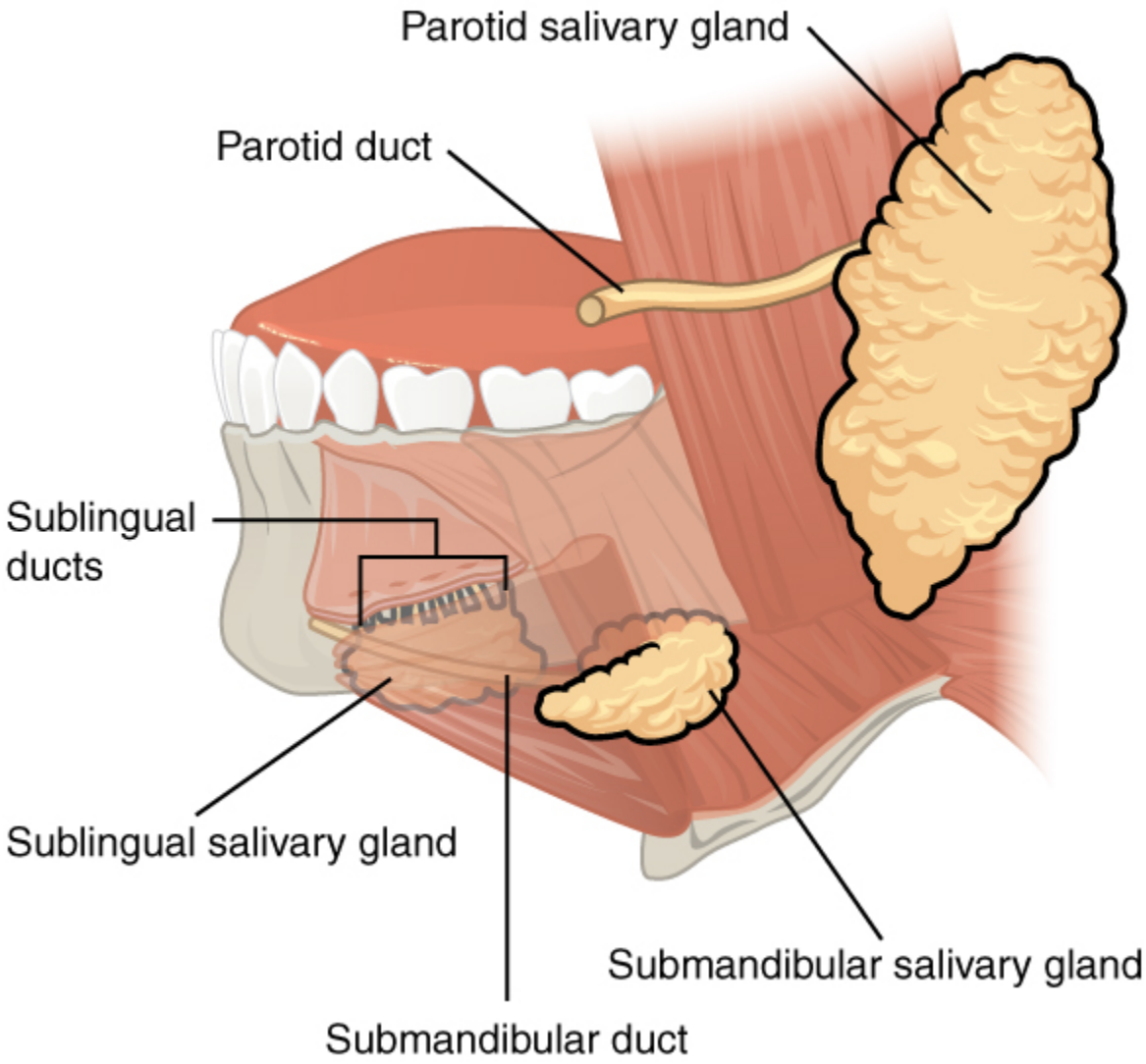


Figure 14.17 Salivary Glands

Saliva is mostly (99.4 percent) water. The remaining 0.6 percent is a mixture of ions, glycoproteins, enzymes, growth factors, and waste products. The most important ingredient in saliva for digestion is the enzyme **salivary amylase**, which begins the chemical breakdown of carbohydrates. Food does not spend enough time in the mouth to allow all the carbohydrates to break down, but salivary amylase continues working until it is inactivated by stomach acid.

Saliva is slightly acidic with a pH between 6.35 and 6.85. Salivary mucus helps lubricate food, facilitating movement in the mouth, bolus (mass of chewed food) formation, and swallowing.

Tongue

It has been said that the **tongue** is the strongest muscle in the body. Those who make this claim cite its strength proportionate to its size. Although it is difficult to quantify the relative strength of different muscles, it remains indisputable that the tongue is a workhorse, facilitating ingestion, mechanical digestion, chemical digestion (lingual lipase), sensation (taste, texture, and temperature of food), swallowing, and vocalization.

The superior and lateral regions of the tongue are covered with **papillae**, extensions of the lamina propria of the mucosa, which are covered in stratified squamous epithelium. A special type of papillae is called **fungiform papillae**, which are mushroom-shaped and cover a large area of the tongue. These fungiform papillae contain taste buds. See Figure 14.18[19] for an illustration of papillae. Read more about the sensation of taste in the "**Senses**" section of the "Nervous System" chapter.

19. OpenStax. (2013). *2407 Tongue* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2407_Tongue.jpg

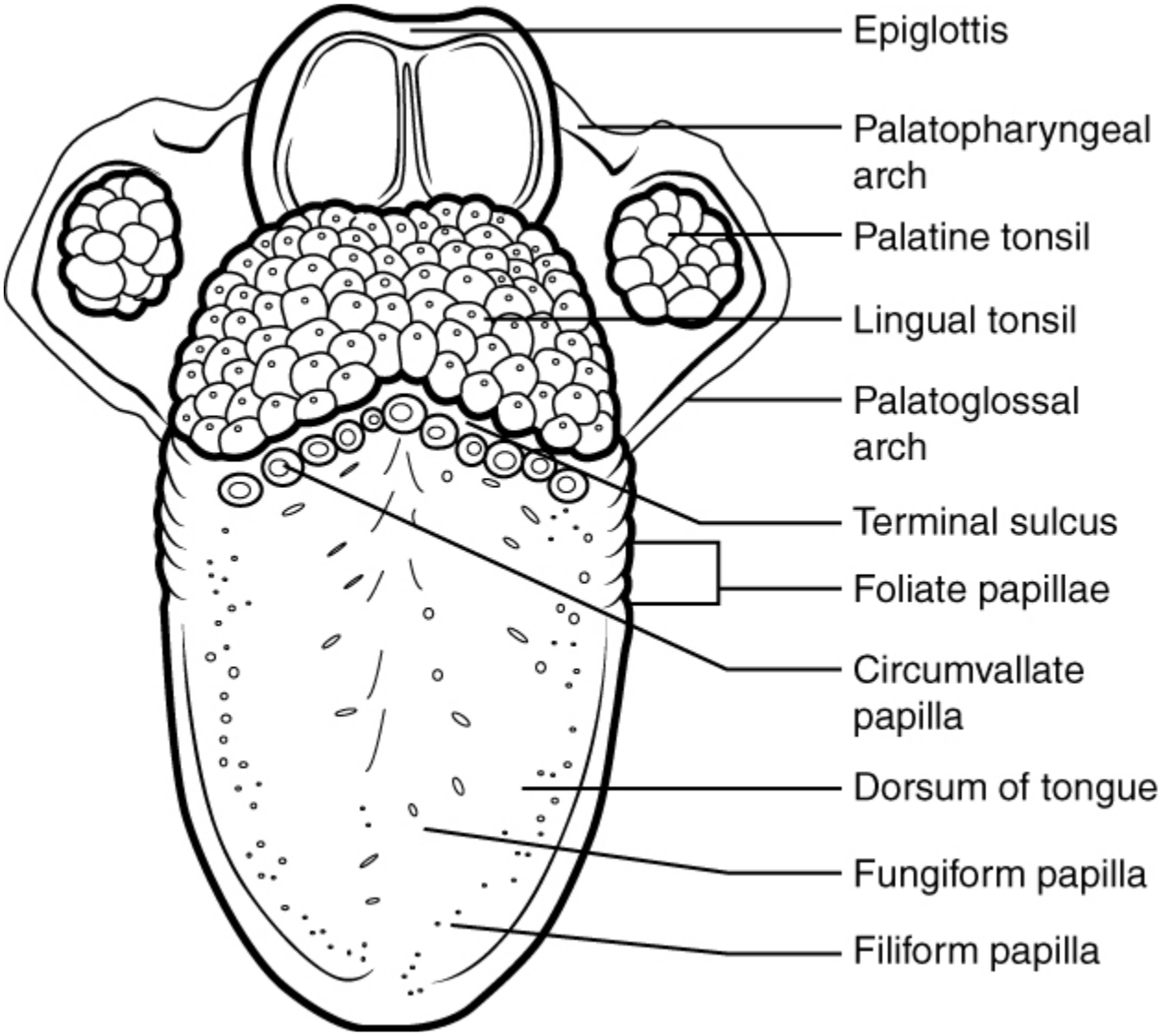


Figure 14.18 Tongue

Deglutition is another word for swallowing—the movement of food from the mouth to the stomach. The entire process takes about four to eight seconds for solid or semisolid food and about one second for very soft food and liquids. Although this sounds quick and effortless, deglutition is a complex process that involves both the skeletal muscle of the tongue and the muscles of the pharynx and esophagus. It is aided by the presence of mucus and saliva.

Teeth

The teeth, or **dentes** (singular = dens), are organs similar to bones that are used to tear, grind, and otherwise mechanically break down food.

The teeth are secured in the alveolar processes (sockets) of the maxilla and the mandible. **Gingivae** (commonly called the gums) are soft tissues that line the alveolar processes and surround the necks of the teeth.

During the course of a lifetime, most individuals have two sets of teeth (one set of teeth is a dentition). Your 20 **deciduous teeth**, also known as primary or baby teeth, first begin to appear at about six months of age. Between approximately age 6 and 12, these teeth are replaced by 32 permanent teeth. Moving from medial to lateral in the mouth, the teeth are as follows:

- The eight **incisors**, four top and four bottom, are the sharp front teeth you use for biting into food.
- The four **cuspids** (or canines) are lateral to the incisors and have a pointed edge (cusp) to tear up food. These fang-like teeth are excellent for piercing tough or fleshy foods.
- Posterior to the cuspids are the eight **premolars** (or bicuspids), which have an overall flatter shape with two rounded cusps useful for mashing foods.
- The most posterior and largest are the 12 **molars**, which have several pointed cusps used to crush food, so it is ready for swallowing. The third of each set of three molars, top and bottom, is commonly referred to as the wisdom tooth because its eruption is commonly delayed until early adulthood. It is not uncommon for wisdom teeth to fail to erupt; that is, they remain impacted. In these cases, the teeth are typically removed by oral surgery.

  See Figure 14.19[20] for an illustration of the deciduous and permanent teeth.

20. OpenStax. (2013). *2410_Permanent and deciduous teethN* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2410_Permanent_and_Deciduous_TeethN.jpg

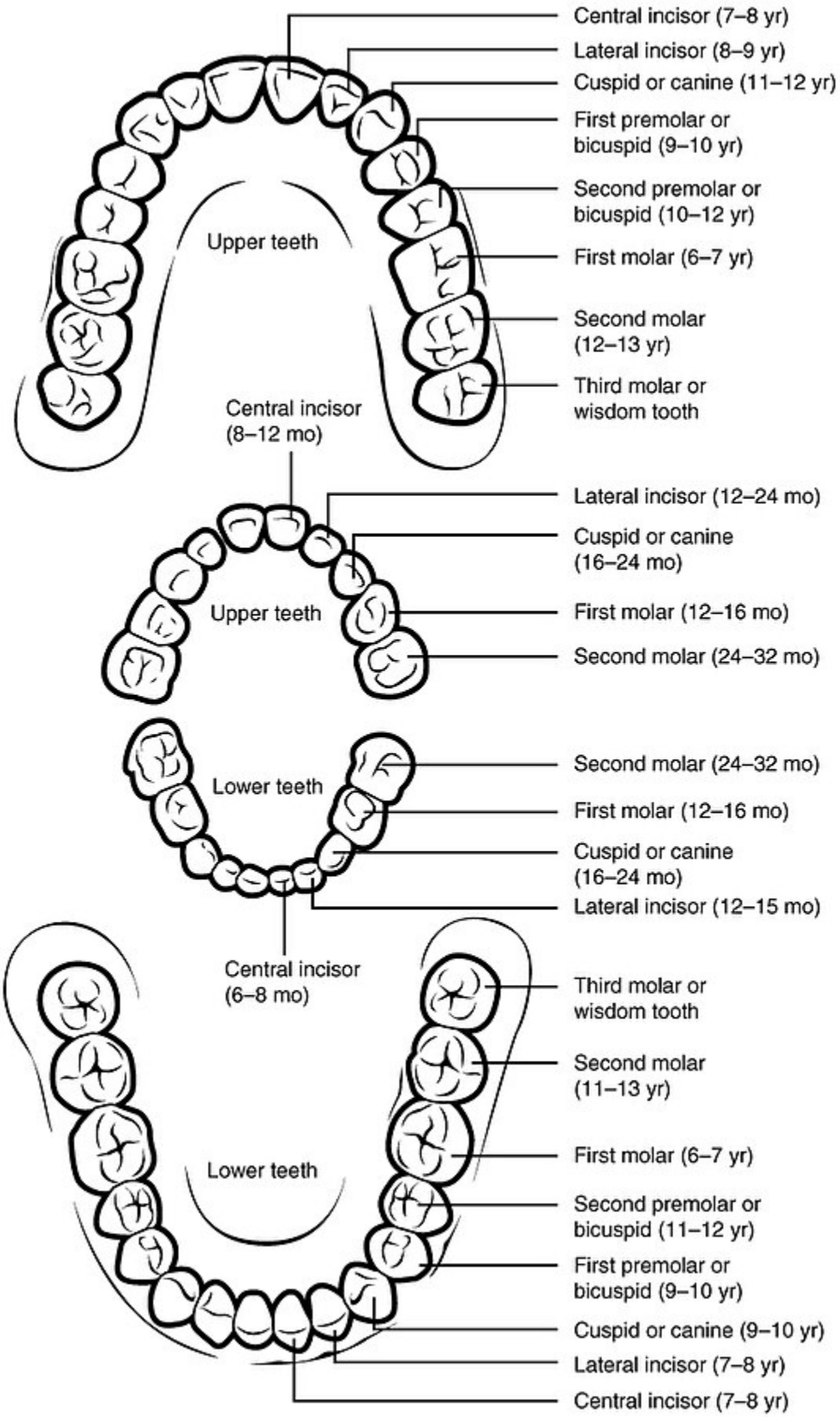


Figure 14.19 Permanent and Deciduous Teeth

The two main parts of a tooth are the crown, which is the visible portion superior to the gum line, and the **root**, which is embedded within sockets of the maxilla and mandible. Both parts contain an inner pulp cavity, containing loose connective tissue with nerves and blood vessels. The region of the pulp cavity that runs through the root of the tooth is called the root canal.

Surrounding the pulp cavity is dentin, a bone-like tissue. In the root of each tooth, the dentin is covered by a layer of modified bone called **cementum**. In the crown of each tooth, the dentin is covered by an outer layer of enamel, the hardest substance in the body. See Figure 14.20[21] for an illustration of tooth structure.

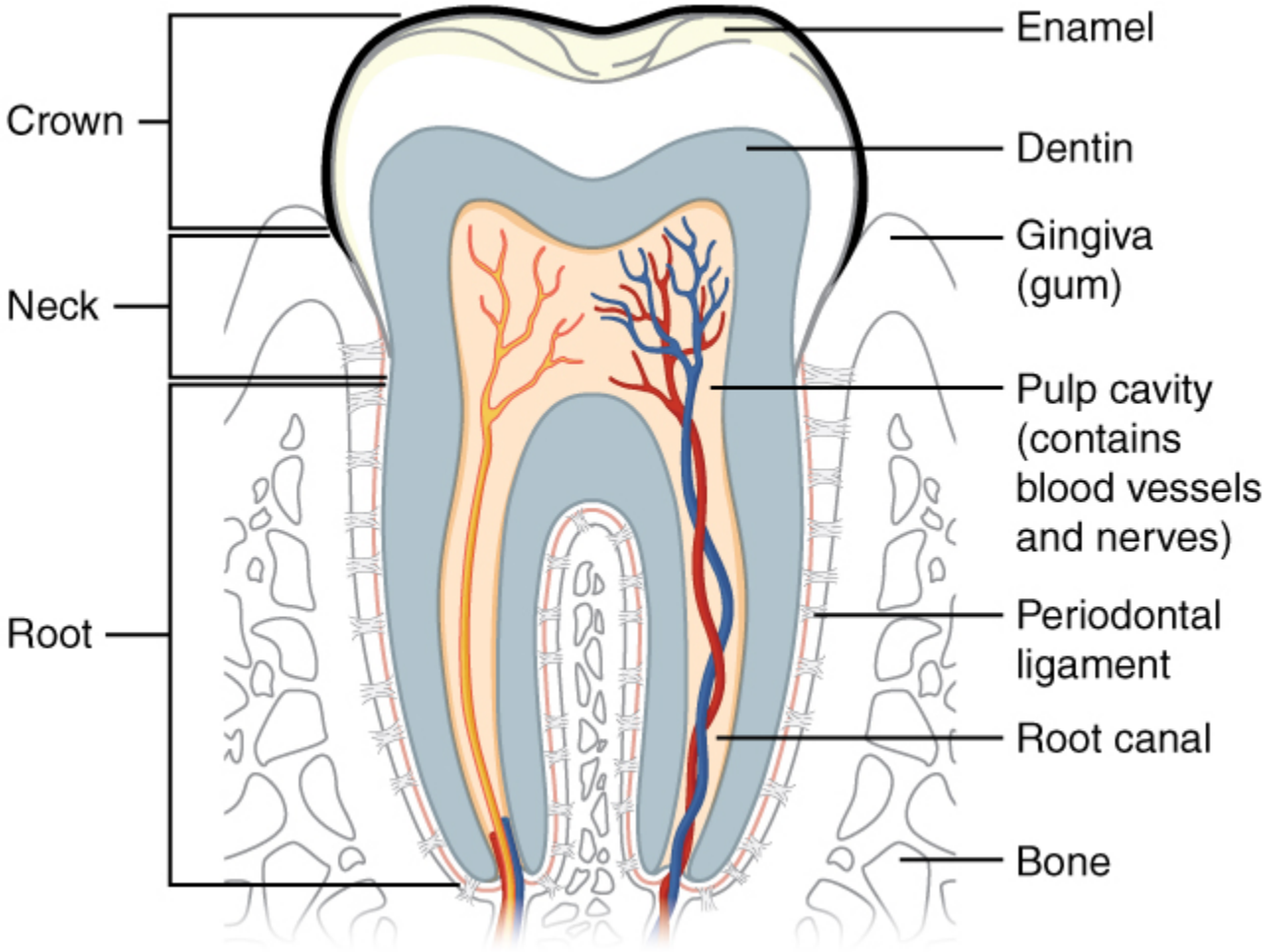


Figure 14.20 Structure of the Tooth

21. OpenStax. (2013). *2409_Tooth* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2409_Tooth.jpg

Although enamel protects the underlying dentin and pulp cavity, it is still susceptible to mechanical and chemical erosion, or what is known as **tooth decay**. The most common form, dental caries (cavities), develops when colonies of bacteria feeding on sugars in the mouth release acids that cause soft tissue inflammation and breakdown of the calcium crystals of the enamel.

Pancreas

The soft, oblong, glandular **pancreas** lies transversely posterior to the stomach and in the posterior region of the peritoneum (retroperitoneal). Its head is nestled into the "c-shaped" curvature of the duodenum of the small intestine, with the body extending to the left about 6 inches and ending as a tapering tail in the hilum of the spleen. The pancreas has both exocrine (secreting digestive enzymes) and endocrine (releasing hormones into the blood) functions. See Figure 14.21[22] for an illustration of the pancreas.

22. OpenStax. (2013). *2424_Exocrine and endocrine pancreas* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2424_Exocrine_and_Endocrine_Pancreas.jpg

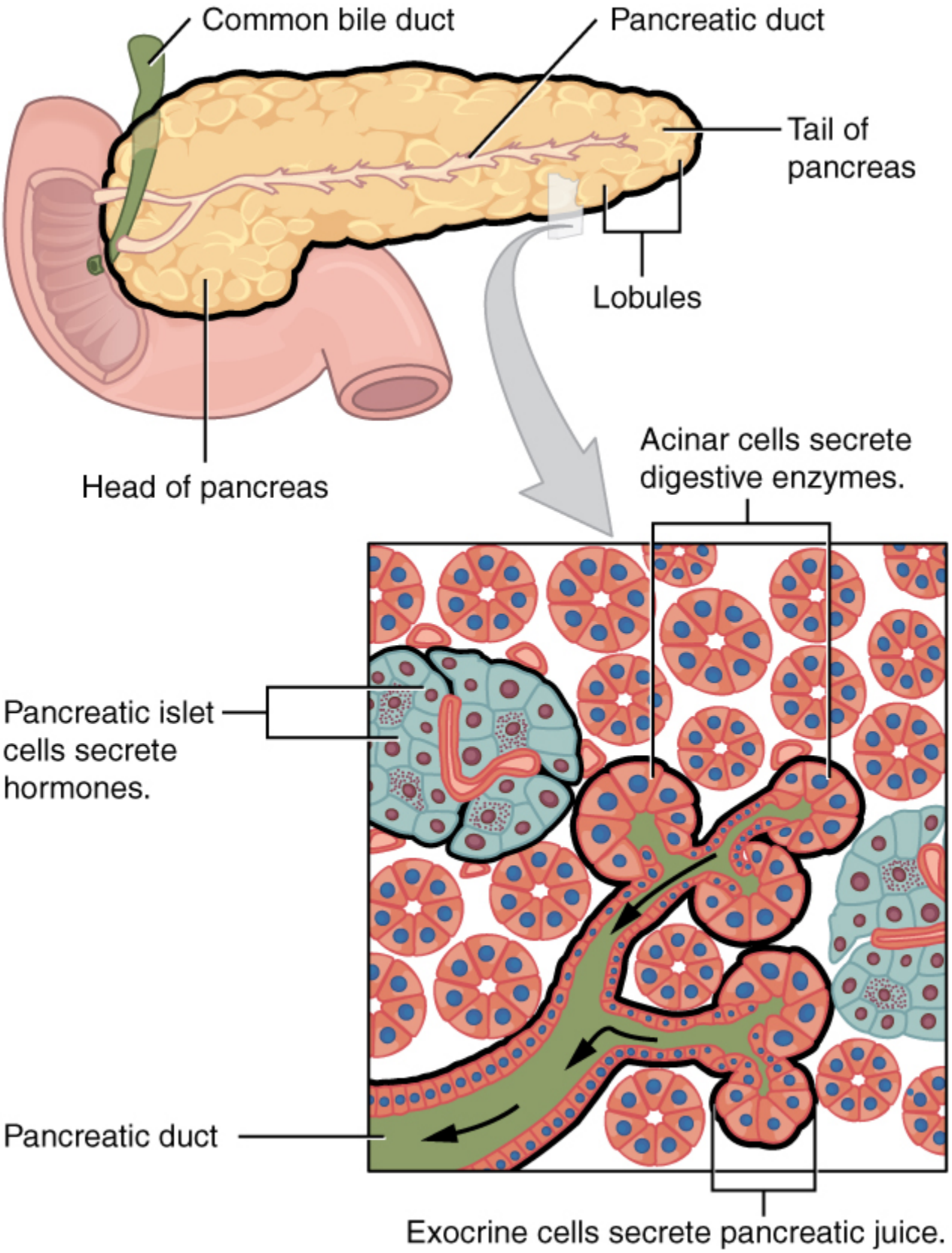


Figure 14.21 Pancreas

The exocrine part of the pancreas arises as little grape-like cell clusters, each called an **acinus** (plural = acini) and located at the ends of pancreatic ducts. These acinar cells secrete enzyme-rich **pancreatic juice**. Scattered among the acini are small islands of endocrine cells, the **pancreatic islets**. These cells produce the hormones insulin, glucagon, somatostatin, and pancreatic polypeptide.

Pancreatic Juice

The pancreas produces over a liter of pancreatic juice each day. It is clear and made mostly of water, along with some salts, sodium bicarbonate, and several digestive enzymes. Sodium bicarbonate is responsible for the slight alkalinity of pancreatic juice (pH 7.1 to 8.2), which buffers the acidic gastric juice in chyme, inactivates pepsin from the stomach, and creates an optimal environment for the activity of pH-sensitive digestive enzymes in the small intestine. Pancreatic enzymes are active in the digestion of sugars, proteins, nucleic acids, and fats.

The pancreas produces protein-digesting enzymes in their inactive forms, which are then activated in the duodenum. If produced in an active form, they would be digested in the pancreas (which is exactly what occurs in the disease pancreatitis).

The enzymes that digest starch (pancreatic amylase), fat (pancreatic lipase), and nucleic acids (nucleases) are secreted in their active forms because they do not attack the pancreas.

See Table 14.3a for a summary of digestive enzymes and their functions.

Table 14.3a. Digestive Enzymes

Enzyme Category	Enzyme Name	Source	Substrate	Product
Salivary Enzymes	Lingual lipase	Lingual glands	Triglycerides	Free fatty acids and mono- and diglycerides
Salivary Enzymes	Salivary amylase	Salivary glands	Polysaccharides	Disaccharides and trisaccharides
Gastric Enzymes	Gastric lipase	Chief cells	Triglycerides	Fatty acids and monoacylglycerides
Gastric Enzymes	Pepsin	Chief cells	Proteins	Peptides
Brush Border Enzymes	α-Dextrinase	Small intestine	α-Dextrins	Glucose
Brush Border Enzymes	Enteropeptidase	Small intestine	Trypsinogen	Trypsin
Brush Border Enzymes	Lactase	Small intestine	Lactose	Glucose and galactose
Brush Border Enzymes	Maltase	Small intestine	Maltose	Glucose

Brush Border Enzymes	Nucleosidases and phosphatases	Small intestine	Nucleotides	Phosphates, nitrogenous bases, and pentoses
Brush Border Enzymes	Peptidases	Small intestine	Aminopeptidase: amino acids at the amino end of peptides Dipeptidase: dipeptides	Aminopeptidase: amino acids and peptides Dipeptidase: amino acids
Brush Border Enzymes	Sucrase	Small intestine	Sucrose	Glucose and fructose
Pancreatic Enzymes	Carboxy-peptidase	Pancreatic acinar cells	Amino acids at the carboxyl end of peptides	Amino acids and peptides
Pancreatic Enzymes	Chymotrypsin	Pancreatic acinar cells	Proteins	Peptides
Pancreatic Enzymes	Elastase	Pancreatic acinar cells	Proteins	Peptides
Pancreatic Enzymes	Nucleases	Pancreatic acinar cells	• Ribonuclease: ribonucleic acids • Deoxyribonuclease: deoxyribonucleic acids	Nucleotides
Pancreatic Enzymes	Pancreatic amylase	Pancreatic acinar cells	Polysaccharides (starches)	α-Dextrins, disaccharides (maltose), trisaccharides (maltotriose)

Pancreatic Enzymes	Pancreatic lipase	Pancreatic acinar cells	Triglycerides that have been emulsified by bile salts	Fatty acids and monoacylglycerides
Pancreatic Enzymes	Trypsin	Pancreatic acinar cells	Proteins	Peptides

Liver

The **liver** is the largest internal organ in the body, weighing about three pounds in an adult. The liver is divided into two primary lobes: a right lobe and a much smaller left lobe. In the right lobe, some anatomists also identify an inferior quadrate lobe and a posterior caudate lobe that are defined by internal features.

In addition to being an accessory digestive organ, the liver plays important roles in metabolism and regulation. It processes and detoxifies drugs and alcohol, recycles old blood cells, produces plasma proteins, activates vitamin D, and stores glycogen and some vitamins and minerals. The liver lies inferior to the diaphragm in the right upper quadrant of the abdominal cavity and receives protection from the surrounding ribs. See Figure 14.22[23] for an illustration of the liver and other accessory organs.

23. OpenStax. (2013). *2422_Accessory organs* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2422_Accessory_Organs.jpg

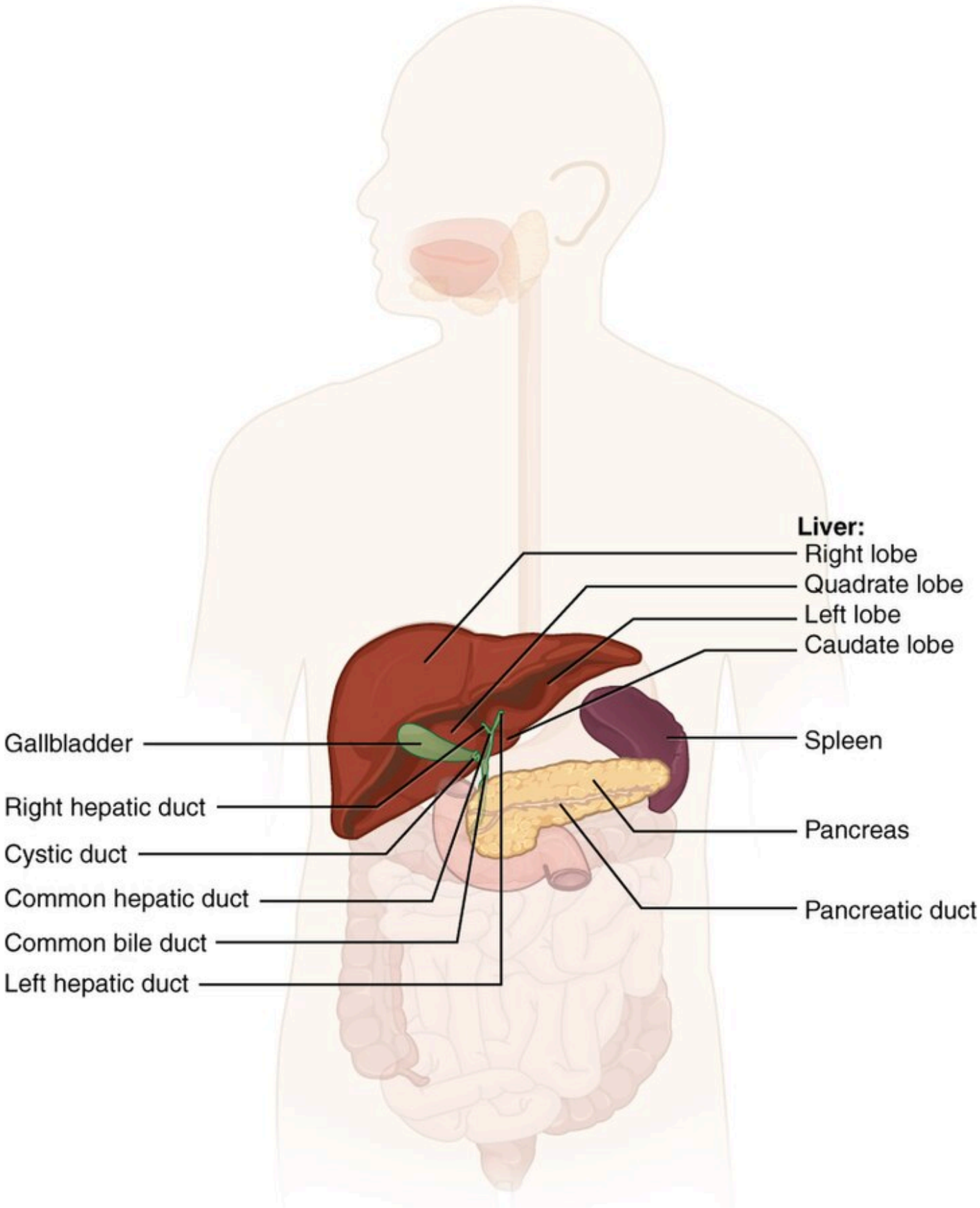


Figure 14.22 Accessory Gastrointestinal Organs

The **hepatic portal vein** delivers partially deoxygenated blood containing nutrients absorbed from the small intestine and actually supplies more oxygen to the liver than do the much smaller hepatic arteries. In addition to nutrients, drugs and toxins are also absorbed. After processing the bloodborne nutrients and toxins, the liver releases nutrients needed by other cells back into the blood, which drains into the central vein and then through the hepatic vein to the inferior vena cava. With this hepatic portal circulation, all blood from the GI tract passes through the liver. This largely explains why the liver is the most common site for the metastasis of cancers that originate in the alimentary canal.

The liver has three main components: hepatocytes, bile canaliculi, and hepatic sinusoids. A **hepatocyte** is the liver's main cell type and makes up around 80 percent of the liver's volume. These cells play a role in a wide variety of secretory, metabolic, and endocrine functions.

These hepatocytes are arranged into hexagonal units called hepatic lobules. Between adjacent hepatocytes, grooves in the cell membranes provide room for each bile canaliculus (plural = canaliculi). These small ducts collect the bile produced by hepatocytes. From here, bile flows first into bile ductules and then into bile ducts. The bile ducts unite to form the larger right and left hepatic ducts, which themselves merge and exit the liver as the common hepatic duct. This duct then joins with the cystic duct from the gallbladder, forming the common bile duct through which bile flows into the duodenum of the small intestine.

A **hepatic sinusoid** is an open, porous blood space formed by fenestrated capillaries from nutrient-rich hepatic portal veins and oxygen-rich hepatic arteries. Hepatocytes are tightly packed around the fenestrated endothelium of these spaces, giving them easy access to the blood. From their central position, hepatocytes process the nutrients, toxins, and waste materials carried by the blood. Materials such as bilirubin are processed and excreted into the bile canaliculi. Other materials, including proteins, lipids, and carbohydrates, are processed and secreted into the sinusoids or just stored in the cells until called upon. The hepatic sinusoids combine and send blood to a central vein. Blood then flows through a hepatic vein to the inferior vena cava. This means that blood and bile flow in opposite directions. The hepatic sinusoids also contain star-shaped reticuloendothelial cells (Kupffer cells), phagocytes that remove dead red and white blood cells, bacteria, and other foreign material that enter the sinusoids. The portal triad is a distinctive arrangement around the perimeter of hepatic lobules, consisting

of three basic structures: a bile duct, a hepatic artery branch, and a hepatic portal vein branch. See Figure 14.23[24] for an illustration of the microscopic anatomy of the liver.

24. OpenStax. (2013). *2423_Microscopic anatomy of liver* [Diagram]. Wikimedia Commons. Public Domain. http://commons.wikimedia.org/wiki/File:2423_Microscopic_Anatomy_of_Liver.jpg

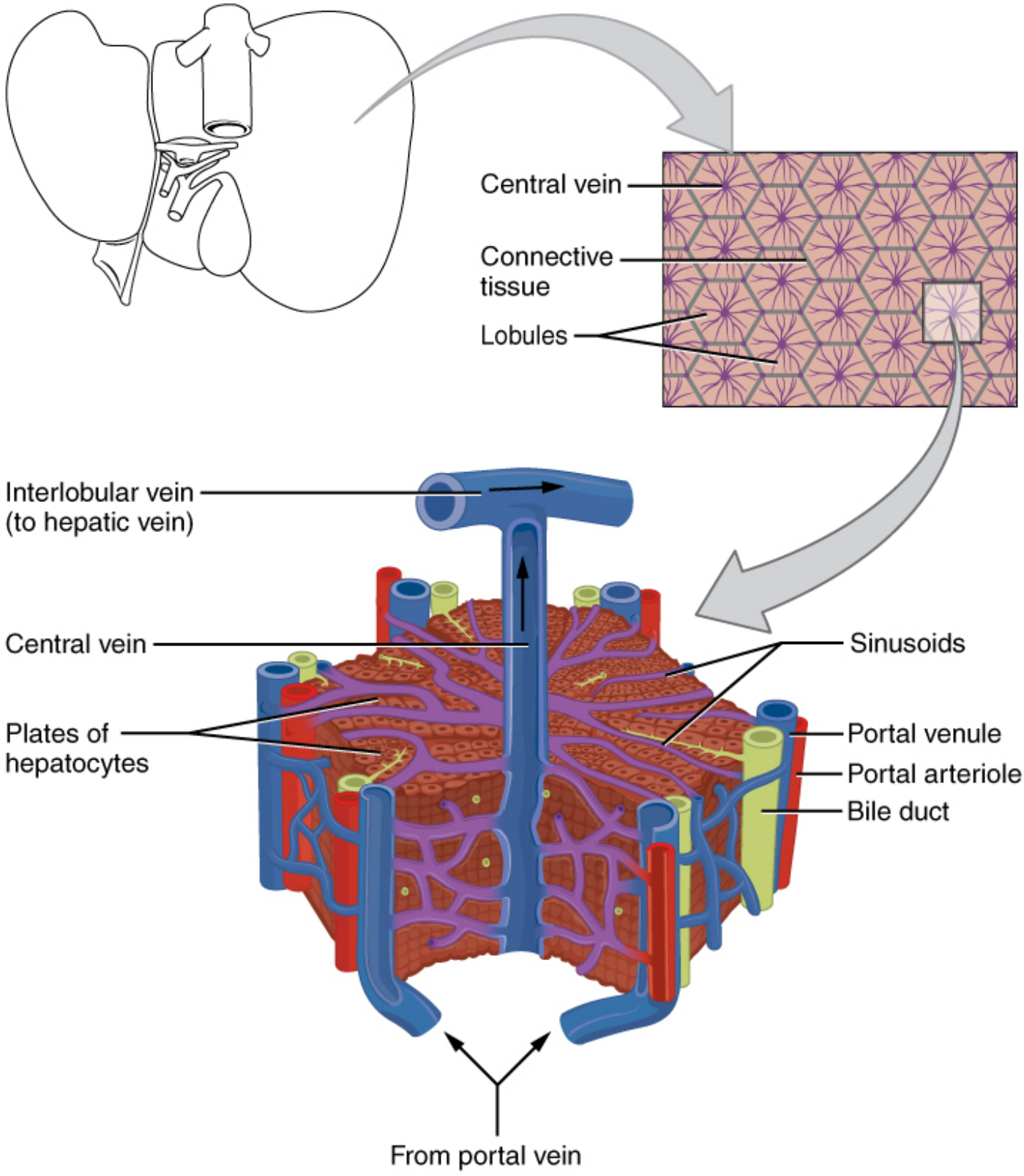


Figure 14.23 Microscopic Anatomy of the Liver

Bile

Recall that lipids are hydrophobic, that is, they do not dissolve in water. Thus, before they can be digested in the watery environment of the small intestine, large lipid globules must be broken down into smaller lipid globules, a process called **emulsification**. **Bile** is a mixture secreted by the liver to accomplish the emulsification of lipids in the small intestine.

Hepatocytes secrete about one liter of bile each day. A yellow-brown or yellow-green alkaline solution (pH 7.6 to 8.6), bile is a mixture of water, bile salts, bile pigments, phospholipids (such as lecithin), electrolytes, cholesterol, and triglycerides.

Bile salts act as emulsifying agents, so they are also important for the absorption of digested lipids. While most constituents of bile are eliminated in feces, bile salts are reclaimed and returned to the liver in the hepatic portal blood. The hepatocytes then excrete the bile salts into newly formed bile.

Bilirubin, the main bile pigment, is a waste product produced when the spleen removes old or damaged red blood cells from the circulation. These breakdown products, including proteins, iron, and toxic bilirubin, are transported to the liver, where proteins and iron are recycled, but bilirubin is excreted in the bile, accounting for the green color of bile. Bilirubin is eventually transformed by intestinal bacteria into stercobilin, a brown pigment that gives your stool its characteristic color.

Hepatocytes work continuously, but bile production increases when fatty chyme enters the duodenum. Between meals, bile is produced but conserved. The valve-like hepatopancreatic ampulla closes, allowing bile to divert to the gallbladder, where it is concentrated and stored until the next meal.

Gallbladder

The **gallbladder** is 3–4 inches long and is nested in a shallow area on the posterior aspect of the right lobe of the liver. This muscular sac stores, concentrates, and, when stimulated, releases the bile into the duodenum via the cystic and common bile ducts. The gallbladder is divided into three regions. The fundus is the widest portion and tapers medially into the body, which, in turn, narrows to become the neck. The cystic duct is 1–2 cm (less than 1 inch) long and connects the neck and the common hepatic duct. When the smooth muscle of the gallbladder contracts, the contents are ejected through the

cystic duct and into the common bile duct. See Figure 14.24[25] for an illustration of the gallbladder.

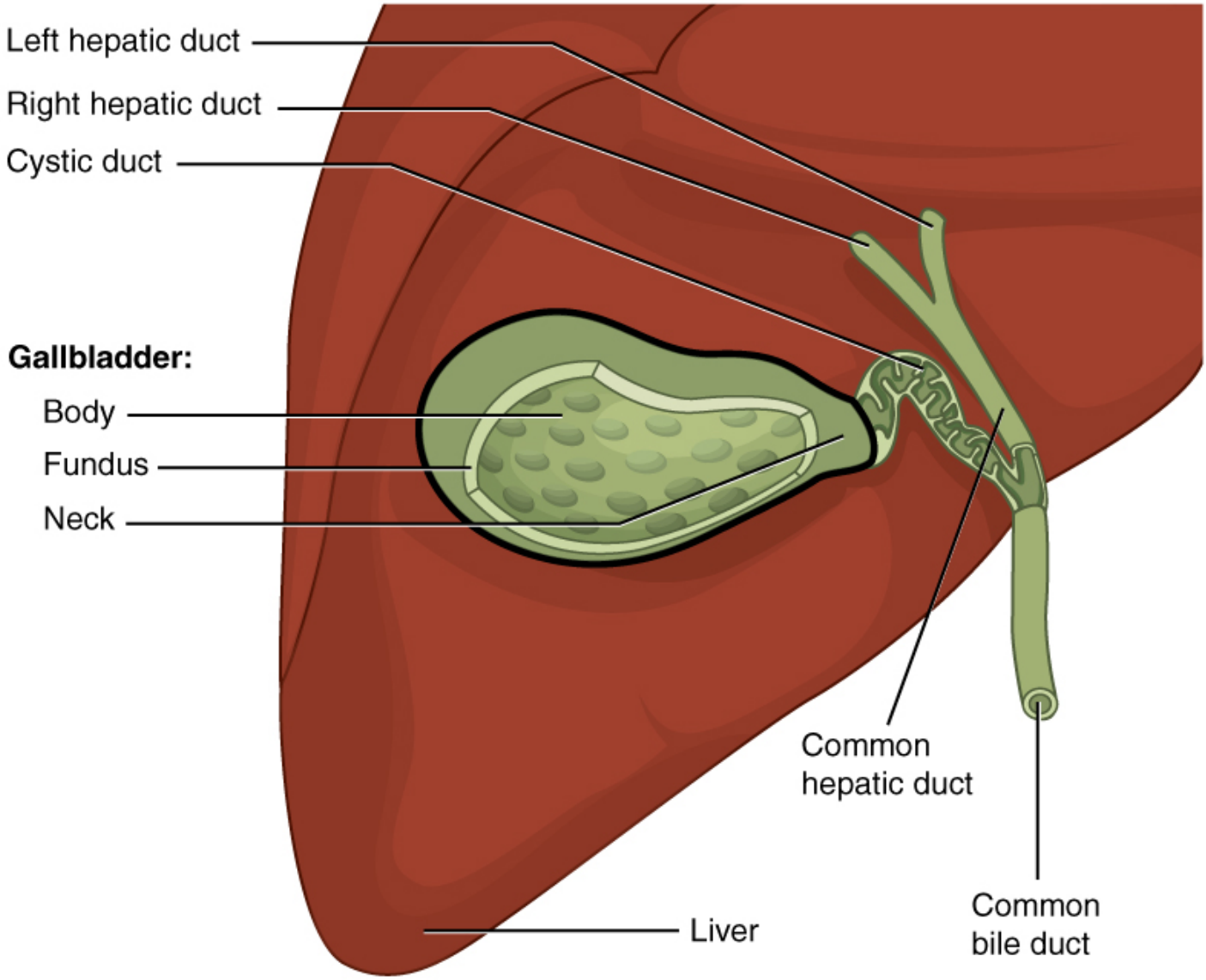


Figure 14.24 Gallbladder

Video

*]:pointer-events-auto [content-visibility:auto] supports-[content-

25. OpenStax. (2013). *2425_Gallbladder* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2425_Gallbladder.jpg

visibility:auto]:[contain-intrinsic-size:auto_100lvh] R6Vx5W_threadScrollVars scroll-mb-[calc(var(--scroll-root-safe-area-inset-bottom,0px)+var(--thread-response-height))] scroll-mt-[calc(var(--header-height)+min(200px,max(70px,20svh)))]" dir="auto" data-turn-id="request-69f3891f-cad4-8328-be35-d4d3dbd28b71-78" data-testid="conversation-turn-148" data-scroll-anchor="false" data-turn="assistant">
Watch the video “Digestive System” below to learn how the digestive system breaks down food, absorbs nutrients, and eliminates waste from the body.[26]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.



26. Amoeba Sisters. (2021, January 31). *Digestive system* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=1UvuBYUbFk0

14.4 Metabolism and Nutrition

A balanced diet rich in fruits and vegetables is essential for good health. A range of nutrients is necessary for cells to carry out their daily jobs to build, repair, and maintain the body. Diet, including what and how much is consumed, can have a dramatic impact on health. Unhealthy diet choices can increase risk for cardiovascular disease, cancer, anorexia, diabetes, and other chronic diseases.

Metabolism is the sum of all the chemical reactions that occur in the body. Metabolism across individuals varies, depending on genetics, age, sex, activity level, nutrient consumption, and lean body mass. Metabolic rate also fluctuates throughout life and can be modified by diet and exercise regimens. Aging decreases the metabolic rate by as much as 5 percent per year. Additionally, because males tend to have more lean muscle mass than females, their basal metabolic rate (metabolic rate at rest) is higher, so males tend to burn more calories than females do.

Despite factors affecting metabolism, all humans have the same overall metabolic processes. Metabolism can be categorized based on reactions that break down or build up. **Catabolism** (also referred to as a catabolic reaction) is the breakdown of large molecules into smaller ones. In digestion, food is broken down to obtain energy. Anabolic reactions, or **anabolism**, use the energy produced by catabolic reactions to build larger molecules from smaller ones, such as when the body forms proteins by stringing together amino acids. Both sets of reactions are critical to maintaining life.[1]

Nutrients

A **nutrient** is a substance in foods and beverages that is essential for energy, growth, and the maintenance and repair of tissues. The three basic nutrient classes are water, macronutrients (carbohydrates, lipids, and proteins), and micronutrients (vitamins and minerals). Water and **macronutrients** are needed in large amounts.[2]

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Water

The most critical nutrient is water. Depending on the environmental temperature and one's state of health, humans can survive for only a few days without water. The body's chemicals are dissolved and transported in water, and the chemical reactions of life take place in water. Water is the largest component of cells, blood, and the fluid between cells, making up about 70 percent of an adult's body mass. Water also helps regulate our internal temperature and cushions, protects, and lubricates joints and many other body structures.

Energy Yielding and Body Building Nutrients

The energy-yielding nutrients are primarily carbohydrates and lipids, while proteins mainly supply the amino acids that are the building blocks of the body itself. These nutrients are ingested in foods and beverages made from animal and plant sources, and the digestive system breaks them down into molecules small enough to be absorbed. The breakdown products of carbohydrates and lipids can then be used in the metabolic processes that convert them to ATP. See the "**Organic and Inorganic Compounds**" section of Chapter 2 for a review of the chemical structure of nutrients and the action of ATP.

Vitamins and Minerals

Micronutrients are nutrients that are needed by the body in small amounts and include vitamins and minerals. While they are needed in smaller amounts than macronutrients, they are absolutely essential for homeostasis. These elements and compounds participate in many essential chemical reactions and processes, such as nerve impulses. Some also contribute to the body's structure, such as calcium. The body can store some micronutrients in tissues and draw on those reserves if they are not obtained in the diet for a few days or weeks. Other micronutrients, such as vitamin C and most of the B vitamins, are water-soluble and cannot be stored, so these nutrients must be consumed in the diet every day or two.

Vitamins

Vitamins are organic compounds found in foods and are a necessary part of the

biochemical reactions in the body. They are involved in a number of processes, including mineral and bone metabolism, cell and tissue growth, and energy metabolism. The B vitamins play the largest role of any vitamins in metabolism. Most vitamins are consumed through food, although some can be formed from substances absorbed during digestion. For example, the body makes vitamin A from the β-carotene in orange vegetables such as carrots and sweet potatoes.

Vitamins are either fat-soluble or water-soluble. **Fat-soluble vitamins** (vitamins A, D, E, and K) are absorbed into the lymphatic system through the intestinal tract. Vitamin D is also made in the skin through exposure to sunlight. Because they are carried in lipids, fat-soluble vitamins can accumulate in the lipids stored in the body. If excess vitamins accumulate in the body, hypervitaminosis can result.

Water-soluble vitamins (including vitamin C and the eight B vitamins) are absorbed with water in the gastrointestinal tract. These vitamins move easily through bodily fluids that are water-based, so they are not stored in the body. Excess water-soluble vitamins are excreted in the urine. Therefore, hypervitaminosis of water-soluble vitamins rarely occurs, except if an excess of vitamin supplements is consumed.

See Table 14.4a for a summary of fat-soluble vitamins and Table 14.4b for a summary of water-soluble vitamins.

Table 14.4a. Fat-Soluble Vitamins[3]

3. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/

Vitamin	Sources	Recommended Daily Allowance	Function	Problems Associated With Deficiency
A (retinol or β-carotene)	Yellow and orange fruits and vegetables, dark green leafy vegetables, eggs, milk, liver	700–900 µg	Eye and bone development and immune function	Night blindness, skin issues, and an immune system deficiency
D (cholecalciferol)	Dairy products and egg yolks; also synthesized in the skin from exposure to sunlight	5–15 µg	Aids in calcium absorption, promoting bone growth	Rickets, bone pain, muscle weakness, increased risk of death from cardiovascular disease, cognitive impairment, asthma in children, and cancer
E (tocopherols)	Seeds, nuts, vegetable oils, avocados, and wheat germ	15 mg	Antioxidant	Anemia
K (phytonadione)	Dark green leafy vegetables, broccoli, Brussels sprouts, and cabbage	90–120 µg	Blood clotting, bone health	Hemorrhagic disease of newborn in infants; uncommon in adults

Table 14.4b. Water-Soluble Vitamins[4]

4. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/

Vitamin	Sources	Recommended Daily Allowance	Function	Problems Associated With Deficiency
B1 (thiamine)	Whole grains, enriched bread and cereals, milk, and meat	1.1–1.2 mg	Carbohydrate metabolism	Beriberi and Wernicke-Korsakoff syndrome
B2 (riboflavin)	Brewer's yeast, almonds, milk, organ meats, legumes, enriched breads and cereals, broccoli, and asparagus	1.1–1.3 mg	Cellular metabolism and production of red blood cells	Fatigue, slowed growth, digestive problems, light sensitivity, and epithelial problems like cracks in the corners of the mouth
B3 (niacin)	Meat, fish, poultry, enriched breads and cereals, peanuts	14–16 mg	Cellular metabolism, nerve function, and cholesterol production	Cracked, scaly skin and dementia; diarrhea; also known as pellagra
B5 (pantothenic acid)	Meat, poultry, potatoes, oats, enriched breads and cereals, and tomatoes	5 mg	Synthesis of coenzyme A in fatty acid metabolism	Rare: symptoms may include fatigue, insomnia, depression, and irritability

B6 (pyridoxine)	Potatoes, bananas, beans, seeds, nuts, meat, poultry, fish, eggs, dark green leafy vegetables, soy, and organ meats	1.3–1.5 mg	Sodium and potassium balance, red blood cell synthesis, and protein metabolism	Confusion, irritability, depression, and mouth and tongue sores
B7 (biotin)	Liver, fruits, and meats	30 µg	Cell growth, metabolism of fatty acids, and production of blood cells	Rare in developed countries; symptoms include dermatitis, hair loss, and loss of muscular coordination
B9 (folic acid)	Liver, legumes, dark green leafy vegetables, enriched breads and cereals, citrus fruits	400 µg	DNA/protein synthesis	Poor growth, gingivitis, appetite loss, shortness of breath, gastrointestinal problems, and mental deficits; deficiency during pregnancy can cause neural tube defects in the embryo
B12 (cyanocobalamin)	Fish, meat, poultry, dairy products, and eggs	2.4 µg	Fatty acid oxidation, nerve cell function, and red blood cell production	Pernicious anemia, leading to nerve cell damage

C (ascorbic acid)	Citrus fruits, red berries, peppers, tomatoes, broccoli, and dark green leafy vegetables	75–90 mg	Necessary to produce collagen for formation of connective tissue and teeth and for wound healing	Dry hair, gingivitis, bleeding gums, dry and scaly skin, slow wound healing, easy bruising, and compromised immunity; can lead to scurvy

Minerals

Minerals are inorganic compounds that work with other nutrients to ensure the body functions properly. Minerals cannot be produced in the body, so they must be consumed through food. The amount of minerals in the body is small, only 4% of the total body mass. Minerals that the body requires in moderate quantities include potassium, sodium, calcium, phosphorus, magnesium, and chloride.

The most common minerals in the body are calcium and phosphorus, both of which are stored in the skeleton and are necessary for the hardening of bones. Most minerals exist in the body as their ionic form (cation or anion), and these ionic forms are used in physiological processes throughout the body. Sodium and chloride ions act as electrolytes in the blood and extracellular tissues, and iron ions are critical to the formation of hemoglobin. There are additional trace minerals that are still important to the body's functions, but their required quantities are much lower.

A healthy diet includes most of the minerals the body requires, so supplements and processed foods can add potentially toxic levels of minerals. Like vitamins, minerals can be consumed in toxic quantities, although it is rare. See 14.4c for a summary of major minerals and Table 14.4d for a summary of trace minerals.

Table 14.4c. Major Minerals[5]

5. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/

Mineral	Sources	Recommended Daily Allowance	Function	Problems Associated With Deficiency
Potassium	Meats, some fish, fruits, vegetables, legumes, and dairy products	4,700 mg	Nerve and muscle function; acts as an electrolyte	Hypokalemia: weakness, fatigue, muscle cramping, gastrointestinal problems, and cardiac problems
Sodium	Table salt, milk, beets, celery, and processed foods	2,300 mg	Blood pressure, blood volume, and muscle and nerve function	Rare
Calcium	Dairy products, dark green leafy vegetables, blackstrap molasses, nuts, brewer's yeast, and some fish	1,000 mg	Bone structure and health; nerve and muscle functions, especially cardiac function	Slow growth and weak and brittle bones
Phosphorous	Meat and milk	700 mg	Bone formation, metabolism, and ATP production	Rare
Magnesium	Whole grains, nuts, and leafy green vegetables	310–420 mg	Enzyme activation, production of energy, and regulation of other nutrients	Agitation, anxiety, sleep problems, nausea and vomiting, abnormal heart rhythms, low blood pressure, and muscular problems

Chloride	Most foods, salt, and vegetables, especially seaweed, tomatoes, lettuce, celery, and olives	2,300 mg	Balance of body fluids and digestion	Loss of appetite and muscle cramps

Table 14.4d. Trace Minerals[6]

6. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/

Mineral	Sources	Recommended Daily Allowance	Function	Problems Associated with Deficiency
Iron	Meat, poultry, fish, shellfish, legumes, nuts, seeds, whole grains, and dark leafy green vegetables	8–18 mg	Transport of oxygen in blood and production of ATP	Anemia, weakness, and fatigue
Zinc	Meat, fish, poultry, cheese, and shellfish	8–11 mg	Immunity, reproduction, growth, blood clotting, and insulin and thyroid function	Loss of appetite, poor growth, weight loss, skin problems, hair loss, vision problems, and lack of taste or smell
Copper	Seafood, organ meats, nuts, legumes, chocolate, enriched breads and cereals, and some fruits and vegetables	900 µg	Red blood cell production, nerve and immune system function, and collagen formation; acts as an antioxidant	Anemia, low body temperature, bone fractures, low white blood cell concentration, irregular heartbeat, and thyroid problems
Iodine	Fish, shellfish, garlic, lima beans, sesame seeds, soybeans, and dark leafy green vegetables	150 µg	Thyroid function	Hypothyroidism: fatigue, weight gain, dry skin, and temperature sensitivity
Sulfur	Eggs, meat, poultry, fish, and legumes	None	Component of some amino acids	Protein deficiency

Fluoride	Fluoridated water	3–4 mg	Maintenance of bone and tooth structure	Increased cavities and weak bones and teeth
Manganese	Nuts, seeds, whole grains, and legumes	1.8–2.3 mg	Formation of connective tissue and bones, blood clotting, sex hormone development, metabolism, and brain and nerve function	Infertility, bone malformation, weakness, and seizures
Cobalt	Fish, nuts, leafy green vegetables, and whole grains	None	Component of B12	None
Selenium	Brewer’s yeast, wheat germ, liver, butter, fish, shellfish, and whole grains	55 µg	Antioxidant, thyroid function, and immune system function	Muscle pain
Chromium	Whole grains, lean meats, cheese, black pepper, thyme, and brewer’s yeast	25–35 µg	Insulin function	High blood sugar, triglyceride, and cholesterol levels
Molybdenum	Legumes, whole grains, and nuts	45 µg	Cofactor for enzymes	Rare

14.5 Digestive System Disorders

Appendicitis

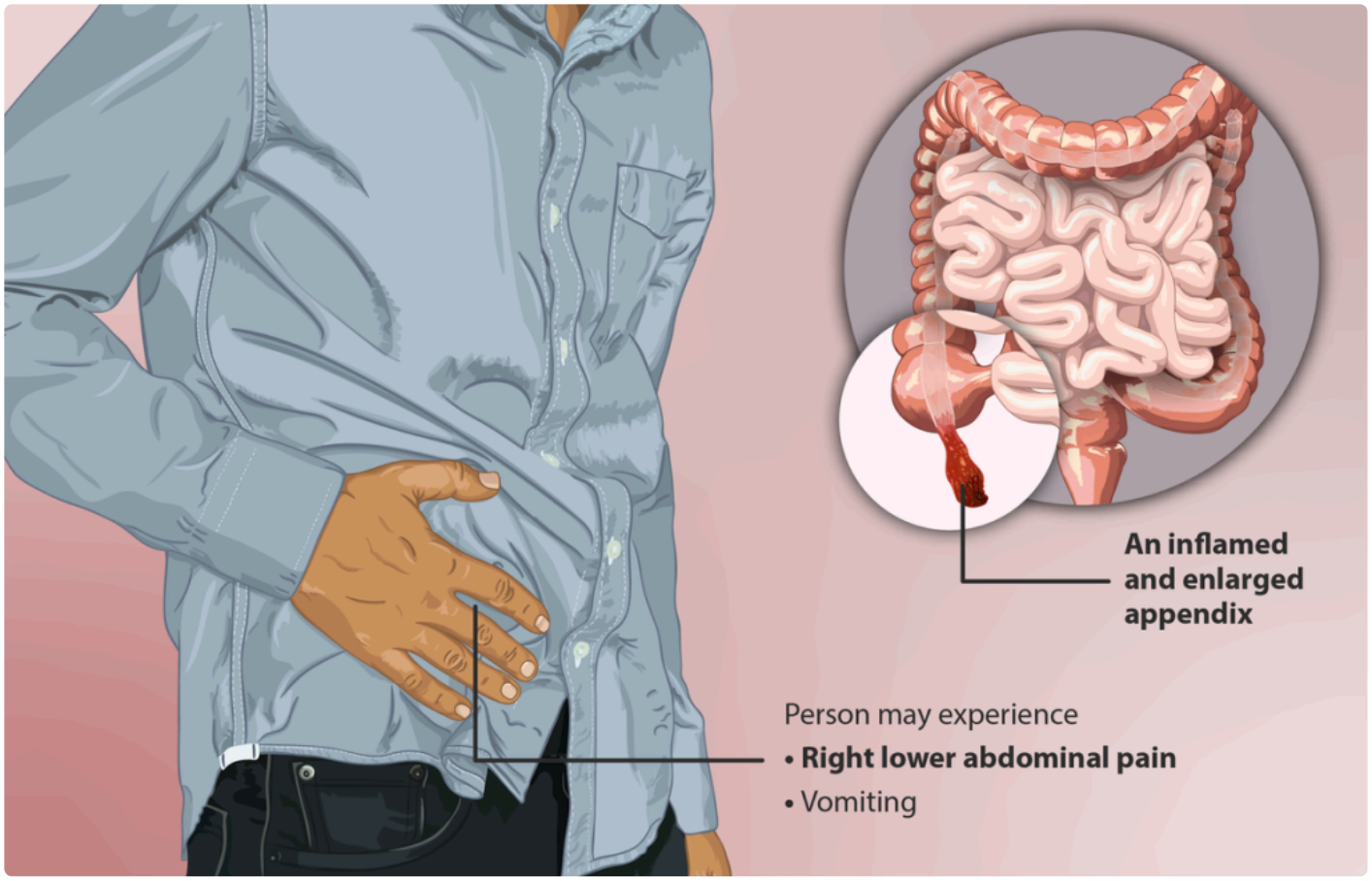
Appendicitis is a condition in which the appendix becomes inflamed and is a common reason for emergency surgery. Appendicitis occurs when the appendix becomes blocked by feces, a foreign object, a tumor, or, in rare cases, a parasite.

The symptoms of appendicitis can vary. It can be difficult to detect appendicitis in young children, older people, and women of childbearing age. The first symptom is often pain around the navel or mid-upper abdomen. Pain may be minor at first, but becomes more sharp, severe, and localized to the right lower quadrant. The pain focuses on a spot directly above the appendix, called McBurney's point. This most often occurs 12 to 24 hours after the illness starts. Pain may be worse when walking, coughing, or making sudden movements. There may also be a loss of appetite, nausea, vomiting, and a low-grade fever.

Typically, the appendix is surgically removed as soon as appendicitis is diagnosed. If a CT scan shows an abscess, treatment with antibiotics may occur first, and the appendix will be removed after the infection and swelling have gone away.[1]

See Figure 14.24[2] for an illustration of appendicitis.

1. Phillips, M. M. (2023). *Appendicitis.* MedlinePlus [Internet]. https://medlineplus.gov/ency/article/000256.htm
2. Myupchar. (2019). *Depiction of a person suffering from appendicitis* [Illustration]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Depiction_of_a_person_suffering_from_Appendicitis.png



14.24 Appendicitis

Celiac Disease

Celiac disease is an inherited autoimmune disorder that causes the immune system to produce antibodies against the gluten protein. These antibodies damage the mucosal lining of the small intestine, impairing its ability to absorb nutrients from food, resulting in nutritional deficiencies and weight loss. Other common symptoms are diarrhea, abdominal distension or bloating, and nausea and vomiting after consuming food that contains gluten.

Celiac disease is most commonly found in people of Northern European descent and affects 1% of the European and North American population. There is a 10% chance of developing the disease if it is present in a first-degree relative, such as a parent. About 97% of people diagnosed with celiac disease have a gene variant associated with it.

Celiac disease is also more prevalent in people with certain inherited chromosomal disorders, such as Down syndrome. It's also more frequently seen in people with other autoimmune diseases because these diseases often share similar genes and trigger

each other. Like other autoimmune diseases, celiac disease is more common in females than males, with the ratio of affected females to males being at least 2:1.

Gluten is a protein found in grains—particularly wheat, barley, and rye. These grains, especially wheat, make up many of the staple foods of the standard Western diet and are found in breads, cereals, pasta, baked goods, and even beer. Gluten is also a common additive in sauces, soups, and packaged foods. The primary treatment for individuals with celiac disease is adhering to a gluten-free diet.[34]

Cirrhosis

Cirrhosis is advanced scarring of the liver commonly caused by hepatitis or alcoholism. Each time the liver is injured — whether by alcohol or infection — it tries to repair itself. In the process, scar tissue forms. As cirrhosis worsens, more scar tissue forms, which decreases the liver's ability to function. Advanced cirrhosis is life-threatening. See Figure 14.25[5] for an image of a liver damaged by cirrhosis.

3. Cleveland Clinic. (2022). *Celiac disease.* https://my.clevelandclinic.org/health/diseases/14240-celiac-disease

4. Daley, S. F., & Haseeb, M. (2025). *Celiac disease*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK441900/

5. Myupchar. (2019). *Depiction of a cirrhosis patient* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Depiction_of_a_Cirrhosis_patient.png

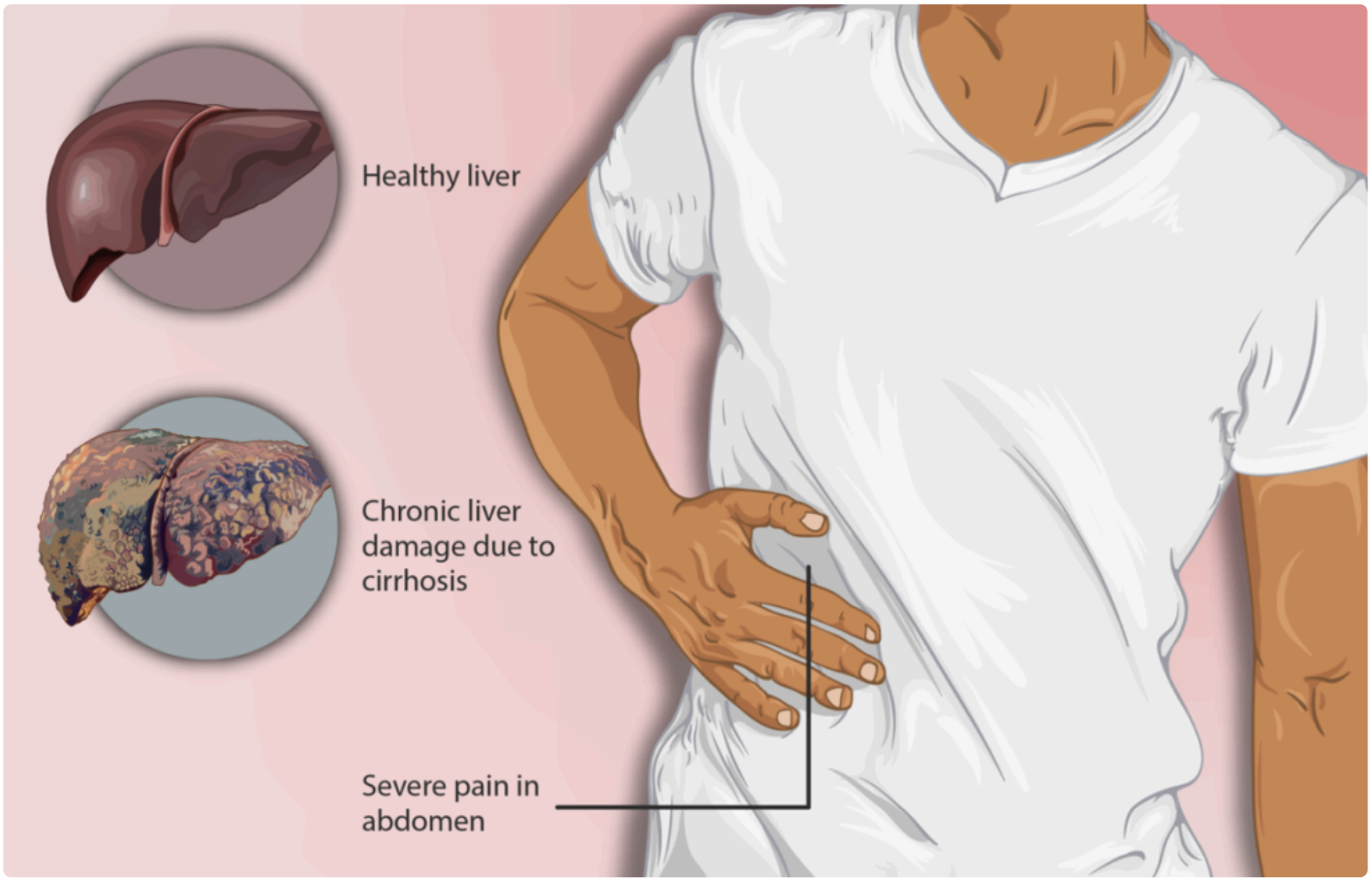


Figure 14.25 Comparison of a Normal Versus a Cirrhotic Liver

Individuals with cirrhosis may or may not have symptoms depending on the severity of the condition. Common symptoms are an enlarged liver, jaundice (yellowing of the skin and eyes), ascites (accumulation of fluid in the abdominal cavity), and bleeding varices (enlarged veins caused by increased pressure in the portal vein of the liver).

The liver damage caused by cirrhosis generally can't be reversed, but if cirrhosis is diagnosed early and the underlying cause is treated, further damage can be prevented. In some cases, liver transplantation may be a treatment option.[6,7,8]

6. Mayo Clinic. (2025). *Cirrhosis.* https://www.mayoclinic.org/diseases-conditions/cirrhosis/symptoms-causes/syc-20351487

7. American Cancer Society. (2024). *American Cancer Society guideline for colorectal cancer screening*. https://www.cancer.org/cancer/types/colon-rectal-cancer/detection-diagnosis-staging/acs-recommendations.html

8. Sharma, B., & John, S. (2022). *Hepatic cirrhosis*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK482419/

Cholelithiasis

The medical condition of having gallstones is **cholelithiasis**. A gallstone is a piece of hardened bile residue that can form for a variety of reasons, including elevated cholesterol levels. Gallstones are often asymptomatic, but when a gallstone gets stuck in a bile duct, it can cause bile to back up into the gallbladder, causing sudden, severe upper right abdominal pain, back pain, nausea, vomiting, and fever. To remove gallstones, a surgical procedure called an endoscopic retrograde cholangiopancreatography (ERCP) may be performed.[9]

See Figure 14.26[10] for an image of a gallstone in the gallbladder on an ultrasound.



Figure 14.26 Gallstone

9. Mayo Clinic. (2025). *Gallstones.* https://www.mayoclinic.org/diseases-conditions/gallstones/symptoms-causes/syc-20354214
10. Heilman, J. (2017). *Gallstone in neck of gallbladder on CT* [Image]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Gallstone_in_neck_of_Gallbladder_on_CT.jpg

Colorectal Cancer

Each year, approximately 140,000 Americans are diagnosed with colorectal cancer, and another 49,000 die from it, making it one of the deadliest cancers. A family history of colorectal cancer, smoking, excessive alcohol consumption, and a diet high in animal fat and protein increase the risk for colorectal cancer. Screening for colorectal cancer is recommended at 45 years of age for people who have an average risk of developing colorectal cancer. For those considered high risk for colorectal cancer, screenings may start younger. Screening is performed using stool tests and colonoscopy.

Colorectal cancer may be asymptomatic in its early stages or include symptoms such as rectal bleeding or unusual constipation, diarrhea, or abdominal pain. Rectal bleeding may be obvious or occult (hidden in feces). Most colon cancers arise from benign mucosal growths called polyps, so cancer prevention is focused on identifying these polyps early via colonoscopy. A colonoscopy not only allows identification of precancerous polyps but also enables them to be removed before they become malignant.[11,12]

See Figure 14.27[13] for an image depicting colorectal cancer detected via colonoscopy.

11. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e*. Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/

12. American Cancer Society. (2024). *American Cancer Society guideline for colorectal cancer screening*. https://www.cancer.org/cancer/types/colon-rectal-cancer/detection-diagnosis-staging/acs-recommendations.html

13. Endoscopy1. (2025). *Colorectal_cancer_endo_2* [Image] . Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Colorectal_cancer_endo_2.jpg

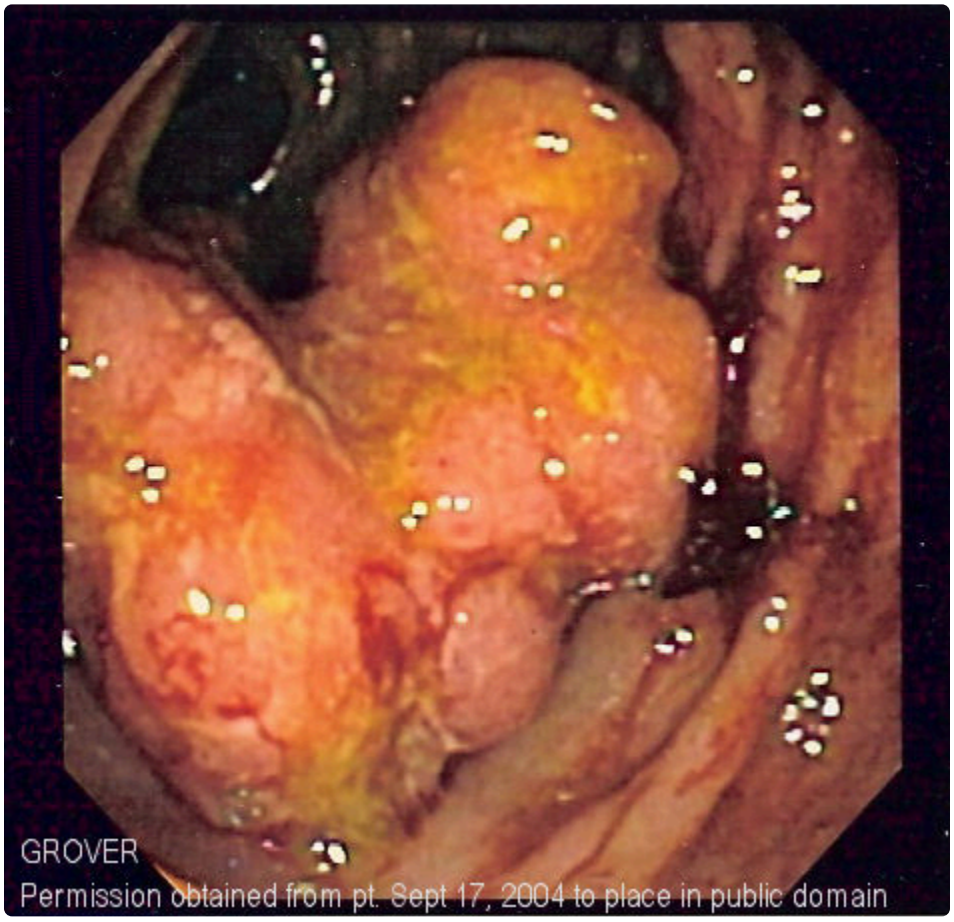


Figure 14.27 Colorectal Cancer Discovered During Endoscopy

Crohn's Disease

Crohn's disease is a type of inflammatory bowel disease (IBD) that causes swelling and irritation of the tissues in the digestive tract. This inflammation can lead to abdominal pain, severe diarrhea, fatigue, weight loss, and malnutrition. Inflammation caused by Crohn's disease can affect different areas of the digestive tract in different people. Although Crohn's can affect any part of the digestive tract, it most commonly affects the end of the small intestine and the beginning of the large intestine. The inflammation often spreads into the deeper layers of the bowel. In some cases, the inflammation of Crohn's disease can also be systemic and lead to inflammation of the eyes, kidneys, liver, skin, and joints. Crohn's disease can be both painful and debilitating. Sometimes, it may lead to serious or life-threatening complications.

There's no known cure for Crohn's disease, but medical treatment can greatly reduce

its symptoms and bring about long-term remission of symptoms and healing of inflammation.[14,15]

Diarrhea

Diarrhea is a common problem with frequent passage of loose or watery stool. It may be associated with other symptoms, such as nausea, vomiting, abdominal pain, or weight loss.

A number of diseases and conditions can cause diarrhea, including the following:[16]

- Viruses: Viruses that can cause diarrhea include Norwalk virus, also known as Norovirus, enteric adenoviruses, astrovirus, cytomegalovirus, and viruses that cause hepatitis. Rotavirus is a common cause of sudden childhood diarrhea. The virus that causes coronavirus disease (COVID-19) has also been linked to gastrointestinal symptoms, including nausea, vomiting, and diarrhea.
- Bacteria and parasites: Exposure to certain bacteria, such as *Escherichia coli*, or parasites through contaminated food or water can lead to diarrhea. When traveling in developing countries, diarrhea caused by bacteria or parasites is often called traveler's diarrhea. *Clostridium difficile*, also known as C. diff, is another bacterium that causes diarrhea, and it can occur after a course of antibiotics or during a hospital stay.
- Medications: Many medications, such as antibiotics, can cause diarrhea. Antibiotics get rid of infections by killing bacteria that cause illness, but they also kill good bacteria that are helpful in the body. This disturbs the natural balance of bacteria in the intestines, leading to diarrhea or an infection such as C. diff. Other medicines that cause diarrhea are anticancer drugs and antacids with magnesium.
- Lactose intolerance: Lactose is a sugar found in milk and other dairy products. People who have trouble digesting lactose often have diarrhea after eating dairy products. Lactose intolerance can increase with age because levels of the enzyme that helps digest lactose become lower as people get older.

14. Mayo Clinic. (2024). *Crohn's disease*. https://www.mayoclinic.org/diseases-conditions/crohns-disease/symptoms-causes/syc-20353304
15. Ranasinghe, I. R., Tian, C., & Hsu, R. (2024). *Crohn disease*. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK436021/
16. Mayo Clinic. (n.d.). Diarrhea. https://www.mayoclinic.org/diseases-conditions/diarrhea/symptoms-causes/syc-20352241?p=1

- Fructose: Fructose is a sugar found naturally in fruits and honey. It's sometimes added as a sweetener to certain beverages. Fructose can lead to diarrhea in people who have trouble digesting it.
- Artificial sweeteners: Sorbitol, erythritol, and mannitol—non-absorbable sugars used as artificial sweeteners in chewing gum and other sugar-free products—can cause diarrhea in some otherwise healthy people.
- Surgery: Partial intestine or gallbladder removal surgeries can sometimes cause diarrhea.
- Other digestive disorders: Chronic diarrhea has a number of other causes, such as IBS, Crohn's disease, ulcerative colitis, celiac disease, microscopic colitis, and small intestinal bacterial overgrowth (SIBO).

Diverticulosis and Diverticulitis

Diverticulosis is a condition that occurs when small pouches, or sacs, form and push outward through weak spots in the wall of the colon. These pouches form mostly in the lower part of the colon, called the sigmoid colon. One pouch is called a diverticulum. Multiple pouches are called diverticula. Most people who have diverticula in their colon do not have symptoms or problems. Diverticulosis is quite common, especially as people age. More than 30% of U.S. adults between the ages of 50 and 59 and more than 70% of those older than age 80 have diverticulosis. Most people with diverticulosis will never develop symptoms or problems.

Diverticulitis occurs when diverticula become inflamed. Diverticulitis can come on suddenly and may lead to serious complications. Less than 5% of people with diverticulosis develop diverticulitis.

Most people first notice symptoms when they develop complications, such as diverticular bleeding or diverticulitis. Some people have chronic symptoms related to diverticula, even when diverticulitis is not present. Chronic symptoms may include bloating, constipation or diarrhea, and cramping or pain in the lower abdomen.

Diverticulitis may cause acute symptoms such as abdominal pain, most often in the lower left side of the abdomen, constipation or diarrhea, fevers and chills, and nausea or vomiting. The pain caused by diverticulitis is typically severe and comes on suddenly, although the pain may also be mild and worsen over several days. The intensity of the pain may change over time.

Treatments are based on whether an individual has chronic symptoms of diverticula, diverticulitis, or other complications of diverticular disease.[17,18,19]

Gastroenteritis

Gastroenteritis is an inflammation of the lining of the stomach and intestines. The main symptoms include vomiting and diarrhea. It is usually not serious in healthy people, but it can sometimes lead to dehydration or cause severe symptoms. There can be many different causes of gastroenteritis, including viruses, bacteria, parasites, chemicals, and reactions to certain medications and food

Viral gastroenteritis is the most common type. It can be caused by many different viruses, including noroviruses and rotaviruses. Some people call viral gastroenteritis the "stomach flu." But this name is not medically correct. It is not caused by flu viruses. The flu is a respiratory infection that affects your nose, throat, and lungs. When gastroenteritis is caused by consuming foods or drinks contaminated with viruses, bacteria, parasites, or chemicals, this is called food poisoning.

The viruses, bacteria, and parasites that cause gastroenteritis can also spread from person to person or be picked up when touching something that has the germs on it and then touching the eyes, mouth, or nose.

The symptoms of gastroenteritis include diarrhea, pain or cramping in the abdomen, nausea, vomiting, and sometimes fever. Usually, people with gastroenteritis get better on their own, with rest and plenty of fluids and electrolytes.[20]

Gastroesophageal Reflux Disease (GERD)

Gastroesophageal reflux disease (GERD) is a condition in which stomach acid

17. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e.* Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/
18. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
19. National Institute of Diabetes and Digestive and Kidney Diseases. (2021). *Definition & facts for diverticular disease*. https://www.niddk.nih.gov/health-information/digestive-diseases/diverticulosis-diverticulitis/definition-facts
20. MedlinePlus [Internet]. (n.d.). *Gastroenteritis*. https://medlineplus.gov/gastroenteritis.html

repeatedly flows back up into the esophagus due to an incompetent lower esophageal sphincter, as shown in Figure 14.28.[21] This backflow is known as acid reflux, and it can irritate the lining of the esophagus.

21. BruceBlaus. (2015). *GERD* [Diagram]. Wikimedia Images. CC BY 4.0. https://en.m.wikipedia.org/wiki/File:GERD.png

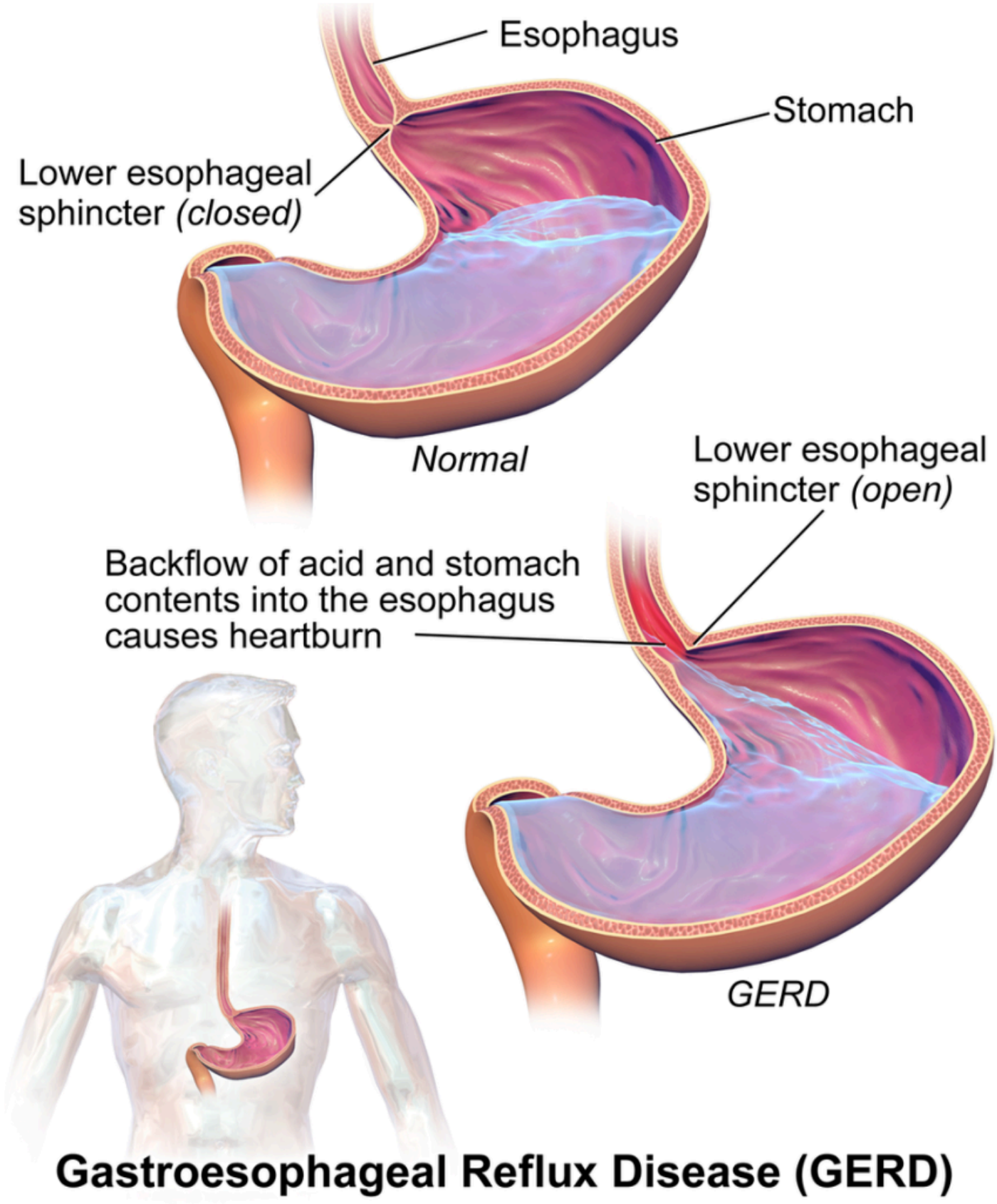


Figure 14.28 Backflow of Stomach Contents in GERD

Common symptoms of GERD include a burning sensation in the chest, often called heartburn, backflow of food or sour liquid in the throat, upper abdominal or chest pain, trouble swallowing (dysphagia), and a sensation of a lump in the throat. Heartburn usually happens after eating and might be worse at night or while lying down. Nighttime acid reflux might also cause an ongoing cough, inflammation of the vocal cords (laryngitis), and new or worsening asthma.

Conditions that can increase the risk of GERD include obesity, bulging of the top of the stomach above the diaphragm (hiatal hernia), pregnancy, connective tissue disorders, such as scleroderma, and delayed stomach emptying. Factors that can aggravate acid reflux include smoking, eating large meals or eating late at night, eating fatty or fried foods, drinking alcohol or coffee, and taking certain medicines such as aspirin. Most people can manage the discomfort of GERD with lifestyle changes and medications, although some may require surgery on the lower esophageal sphincter.[22]

Hemorrhoids

Hemorrhoids, also called piles, are swollen veins in the anus and lower rectum. Hemorrhoids can develop inside the rectum, called internal hemorrhoids. Hemorrhoids can also develop under the skin around the anus, called external hemorrhoids. See Figure 14.29[23] for a depiction of internal versus external hemorrhoids.

22. Mayo Clinic. (2024). *Gastroesophageal reflux disease.* https://www.mayoclinic.org/diseases-conditions/gerd/symptoms-causes/syc-20361940

23. BruceBlaus. (2017). *Hemorrhoids* [Diagram]. Wikimedia Images. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Hemorrhoids.png

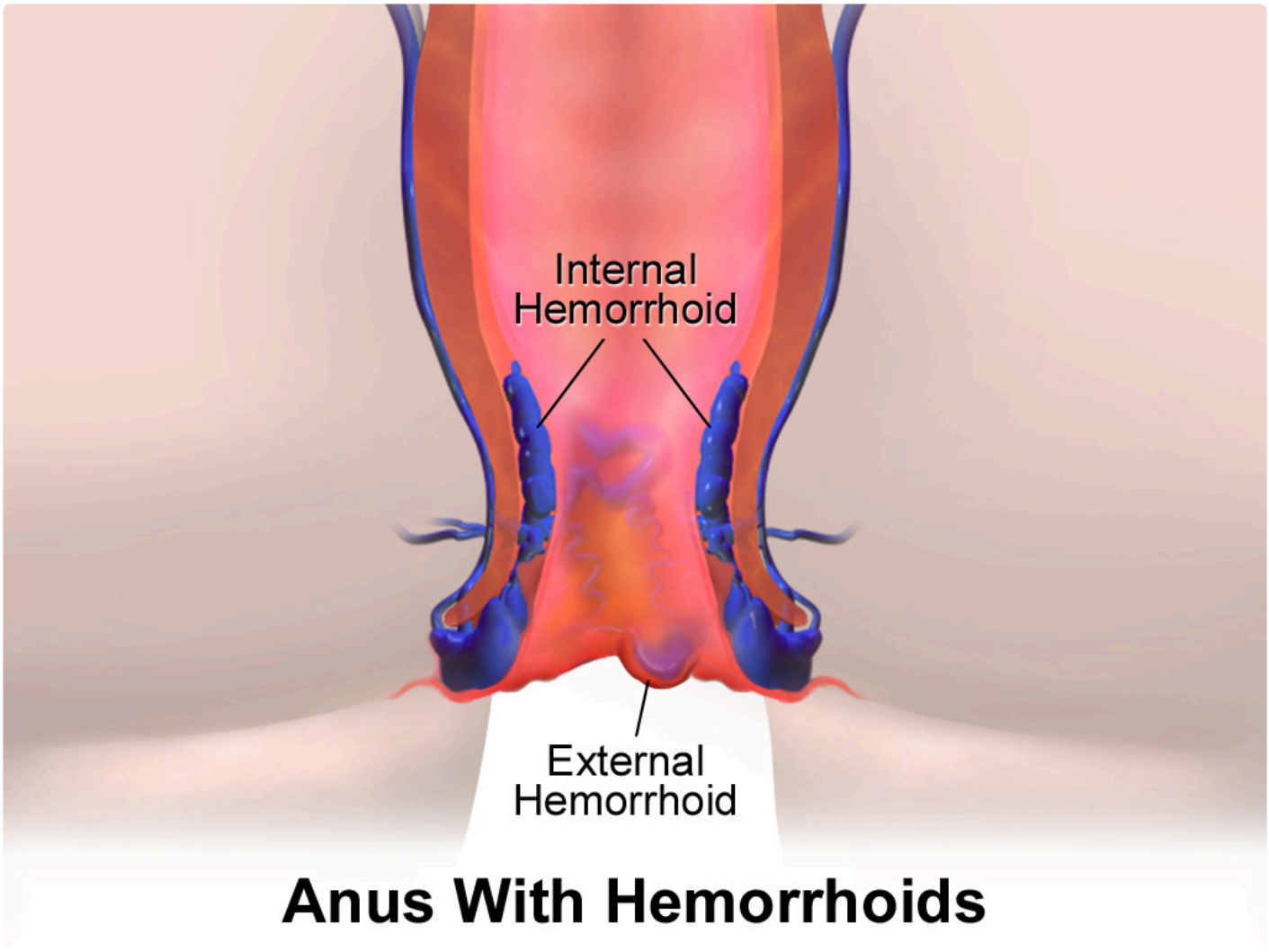


Figure 14.29 Internal and External Hemorrhoids

Symptoms of hemorrhoids may include itching or irritation in the anal region, pain or discomfort, swelling around the anus, and bleeding. If bleeding occurs, it can pool in an external hemorrhoid and form a clot, called a thrombosed hemorrhoid. Thrombosed hemorrhoids can result in severe pain, swelling, inflammation, and a hard, discolored lump near the anus.

Hemorrhoids can develop from increased pressure in the lower rectum due to straining during bowel movements; sitting for long periods of time, especially on the toilet; having chronic diarrhea or constipation; being obese; being pregnant; or having anal intercourse. As people age, the risk of hemorrhoids increases because the tissues that support the veins in the rectum and anus can weaken and stretch. This stretching can also happen during pregnancy because there is added pressure on the anal region.

There are several options available to treat hemorrhoids, including lifestyle changes

and medications. However, if conservative management is not effective or a thrombosed hemorrhoid occurs, surgical treatment may be needed.[24]

Hepatitis

Hepatitis refers to inflammation of the liver. When the liver is inflamed or damaged, it cannot do its job effectively. Heavy alcohol use, toxins, some medications, and certain medical conditions can cause hepatitis. However, hepatitis is often caused by one of the hepatitis viruses that can range from mild to severe, with many people not realizing they are infected. Nonspecific signs and symptoms include poor appetite, nausea, vomiting, and fatigue that progress to specific signs of liver dysfunction such as jaundice, clay-colored stools, dark urine, abdominal pain, and enlargement of the liver.

Tens of thousands of people are newly infected with viral hepatitis every year in the US. The most common types of viral hepatitis are hepatitis A, hepatitis B, and hepatitis C:

[25] [26]
,

- Hepatitis A: Hepatitis A is caused by the hepatitis A virus (HAV). It spreads through close person-to-person contact or by eating or drinking contaminated food or drink, and typically causes a mild, short-term illness. Vaccination is the best way to prevent infection.
- Hepatitis B: Hepatitis B is caused by the hepatitis B virus (HBV) and spreads through infected body fluids. Infection can result in acute (short-term) or chronic (long-term) illness. Vaccination is the best way to prevent infection.
- Hepatitis C: Hepatitis C is caused by the hepatitis C virus (HCV) and spreads through infected body fluids. It is commonly caused by sharing contaminated needles during illicit drug use. Many people with hepatitis C don't look or feel sick, so they might not know they have the virus. If left untreated, hepatitis C can lead to serious liver problems, like damage, scarring, or cancer. There is no vaccine for hepatitis C, but it can be treated with oral medication.

24. Mayo Clinic. (2024). *Hemorrhoids.* https://www.mayoclinic.org/diseases-conditions/hemorrhoids/symptoms-causes/syc-20360268

25. Centers for Disease Control and Prevention. (2025). Viral hepatitis basics. https://www.cdc.gov/hepatitis/about/index.html

26. Mehta, P., Grant, L. M., & Reddivari, A. K. R. (2024). Viral hepatitis. StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK554549/

Read more about hepatitis symptoms and treatments in the **"Hepatitis" section of the Open RN *Health Alterations* textbook**.

Irritable Bowel Syndrome (IBS)

Irritable bowel syndrome (IBS) is a group of gastrointestinal symptoms that include changes in bowel movements, such as chronic diarrhea, constipation, or both. These symptoms occur without visible signs of damage or disease in the digestive tract. There is no known cause of IBS, but psychological stress may contribute to the development of IBS. Irritable bowel syndrome (IBS) is treated with diet and lifestyle changes, medications, probiotics, and mental health counseling.[27,28,29]

Jaundice

Jaundice, also called icterus, causes the skin and the whites of the eyes to turn yellow.

27. National Institute of Diabetes and Digestive and Kidney Diseases. (2017). *Irritable bowel syndrome (IBS).* National Institutes of Health. https://www.niddk.nih.gov/health-information/digestive-diseases/irritable-bowel-syndrome
28. Qin, H. Y., Cheng, C. W., Tang, X. D., & Bian, Z. X. (2014). Impact of psychological stress on irritable bowel syndrome. *World Journal of Gastroenterology, 20*(39), 14126–14131. https://doi.org/10.3748/wjg.v20.i39.14126
29. Glazier, E., & Ko, E. (2023). *Study links stress to onset of IBS.* UCLA Health. https://www.uclahealth.org/news/article/study-links-stress-onset-ibs#:~:text=Study%20links%20stress%20to%20onset,Patient%20Resources

See Figure 14.30[30] for an image of a patient with jaundice. The condition is caused by too much bilirubin, a yellow chemical from the breakdown of hemoglobin. As red blood cells break down, they are processed by the liver. However, if the liver cannot process these cells effectively, bilirubin levels build up in the body and cause jaundice.



Figure 14.30 Patient With Jaundice Due to Hepatitis

Many healthy babies have a form of jaundice during the first week of life that typically resolves on its own. The cause of this type of jaundice is due to their immature livers. Premature babies are more likely to be jaundiced and may need light therapy to treat it. Other types of jaundice can occur at any age and can indicate a liver disorder or other medical disorder. Conditions that can cause jaundice include liver disease like hepatitis or cirrhosis, blockage of bile ducts, blood disorders, genetic syndromes, infections, and side effects of certain medications.[31]

30. Toro, S.J. (2011). *Scleral icterus* [Photograph]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Scleral_Icterus.jpg

31. John Hopkins Medicine. (n.d.). *Jaundice.* https://www.hopkinsmedicine.org/health/conditions-and-diseases/jaundice-in-children

Lactose Intolerance

Lactose intolerance is a condition characterized by an inability to digest lactose, the sugar found in dairy products. It occurs when the absorptive cells of the small intestine do not produce enough lactase, the enzyme that digests the milk sugar lactose. In most mammals, the incidence of lactose intolerance increases with age. In contrast, some human populations are able to maintain the ability to produce lactase as adults.

In people experiencing lactose intolerance, the lactose in chyme is not digested. Bacteria in the large intestine ferment the undigested lactose and produce gas. In addition to gas, symptoms include abdominal cramps, bloating, and diarrhea. Symptom severity ranges from mild discomfort to severe pain, but symptoms resolve once the lactose is eliminated.

The hydrogen breath test is used to help diagnose lactose intolerance. Lactose-tolerant people have very little hydrogen in their breath. Those with lactose intolerance exhale hydrogen, which is one of the gases produced by the bacterial fermentation of lactose in the colon. After the hydrogen is absorbed from the intestine, it is transported through blood vessels into the lungs. People with lactose intolerance can purchase lactose-free dairy products available in grocery stores or take dietary supplements that provide lactase to help digest lactose.[32]

Malnutrition

Malnutrition is a condition that develops when the body is deprived of vitamins, minerals, and other nutrients it needs to maintain healthy tissues and organ function. It occurs in people who are either undernourished or overnourished. In the United States, more children suffer from malnutrition due to dietary imbalances than due to nutritional deficiencies. About one percent of children in the United States suffer from chronic malnutrition.

Undernutrition occurs when not enough essential nutrients are consumed or when they are excreted more rapidly than they can be replaced. **Overnutrition** occurs in people who eat too much, eat the wrong things, don't exercise enough, or take too many

32. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e.* Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/

vitamins or other dietary supplements. Risk of overnutrition is increased by being more than 20 percent overweight or consuming a diet high in fat and salt.

Malnourished children may be short for their age, thin or bloated, listless, and have weakened immune systems. Nutritional disorders can affect any system in the body and the senses of sight, taste, and smell. They may also produce anxiety, changes in mood, and other psychiatric symptoms. Other symptoms include pale, thick, and dry skin, bruising easily, rashes, changes in skin pigmentation, thin hair that is tightly curled and pulls out easily, achy joints, bones that are soft and tender, gums that bleed easily, a tongue that may be swollen or shriveled and cracked, night blindness, and increased sensitivity to light and glare.

Patients who cannot or will not eat or who are unable to absorb nutrients taken by mouth may be fed intravenously (parenteral nutrition) or through a tube inserted into the gastrointestinal tract (enteral nutrition). Tube feeding is often used to provide nutrients to patients who have suffered burns or who have inflammatory bowel disease.[33]

Peptic Ulcers

A **peptic ulcer** is an open sore or raw area in the lining of the stomach or intestine. There are two types of peptic ulcers: gastric ulcers (that occur in the stomach) and duodenal ulcers (that occur in the initial portion of the small intestine). The inside wall of the stomach (and duodenum) is protected from acid and enzymes by a mucous lining. Ulcers are caused when there is an imbalance between the digestive juices produced by the stomach and the various factors that protect the lining of the stomach (and/or duodenum). On rare occasions, an ulcer may completely erode the stomach or duodenal wall.

Risk factors for peptic ulcers include regular use of aspirin, ibuprofen, naproxen, or other nonsteroidal anti-inflammatory drugs (NSAIDs); excessive alcohol intake; smoking cigarettes or chewing tobacco; or stress from severe illness or surgery. A rare condition called Zollinger-Ellison syndrome causes the stomach to produce too much acid, leading to stomach and duodenal ulcers.

Small ulcers may not cause symptoms and may heal without treatment, whereas

33. John Hopkins Health. (n.d.). *Malnutrition.* https://www.hopkinsmedicine.org/health/conditions-and-diseases/malnutrition

larger ulcers can cause serious bleeding. See Figure 14.31[34] for an image of a bleeding gastric ulcer. A common symptom of ulcers is abdominal pain (often in the upper mid-abdomen). Other symptoms include a feeling of fullness; problems drinking as much fluid as usual; nausea and vomiting (possibly bloody); bloody or dark, tarry stools; chest pain; fatigue; and weight loss. Symptoms may vary based on the severity of the ulcer and whether it is located in the stomach versus the duodenum.

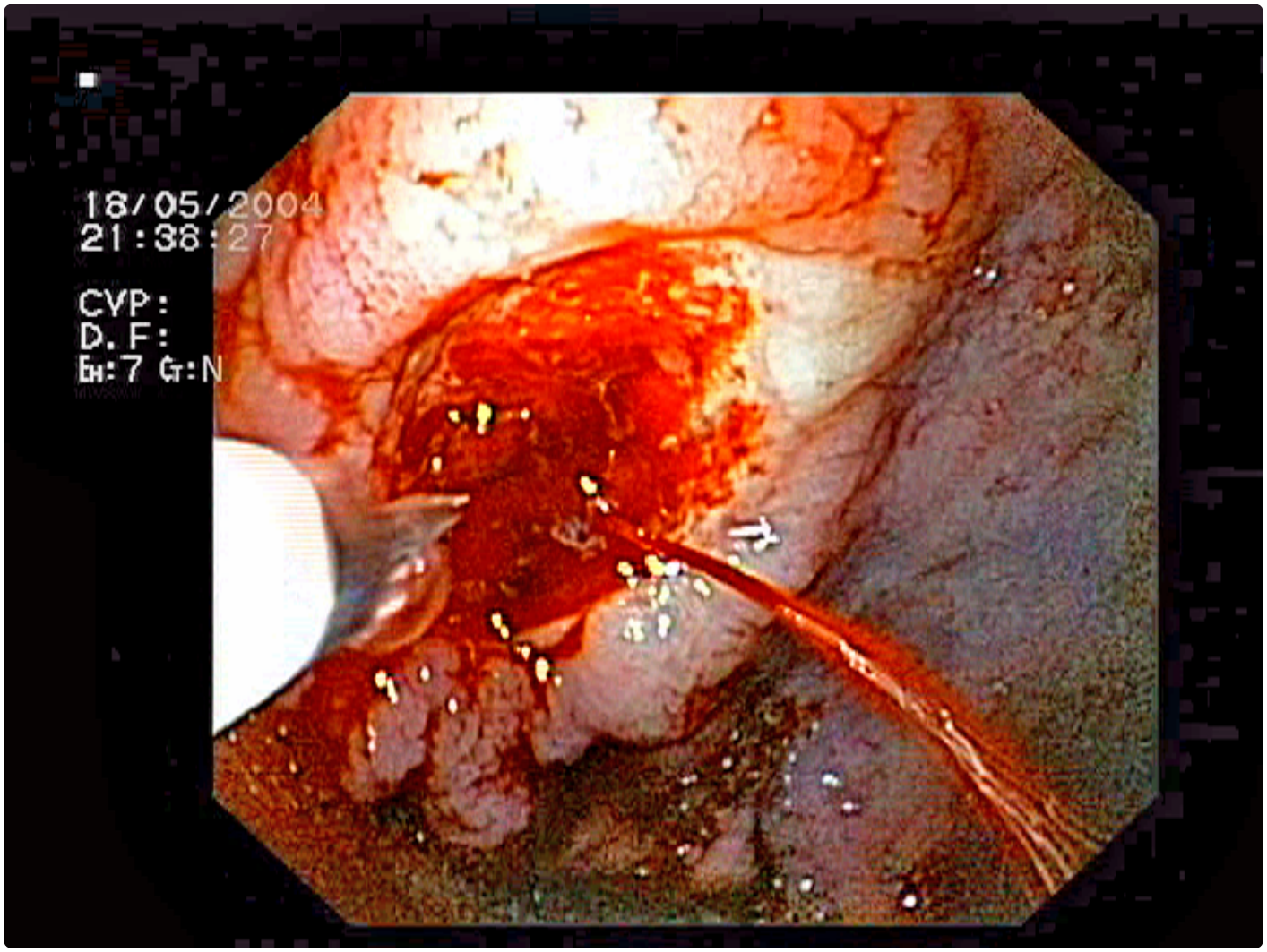


Figure 14.31 Bleeding Gastric Ulcer

A major cause of peptic ulcers is infection with the bacteria called *Helicobacter pylori*. Treatment for ulcers caused by this bacterium usually includes antibiotics to eradicate

34. Jeremias. (2013). *Bleeding gastric ulcer* [Image]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Bleeding_gastric_ulcer.png

the infection, as well as medications to suppress stomach acid. Peptic ulcers tend to recur if left untreated.[35]

Peritonitis

Inflammation of the peritoneum is called **peritonitis**. Chemical peritonitis can develop at any time the wall of the gastrointestinal tract is breached, allowing the contents of the lumen to enter the peritoneal cavity. For example, when an ulcer perforates the stomach wall, gastric juices spill into the peritoneal cavity. Hemorrhagic peritonitis occurs if the peritoneal cavity fills with blood, such as after a traumatic injury to the liver or spleen or a ruptured tubal pregnancy. Severe peritonitis is associated with bacterial infections seen with appendicitis, colonic diverticulitis, and pelvic inflammatory disease.

Peritonitis is life-threatening and often results in emergency surgery to correct the underlying problem, along with intensive antibiotic therapy. Aggressive surgery and antibiotics have greatly improved the mortality rate from this condition, but even so, the mortality rate still ranges from 30 to 40 percent.[36]

Ulcerative Colitis

Ulcerative colitis is a type of inflammatory bowel disease (IBD) that causes inflammation and sores, called ulcers, in part of the digestive tract. Ulcerative colitis affects the innermost lining of the large intestine, called the colon, and rectum. Symptoms usually develop over time, rather than coming on suddenly.

Ulcerative colitis symptoms can vary, depending on how serious the inflammation is and where it happens. Symptoms may include diarrhea, often with blood or pus; rectal bleeding—passing a small amount of blood with stool; abdominal pain and cramping; rectal pain; urgency to pass stool; not being able to pass stool despite urgency; weight loss; fatigue; fever; and in children, failure to grow. About half of the people with

35. Phillips, M. M. (2023). *Peptic ulcer disease.* Penn Medicine. https://www.pennmedicine.org/_site_pennmedicine/conditions/peptic-ulcer

36. Ernstmeyer, K., & Christman, E. (Eds.). (2024). *Medical terminology 2e.* Open RN | WisTech Open. https://wtcs.pressbooks.pub/medterm/

ulcerative colitis have mild to moderate symptoms. The course of ulcerative colitis may vary, with some people having long periods of remission.

The exact cause of ulcerative colitis isn't known. Previously, diet and stress were suspected, but now health care professionals know that these factors may worsen but don't cause ulcerative colitis. Possible causes may include an immune system malfunction or genetics. When the immune system tries to fight off an invading virus or bacterium, an irregular immune response causes the immune system to attack the cells in the digestive tract, too. Several genetic markers have been associated with ulcerative colitis. Heredity also seems to play a role in the fact that the condition is more common in people who have family members with the disease.

Ulcerative colitis can weaken the body and can sometimes lead to life-threatening complications. While it has no known cure, treatment can greatly reduce and relieve symptoms of the disease and may bring about long-term remission. Ulcerative colitis treatment usually involves either drug therapy or surgery.[37]

37. Mayo Clinic. (2024). *Ulcerative colitis.* https://www.mayoclinic.org/diseases-conditions/ulcerative-colitis/diagnosis-treatment/drc-20353331

14.6 Career Connections Related to the Digestive System

The digestive system includes the mouth, teeth, salivary glands, esophagus, stomach, intestines, liver, gallbladder, pancreas, rectum, and anus. It helps the body take in food, break it down, absorb nutrients, and remove waste. When the digestive system is affected by disease, injury, nutrition concerns, or oral health problems, many professionals may help with prevention, testing, treatment, patient education, and support. Careers related to the digestive system can include dental hygienists, dental assistants, nutrition and dietetic technicians, dietary managers, medical assistants, and surgical technologists.

Dental Hygienist

Dental hygienists are oral health professionals who provide preventive dental care and patient education. They may clean teeth, remove plaque and tartar, take dental X-rays, apply fluoride or sealants, screen for oral health concerns, and teach patients how to care for their teeth and gums. This career connects to the digestive system because digestion begins in the mouth.

Dental Assistant

Dental assistants support dentists and dental hygienists during patient care. They may prepare treatment rooms, sterilize instruments, assist during dental procedures, take X-rays, record patient information, and provide patient instructions. Dental assistants help support oral health, which is closely connected to chewing, swallowing, and the beginning of digestion.

Nutrition and Dietetic Technician

Nutrition and dietetic technicians help provide nutrition services under the supervision of registered dietitians or as part of a health care team. This career connects to the digestive system because nutrition is closely related to how the body digests food, absorbs nutrients, and supports overall health. Nutrition and dietetic technicians may help collect diet information, support meal planning, provide basic nutrition education, and assist with food service management.

Dietary Manager

Dietary managers help oversee food service operations in health care, long-term care, and community settings. They may help plan menus, manage food safety, supervise food service staff, and support nutrition care plans. This career connects to the digestive system because dietary managers help provide meals that support digestion, nutrition needs, and overall health.

Medical Assistant

Medical assistants work in clinics and other health care settings where they support patient care and office procedures. In gastroenterology, primary care, dental, or surgical settings, medical assistants may help room patients, collect health information, record symptoms, prepare patients for examinations, assist with basic procedures, support documentation, and communicate follow-up instructions.

Surgical Technologist

Surgical technologists are members of the surgical team who help prepare operating rooms, equipment, instruments, and supplies for procedures. This career connects to the digestive system because surgical technologists may assist during procedures involving the abdomen, gallbladder, intestines, liver, pancreas, mouth, or other digestive structures.

Take a Closer Look

Explore careers related to the human body's digestive system on these websites.

- Dental hygienist from the American Dental Association
- Dental hygiene career options from the American Dental Education Association
- Nutrition and dietetics technician from the Academy of Nutrition and Dietetics
- Dietary manager from the Association of Nutrition & Foodservice Professionals
- Medical assistant from the American Association of Medical Assistants
- Surgical technologist from the Association of Surgical Technologists
- Gastroenterologist from the American College of Gastroenterology

14.7 Learning Activity - Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

14.8 Glossary

Acinus: A small, grape-like cluster of cells in the pancreas that produces and secretes digestive enzymes as part of its exocrine function. (**Chapter 14.3**)

Alimentary canal: Another term for the gastrointestinal tract; it is the muscular tube through which food passes, is digested, and waste is eliminated. (**Chapter 14.1**)

Anabolism: Uses the energy produced by catabolic reactions to build larger molecules from smaller ones, such as when the body forms proteins by stringing together amino acids. (**Chapter 14.4**)

Anal canal: The final 1.5–2 inches of the large intestine that opens to the exterior at the anus and contains both internal and external sphincters to regulate defecation. (**Chapter 14.3**)

Appendicitis: A condition in which the appendix becomes inflamed and is a common reason for emergency surgery. (**Chapter 14.5**)

Appendix: A winding, approximately 3-inch-long tube attached to the cecum that contains lymphatic tissue and is generally considered vestigial with a possible immune role. (**Chapter 14.3**)

Bile: A mixture secreted by the liver to accomplish the emulsification of lipids in the small intestine. (**Chapter 14.3**)

Bile duct: The tube that transports bile from the liver and gallbladder to the duodenum. (**Chapter 14.3**)

Bilirubin: The main bile pigment that is a waste product produced when the spleen removes old or damaged red blood cells from the circulation. (**Chapter 14.3**)

Bolus: Mass of chewed food. (**Chapter 14.2**)

Cardia: The point where the esophagus connects to and through which food passes into the stomach. (**Chapter 14.3**)

Catabolism: The breakdown of large molecules into smaller ones. (**Chapter 14.4**)

Cecum: A pouch-like structure about 2.4 inches long, located below the ileocecal valve, which receives contents from the ileum and continues absorption of water and salts. (**Chapter 14.3**)

Celiac disease: An inherited autoimmune disorder that causes the immune system to produce antibodies against the gluten protein. (**Chapter 14.5**)

Cementum: A layer of modified bone that covers the dentin of a tooth. (**Chapter 14.3**)

Chemical digestion: The process by which enzymes and acids break down food molecules into their chemical building blocks. (**Chapter 14.2**)

Cholelithiasis: Medical condition of having gallstones. (**Chapter 14.5**)

Chyme: Acidic "soup." (**Chapter 14.2**, **Chapter 14.3**)

Circular folds: Deep ridges in the mucosa and submucosa that facilitate absorption. (**Chapter 14.3**)

Cirrhosis: Advanced scarring of the liver commonly caused by hepatitis or alcoholism. (**Chapter 14.5**)

Colectomy: A surgical procedure involving the removal of all or part of the colon. (**Chapter 14.3**)

Constipation: A condition characterized by infrequent, difficult, or painful bowel movements, often caused by slow movement of stool through the colon. (**Chapter 14.3**)

Crohn's disease: A type of inflammatory bowel disease (IBD) that causes swelling and irritation of the tissues in the digestive tract. (**Chapter 14.5**)

Cuspids (canines): Teeth located next to the incisors with pointed edges designed to tear and pierce tough or fleshy foods. (**Chapter 14.3**)

Deciduous teeth: Primary or baby teeth. (**Chapter 14.3**)

Defecation: Final step in digestion as undigested materials are removed from the body as feces. (**Chapter 14.2**)

Deglutition: Another word for swallowing—the movement of food from the mouth to the stomach. (**Chapter 14.3**)

Dentes: Organs similar to bones that are used to tear, grind, and otherwise mechanically break down food. (**Chapter 14.3**)

Diarrhea: A condition in which waste moves too quickly through the intestines, preventing adequate water absorption and resulting in loose, watery stools. (**Chapter 14.3**, **Chapter 14.5**)

Diverticulitis: A condition in which diverticula become inflamed, often suddenly, and may lead to serious complications. (**Chapter 14.5**)

Diverticulosis: A condition that occurs when small pouches, or sacs, form and push outward through weak spots in the wall of the colon. (**Chapter 14.5**)

Duodenum: The shortest part of the small intestine. (**Chapter 14.3**)

Emulsification: The process in which large fat globules are broken down into smaller droplets, increasing their surface area for easier digestion by enzymes. (**Chapter 14.3**)

Epiglottis: A flap of cartilage that closes over the windpipe during swallowing to prevent food and liquids from entering the airway. (**Chapter 14.3**)

Epiploic appendages: Small, fat-filled sacs of visceral peritoneum attached to the teniae coli of the colon. (**Chapter 14.3**)

Esophageal hiatus: An opening in the diaphragm through which the esophagus passes to connect to the stomach. (**Chapter 14.3**)

Esophagus: A muscular tube that connects the pharynx to the stomach. (**Chapter 14.3**)

Fat-soluble vitamins: Vitamins A, D, E, and K that are absorbed into the lymphatic system through the intestinal tract. (**Chapter 14.4**)

Feces: Composed of undigested food residues, unabsorbed digested substances, millions of bacteria, old epithelial cells from the GI mucosa, inorganic salts, and enough water to let it pass smoothly out of the body. (**Chapter 14.3**)

Fundus: The dome-shaped upper part of the stomach, positioned below the diaphragm and above and to the left of the cardia. (**Chapter 14.3**)

Fungiform papillae: Mushroom-shaped and cover a large area of the tongue. (**Chapter 14.3**)

Gallbladder: A small, 3–4-inch-long organ located on the posterior side of the liver's right lobe that stores and concentrates bile. (**Chapter 14.3**)

Gastric emptying: The process by which stomach contents gradually pass into the small intestine. (**Chapter 14.3**)

Gastroenteritis: An inflammation of the lining of the stomach and intestines. (**Chapter 14.5**)

Gastroenterologist: A physician who specializes in the diagnosis and treatment of gastrointestinal disorders. (**Chapter 14.6**)

Gastroenterology: The study of the normal function and diseases of the gastrointestinal (GI) system, also called the digestive system, including the esophagus,

stomach, small intestine, colon and rectum, pancreas, gallbladder, bile ducts, and liver. (Chapter 14.1)

Gastroesophageal reflux disease (GERD): A chronic condition where stomach acid flows backward into the esophagus, causing irritation and heartburn. (Chapter 14.3, Chapter 14.5)

Gastrointestinal tract: A continuous tube from the mouth to the anus responsible for digestion, absorption of nutrients, and elimination of waste. (Chapter 14.1)

Gingivae: Soft tissues that line the alveolar processes and surround the necks of the teeth. (Chapter 14.3)

Glottis: The opening to the larynx. (Chapter 14.3)

Goblet cells: Secrete mucus and fluid into the lumen. (Chapter 14.3)

Hard palate: The bony, anterior part of the palate that provides a rigid floor for the nasal cavity and a surface against which the tongue can press food during chewing. (Chapter 14.3)

Haustra: Pouches formed by the contraction of the teniae coli that give the colon its wrinkled appearance and aid in the movement of fecal material. (Chapter 14.3)

Hemorrhoids: Swollen veins in the anus and lower rectum; also called piles. (Chapter 14.5)

Hepatic portal vein: Delivers nutrient-rich, partially deoxygenated blood from the small intestine to the liver, supplying more oxygen to the liver than the smaller hepatic arteries. (Chapter 14.3)

Hepatic sinusoid: An open, porous blood space formed by fenestrated capillaries from nutrient-rich hepatic portal veins and oxygen-rich hepatic arteries. (Chapter 14.3)

Hepatitis: Inflammation of the liver. (Chapter 14.5)

Hepatocyte: The liver's main cell type, comprising about 80% of its volume, responsible for diverse secretory, metabolic, and endocrine functions. (Chapter 14.3)

Hepatopancreatic ampulla: A dilated chamber where the pancreatic duct and common bile duct merge and empty their secretions into the duodenum. (Chapter 14.3)

Hepatopancreatic sphincter: Regulates the flow of both bile and pancreatic juice from the ampulla into the duodenum. (Chapter 14.3)

Ileocecal valve: Located at the opening between the ileum and the large intestine; regulates the flow of chyme from the small intestine to the large intestine. (Chapter 14.3)

Ileum: The longest part of the small intestine, measuring about six feet in length. (Chapter 14.3)

Incisors: The sharp front teeth used for biting into food. (Chapter 14.3)

Ingestion: Eating or bringing food into the GI tract through the mouth. (Chapter 14.2)

Irritable bowel syndrome (IBS): A group of gastrointestinal symptoms that include changes in bowel movements, such as chronic diarrhea, constipation, or both. (Chapter 14.5)

Jaundice: Yellowing of the skin and eyes due to excess bilirubin. (Chapter 14.5)

Jejunum: The middle section of the small intestine, approximately three feet long, connecting the duodenum to the ileum. (Chapter 14.3)

Lactose intolerance: A condition characterized by an inability to digest lactose, the sugar found in dairy products. (Chapter 14.5)

Lamina propria: A layer of loose connective tissue within the mucosa that contains blood vessels, lymphatic vessels, and immune cells to support nutrient absorption and immune defense. (Chapter 14.3)

Laryngopharynx: The lower part of the throat that directs air to the voice box and food to the swallowing tube, serving as a pathway for both respiration and digestion. (Chapter 14.3)

Lingual lipase: An enzyme released from the glands of the tongue. (Chapter 14.3)

Liver: The largest internal organ in the body, weighing about three pounds in an adult. (Chapter 14.3)

Lower esophageal sphincter (LES): Relaxes to let food pass into the stomach and then contracts to prevent stomach acid from backing up into the esophagus. (Chapter 14.3)

Macronutrients: Carbohydrates, lipids, and proteins. (Chapter 14.4)

Mastication: Chewing. (Chapter 14.2)

Mechanical digestion: A physical process that does not change the chemical nature of the food but makes it smaller to increase surface area and mobility. (Chapter 14.2)

Metabolism: The sum of all the chemical reactions that occur in the body. (Chapter 14.4)

Micronutrients: Nutrients that are needed by the body in small amounts and include vitamins and minerals. (Chapter 14.4)

Minerals: Inorganic compounds that work with other nutrients to ensure the body functions properly. (**Chapter 14.4**)

Molars: Large teeth located at the back of the mouth with broad, flat surfaces designed for grinding and chewing food thoroughly. (**Chapter 14.3**)

Mucosa: The innermost layer of the gastrointestinal tract that secretes mucus and absorbs nutrients. (**Chapter 14.2**, **Chapter 14.3**)

Muscular diaphragm: Helps close the sphincter when no food is being swallowed. (**Chapter 14.3**)

Muscularis: A layer of the gastrointestinal tract composed of smooth muscle responsible for peristalsis and segmentation, typically organized into an inner circular layer and an outer longitudinal layer. (**Chapter 14.3**)

Muscularis mucosae: A thin layer of smooth muscle within the mucosa that helps move the mucosal surface to enhance secretion and absorption. (**Chapter 14.3**)

Nasopharynx: The upper section of the throat behind the nasal cavity that allows air to pass from the nose to the lungs. (**Chapter 14.3**)

Nutrient: A substance in foods and beverages essential for energy, growth, and tissue maintenance and repair, classified as water, macronutrients (carbohydrates, lipids, proteins), and micronutrients (vitamins and minerals). (**Chapter 14.4**)

Oropharynx: The middle section of the throat, located behind the mouth, that serves as a passageway for both food and air. (**Chapter 14.3**)

Overnutrition: Occurs in people who eat too much, eat the wrong things, don't exercise enough, or take too many vitamins or other dietary supplements. (**Chapter 14.5**)

Palate: The arched shape of the palate allows chewing and breathing to occur simultaneously by separating the oral and nasal cavities, supporting both digestion and respiration. (**Chapter 14.3**)

Pancreas: A long, thin organ located mostly behind the lower part of the stomach that produces hormones and digestive enzymes. (**Chapter 14.3**)

Pancreatic duct: The channel that carries pancreatic juice from the pancreas to the duodenum. (**Chapter 14.3**)

Pancreatic islets: Clusters of endocrine cells in the pancreas that produce hormones such as insulin and glucagon to regulate blood glucose levels. (**Chapter 14.3**)

Pancreatic juice: A digestive fluid produced by the pancreas containing enzymes and bicarbonate that aid in digestion and neutralize stomach acid. (**Chapter 14.3**)

Papillae: Small, raised structures on the tongue's surface that contain taste buds and help with food manipulation. (**Chapter 14.3**)

Parotid glands: The largest salivary glands located near the ears that secrete a watery saliva rich in enzymes to begin starch digestion. (**Chapter 14.3**)

Peptic ulcer: An open sore or raw area in the lining of the stomach or intestine. (**Chapter 14.5**)

Peristalsis: Involuntary, alternating wave-like contraction and relaxation of smooth muscles. (**Chapter 14.2**)

Peritoneum: The serous membrane that surrounds several organs in the abdominopelvic cavity, reducing friction between the organs and the abdominal wall. (**Chapter 14.3**)

Peritoneal cavity: Space between the visceral and parietal peritoneal layers. (**Chapter 14.3**)

Peritoneal fluid: Acts as a lubricant to minimize friction between the layers of the peritoneum. (**Chapter 14.3**)

Peritonitis: Inflammation of the peritoneum. (**Chapter 14.5**)

Pharynx (throat): Involved in both digestion and respiration, receiving food and air from the mouth and air from the nasal cavity. (**Chapter 14.3**)

Premolars: Teeth located behind the cuspids that have broad, flat surfaces for crushing and grinding food. (**Chapter 14.3**)

Propulsion: The movement of food through the digestive tract. (**Chapter 14.2**)

Pylorus: The narrow, funnel-shaped lower end of the stomach that connects to the small intestine. (**Chapter 14.3**)

Rectum: The final eight inches of the gastrointestinal tract. (**Chapter 14.3**)

Retroperitoneal: Refers to organs located behind the peritoneum, the lining of the abdominal cavity, meaning they lie between the peritoneum and the posterior abdominal wall. (**Chapter 14.3**)

Root: The part of the tooth that is embedded within the sockets of the maxilla and mandible. (**Chapter 14.3**)

Rugae: Large folds in the mucosa and submucosa that form in the absence of food in the stomach. (**Chapter 14.3**)

Saliva: Composed mostly of water (99.4%), with the remaining 0.6% containing ions,

glycoproteins, enzymes, growth factors, and waste products, where the key digestive enzyme is salivary amylase. (**Chapter 14.3**)

Salivary amylase: An enzyme in saliva that begins the chemical digestion of starches by breaking them down into simpler sugars. (**Chapter 14.3**)

Salivary glands: Exocrine structures in the mouth and tongue that continuously secrete saliva, aiding in digestion and oral hygiene. (**Chapter 14.3**)

Segmentation: Occurs mainly in the small intestine; it consists of localized contractions of the smooth muscle wall. (**Chapter 14.2**)

Serosa: The outermost layer of the alimentary canal, superficial to the muscularis, consisting of a thin layer of connective tissue and a layer of simple squamous epithelium. (**Chapter 14.3**)

Soft palate: The muscular, flexible posterior part of the palate that closes off the nasal passages during swallowing and speech. (**Chapter 14.3**)

Sphincters: Circular muscles that encircle and control the opening of various passages in the body. (**Chapter 14.3**)

Sublingual glands: Smallest salivary glands located beneath the tongue that produce mostly mucus-rich saliva to lubricate the mouth and food. (**Chapter 14.3**)

Submandibular glands: Salivary glands located beneath the lower jaw that produce a mixture of serous (watery) and mucus saliva to aid in digestion and oral lubrication. (**Chapter 14.3**)

Submucosa: A layer of dense connective tissue beneath the mucosa that contains blood vessels, lymphatics, and nerves, providing support and nourishment to the surrounding tissues. (**Chapter 14.3**)

Teniae coli: Three bands of smooth muscle that make up the longitudinal muscle layer of the muscularis of the large intestine, except at its terminal end. (**Chapter 14.3**)

Tongue: The strongest muscle in the body. (**Chapter 14.3**)

Tooth decay: Mechanical and chemical erosion of tooth enamel. (**Chapter 14.3**)

Ulcerative colitis: A type of inflammatory bowel disease (IBD) that causes inflammation and sores, called ulcers, in part of the digestive tract. (**Chapter 14.5**)

Undernutrition: Occurs when not enough essential nutrients are consumed or when they are excreted more rapidly than they can be replaced. (**Chapter 14.5**)

Upper esophageal sphincter (UES): Controls the movement of food from the pharynx into the esophagus. (**Chapter 14.3**)

Uvula: The small, conical projection that hangs from the posterior edge of the soft palate and helps prevent food from entering the nasal cavity during swallowing. (**Chapter 14.3**)

Valsalva's maneuver: A voluntary process of contracting your diaphragm and abdominal wall muscles and closing your glottis to aid in defecation. (**Chapter 14.3**)

Vitamin B12: Necessary for both the production of mature red blood cells and normal neurological functioning. (**Chapter 14.3**)

Vitamins: Organic compounds found in foods and are a necessary part of the biochemical reactions in the body. (**Chapter 14.4**)

Water-soluble vitamins: Include vitamin C and the eight B vitamins that are absorbed with water in the gastrointestinal tract. (**Chapter 14.4**)

PART XV

CHAPTER 15 URINARY SYSTEM

15.1 Introduction to the Urinary System

Chapter Competency

Analyze how the components of the urinary system function in the body.

Learning Objectives

- Identify the gross and microscopic structural components of the urinary system.
- Correlate the structural components of the urinary system with their functions.
- Illustrate the relationships among the components of the urinary system.
- Summarize the functions of the urinary system.

Imagine you are working as a dialysis technician caring for a patient with decreased kidney function. As treatment begins, you monitor fluid removal, blood pressure, electrolyte levels, and signs of fatigue, swelling, or shortness of breath. To support safe and effective care, you must understand how healthy kidneys filter blood, remove wastes, regulate fluid and electrolyte balance, and help maintain homeostasis throughout the body.

The urinary system is responsible for removing wastes and excess fluids from the body through the production and excretion of urine. It consists of two kidneys, two ureters, the urinary bladder, and the urethra. The kidneys filter blood and produce urine, the ureters transport urine to the bladder, the bladder stores urine, and the urethra carries urine out of the body. In addition to waste removal, the urinary system helps regulate water balance, blood volume, electrolyte levels, blood pH, and blood pressure. It also produces hormones that support red blood cell production and calcium balance.

Urology is the study of the male and female urinary systems, as well as the male

reproductive system. **Nephrology** is the study of the anatomy and physiology of the kidneys and kidney diseases. In this chapter, you will explore the structure and function of the urinary system, including the gross anatomy of the urinary tract and the microscopic anatomy of the nephron. You will learn how urine is formed through filtration, reabsorption, secretion, and excretion. You will also examine common urinary system disorders and how changes in kidney or urinary tract function can affect overall health.

By mastering these concepts, you will gain a deeper understanding of how the urinary system removes wastes, maintains fluid and electrolyte balance, regulates blood pressure and pH, and supports homeostasis. This foundation will help you connect urinary structure and function to urinalysis, dialysis, patient assessment, fluid balance, kidney disease, urinary tract infections, and disorders affecting the urinary system.

See Figure 15.1[1] for an illustration of the female urinary system and Figure 15.2[2] for an illustration of the male urinary system.

1. BruceBlaus. (2017). *Urinary system (Female)* [Illustration]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Urinary_System_(Female).png
2. BruceBlaus. (2017). *Urinary System (Male)* [Illustration]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Urinary_System_(Male).png

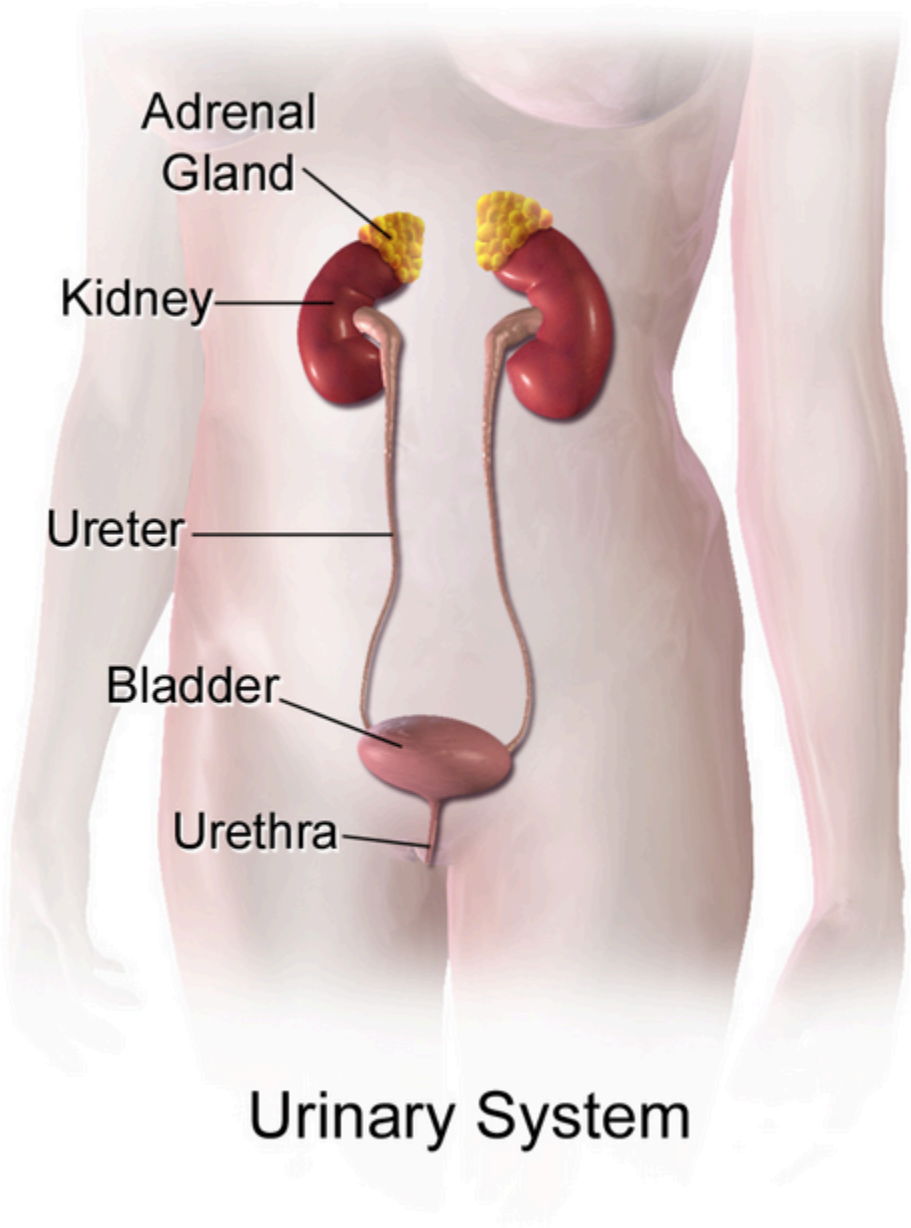


Figure 15.1 Female Urinary System

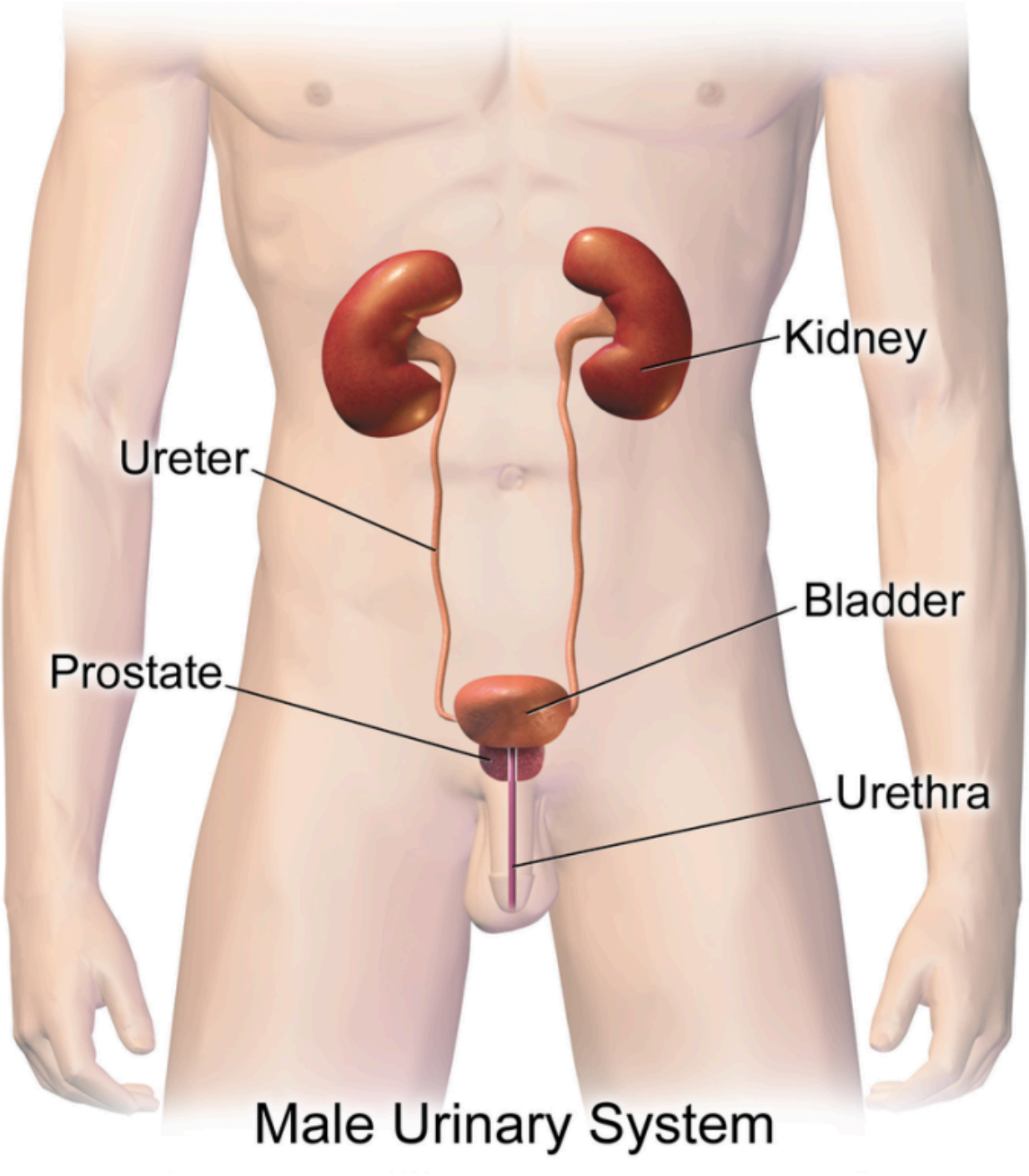


Figure 15.2 Male Urinary System

15.2 Functions of the Urinary System

The urinary system works with other body systems such as the heart, lungs, and endocrine system to maintain homeostasis. The functions of the urinary organs are vital to well-being and include the following:

- Excrete wastes and produce urine
- Regulate water balance, blood volume, and electrolyte levels
- Regulate blood pH
- Regulate blood pressure
- Produce the hormones erythropoietin and calcitriol

If an individual has decreased kidney functioning, several body functions become compromised with potentially devastating effects on homeostasis. Symptoms may include **edema** (swelling) and shortness of breath due to excessive fluid retention; weakness, lethargy, and heart arrhythmias from electrolyte imbalances; **acidosis** (low pH) or **alkalosis** (elevated pH) from an inability to regulate blood pH; anemia (from decreased erythropoietin levels); and or muscular, neurological, or skeletal effects from decreased amounts of active vitamin D (calcitriol).

The functions of the urinary system are further described in the following subsections.[1]

Excrete Wastes and Produce Urine

The urinary system filters blood to remove wastes and maintain water balance, producing about 1.5 liters (1.6 quarts) of urine per day. The kidneys can adjust the concentration of the urine to adjust to the body's water needs, conserving water if the body is dehydrated or eliminating excess water when there is too much.

1. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

In addition to excreting excess water, the kidneys rid the body of many wastes, including excess salts, ammonia, urea (from the breakdown of amino acids), creatinine (from muscle metabolism), uric acid (from the breakdown of nucleic acids), drugs, and other toxins.

Regulate Blood Volume and Electrolytes

The kidneys play a major role in regulating blood volume. As they filter blood, they control the amount of water and sodium excreted in the urine, thus regulating blood volume. Reabsorbing sodium causes water retention, resulting in increased blood volume. Conversely, sodium excretion causes water excretion, thus decreasing blood volume. The kidneys also reabsorb or excrete other electrolytes such as calcium, potassium, and magnesium.[2]

The renin-angiotensin-aldosterone system (RAAS) influences sodium and water retention by the kidneys and helps regulate blood pressure. When blood volume is low, the kidneys release renin, leading to the release of the hormone aldosterone. Aldosterone increases reabsorption of sodium and water, resulting in decreased urine production, increased blood volume, and increased blood pressure.[3]

Antidiuretic hormone (ADH), also known as vasopressin, influences blood volume and blood pressure. ADH is produced in the hypothalamus and released by the posterior pituitary gland. ADH's primary function is to increase water reabsorption by the kidneys, leading to decreased urine production and increased blood volume.[4]

Regulate Blood pH

The pH level of the blood must remain within a narrow range between 7.35 and 7.45 for the normal functioning of body systems. A variety of pH regulation systems exist in

2. Sharma, R., & Sharma, S. (2023). *Physiology, blood volume.* StatPearls [Internet]. https://www.ncbi.nlm.nih.gov/books/NBK526077/

3. Norris, D., & Carr, J. A. (2013). *Vertebrate endocrinology* (5th ed.). Academic Press. https://www.sciencedirect.com/topics/medicine-and-dentistry/renin-release#:~:text=Release%20of%20renin%20is%20controlled,receptors%20in%20the%20juxtaglomerular%20body

4. Gonzalez, A. A., Salinas-Parra, N., Cifuentes-Araneda, F., & Reyes-Martinez, C. (2020). Vasopressin actions in the kidney renin angiotensin system and its role in hypertension and renal disease. *Vitamins and hormones*, *113*, 217–238. https://doi.org/10.1016/bs.vh.2019.09.003

the body to help maintain the blood pH, including the kidneys, lungs, and buffers in the blood. Kidneys help regulate blood pH by adjusting the amounts of HCO_3^- and H^+ reabsorbed in the blood or excreted into the urine.[5]

Produce Erythropoietin and Calcitriol

The kidneys produce the hormones erythropoietin (EPO) and calcitriol. **Erythropoietin** stimulates red blood cell production in the bone marrow. Eighty-five percent of the erythropoietin is produced in the kidneys, with the remainder produced in the liver.

The kidneys perform the final step of vitamin D production, converting calcidiol to **calcitriol**, the active form of vitamin D. Vitamin D helps the body absorb dietary calcium (Ca^{2+}). It also supports the health of the muscles, brain cells, and the immune system. In fact, many scientists suggest that vitamin D be referred to as a hormone because receptors are present in most cells of the body, reflecting the systemic importance of vitamin D.[6,7]

5. Rajkumar, P., & Pluznick, J. L. (2018). Acid-base regulation in the renal proximal tubules: Using novel pH sensors to maintain homeostasis. *American Journal of Physiology Renal Physiology, 315*(5), F1187–F1190. https://doi.org/10.1152/ajprenal.00185.2018

6. Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J., Womble, M. D., & Young, K. A. (2022). *Anatomy and physiology, 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

7. Mayo Clinic. (2025). *Vitamin D.* https://www.mayoclinic.org/drugs-supplements-vitamin-d/art-20363792

15.3 Anatomy of the Urinary System

Kidneys

The urinary system has two kidneys, one on each side of the vertebral column in the retroperitoneal space. The right kidney is slightly inferior to the left due to the presence of the liver. Each kidney is well-protected by muscle, fat, and ribs. The kidneys are roughly the size of a fist, with the male kidneys typically a bit larger than the female kidneys, weighing about 125–175 grams in males and 115–155 grams in females. They are about 11–14 centimeters (cm) in length, 6 cm wide, and 4 cm thick. The kidneys are well-vascularized, receiving about 25% of the cardiac output when a person is at rest. See Figure 15.3[1] for an illustration of the location of the kidneys.

1. OpenStax. (2013). *2608 kidney position in abdomen* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2608_Kidney_Position_in_Abdomen.jpg

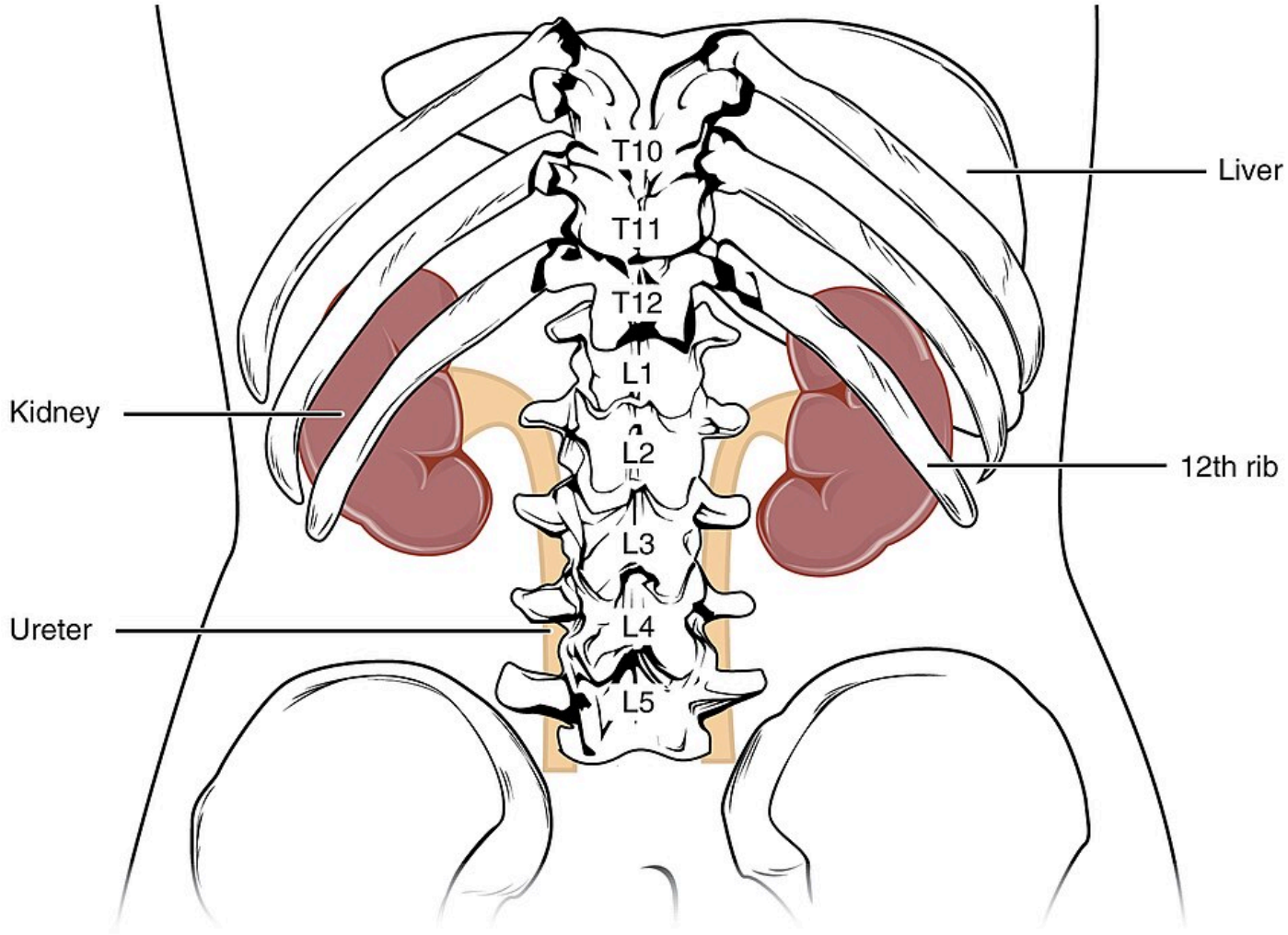


Figure 15.3 Posterior View of Kidneys Showing Location

The kidney is a complex organ with several external and internal features. These features will be discussed in more detail in the following subsections.[2]

2. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

External Anatomy of the Kidneys

Renal Hilum

The **renal hilum** is the slight indentation on the medial side of each kidney where blood vessels, nerves, lymphatic vessels, and the ureters connect.

Layers Surrounding the Kidney

There are three layers of tissue surrounding each kidney. From deepest to superficial, the layers are the renal capsule, the adipose capsule, and the renal fascia.

The deepest layer is the **renal capsule**, a fibrous covering composed of dense, irregular connective tissue that protects the kidney and maintains its shape. This capsule is covered by a shock-absorbing layer of adipose tissue called the **adipose capsule** (renal fat pad), which is covered by a tough **renal fascia**. The fascia and the overlying peritoneum firmly anchor the kidneys to the posterior abdominal wall. See Figure 15.4[3] for an illustration of the layers around the kidneys.

3. ScientificAnimations. (2020). *3D Medical animation depicting kidney layers* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:3D_Medical_Animation_depicting_Kidney_Layers.jpg

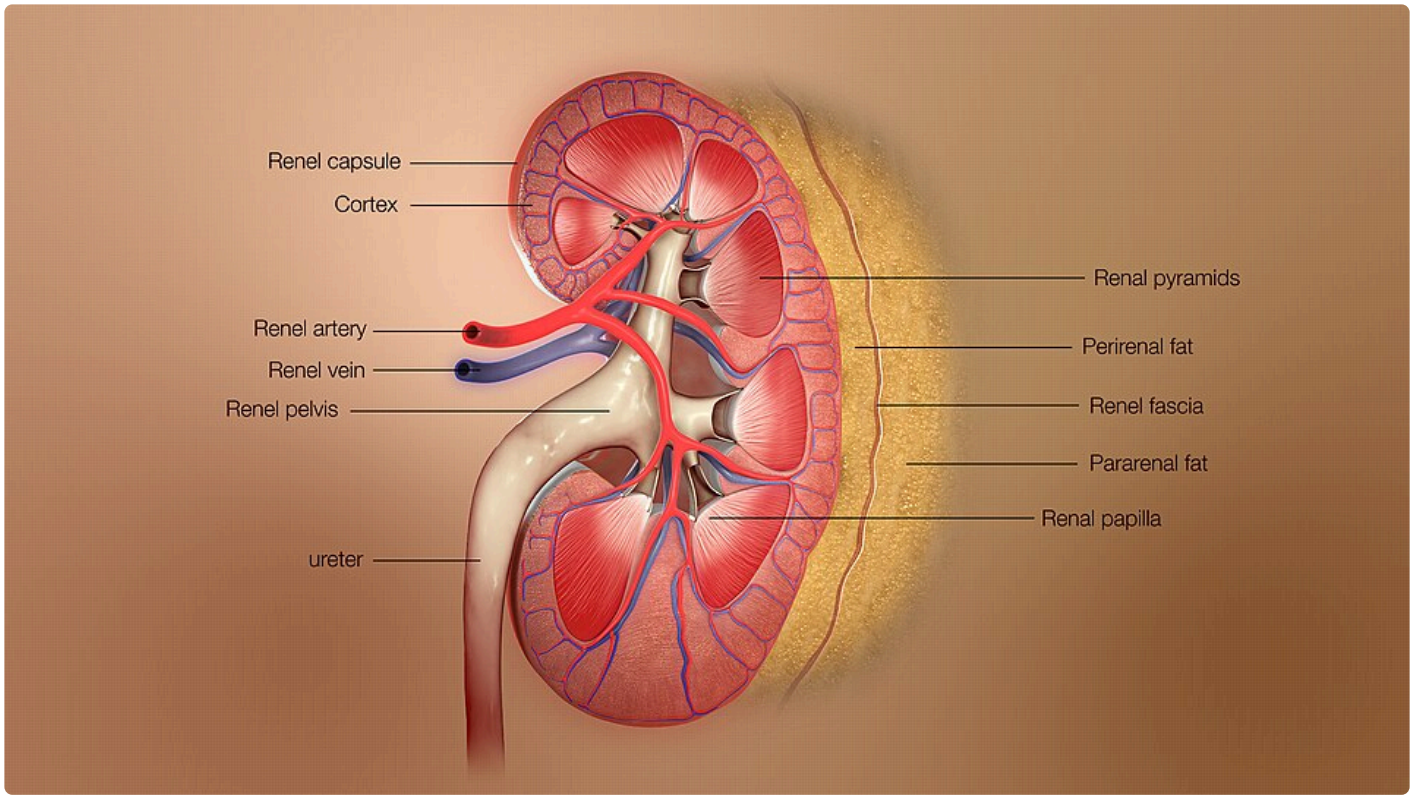


Figure 15.4 Layers Around the Kidneys

Internal Anatomy of the Kidney

The internal anatomy of the kidney can be divided into an outer portion called the renal cortex and an inner portion called the renal medulla.

Renal Cortex

The outer region of the kidney is called the **renal cortex**. In a dissected kidney, it is easy to identify the cortex; it appears lighter in color compared to the rest of the kidney.

Renal Medulla

The inner region of the kidney is called the renal medulla. The renal medulla contains several important renal structures, including the renal columns, renal pyramids, and the renal papillae.

The **renal columns** are extensions of the renal cortex into the medulla to separate the most characteristic feature of the medulla, the renal pyramids. The renal columns also divide the kidney into six to eight lobes and provide a supportive framework for vessels that enter and exit the cortex.

The **renal pyramids** are six to eight cone-shaped tissues in the medulla of each kidney. The renal pyramids contain collecting ducts and some nephron loops, both of which will be described below.

A **kidney lobe** consists of one renal pyramid, the renal cortex overlying it, and half of each renal column on each side of the pyramid.[4]

At the medial tip of the pyramids are the renal papillae. The renal papillae are bundles of collecting ducts that transport urine to the calyces (collecting tubes) of the kidney to be excreted.

See Figure 15.5[5] for an illustration of the anatomy of the kidney.

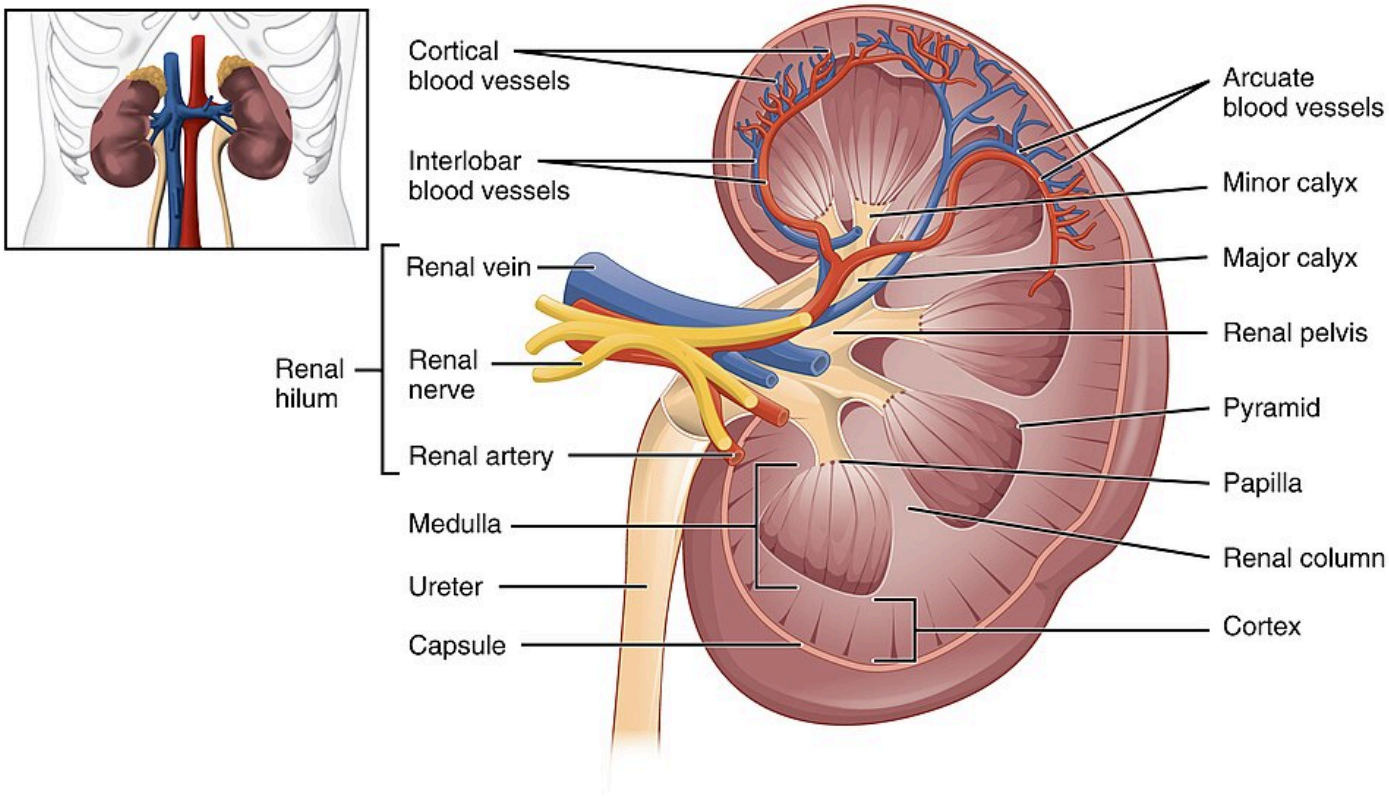


Figure 15.5 Anatomy of the Kidney

4. Tortora, G.J & Derrickson, B. (2012). *Principles of anatomy and physiology*. Wiley Publishing.

5. OpenStax. (2013). *2610 The kidney* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2610_The_Kidney.jpg.

Nephrons

Nephrons are the "functional units" of the kidney. There are over 1.3 million nephrons in each kidney that clean and balance the blood. Nephrons take a simple filtrate from the blood and make it into urine. Many changes take place in the different parts of the nephron before urine is ready to leave the body. The nephron is divided into two main portions: the renal corpuscle and the renal tubule.

Renal Corpuscle

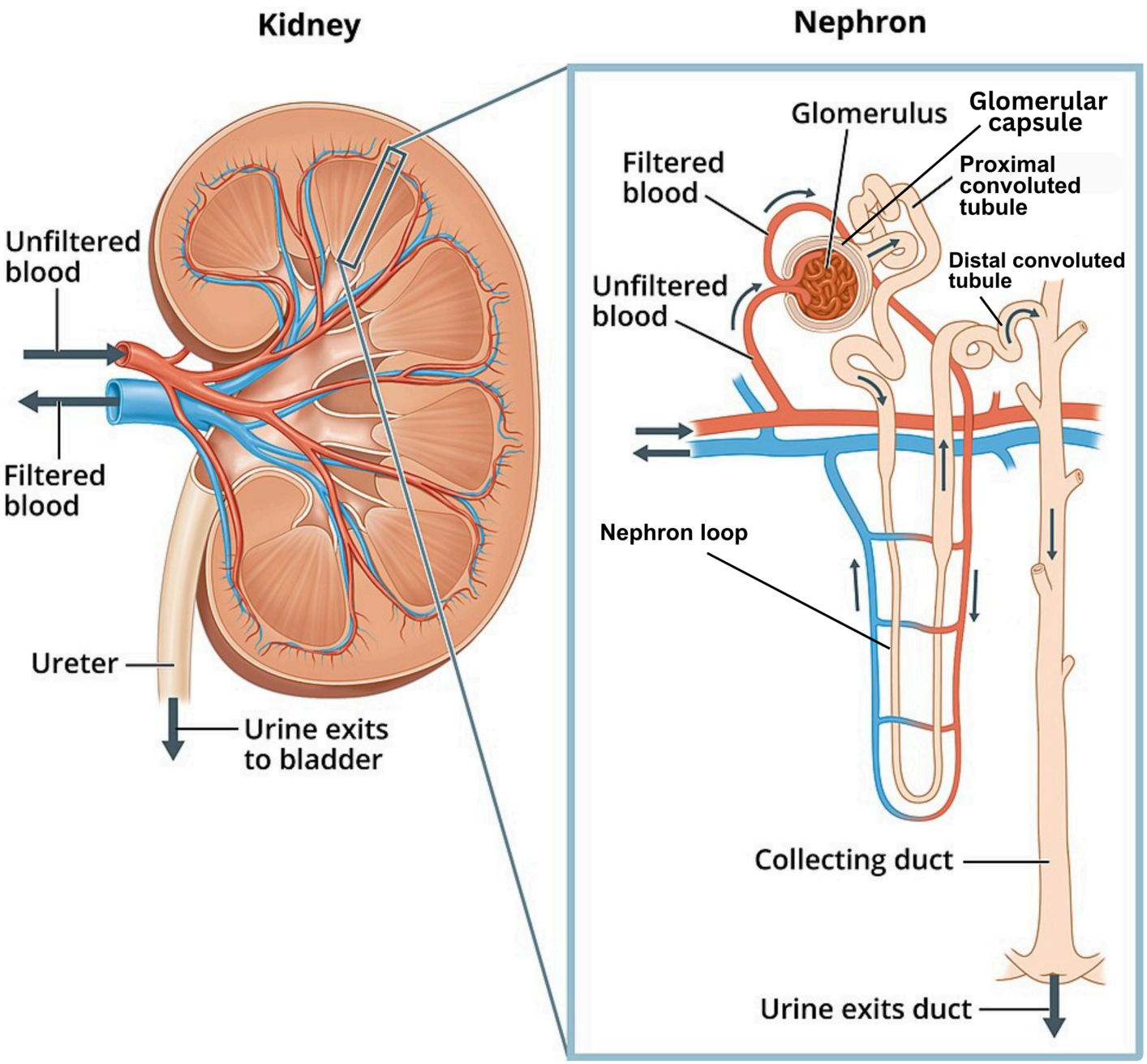
The **renal corpuscle** is a structure composed of two parts: the glomerulus and the glomerular capsule.

The **glomerulus** (plural = glomeruli) is a ball of capillaries at the beginning of each nephron that begins the filtration of blood. Blood pressure inside the glomerulus forces small substances out of the blood during a process called glomerular filtration. Blood enters the glomerulus through a very small **afferent arteriole**. This blood then flows through the glomerular capillaries, which have numerous holes called fenestrations. Water, wastes, and other small solutes that can fit through the fenestrations are pushed out of the glomerular capillaries and into the glomerular capsule, forming filtrate.

The **glomerular capsule** (also known as Bowman's capsule) surrounds the glomerulus and captures the filtrate being pushed out of the glomerular capillaries. The **efferent arteriole** carries the filtered blood away from the glomerulus.

See Figure 15.6[6] for an illustration of blood flow into and out of the kidney, nephron, and glomerulus.

6. National Institute of Diabetes and Digestive and Kidney Diseases. (2022). *Kidney and nephron* [Diagram]. National Institutes of Health. CC0, Public Domain. https://commons.wikimedia.org/wiki/File:Kidney_and_Nephron.jpg



15.6 Blood Flow in the Kidney, Nephron, and Glomerulus

Renal Tubule

The renal tubule carries filtrate from the glomerular capsule to the collecting duct. It includes the proximal convoluted tubule (PCT), the nephron loop (loop of Henle), and the distal convoluted tubule (DCT). With up to 180 liters of filtrate per day passing through the nephrons of the kidney, most of that fluid and its solutes must be reabsorbed into the blood during a process called **tubular reabsorption**. This reabsorption occurs throughout the renal tubule. In addition, other substances need to be secreted into the

renal tubule from the blood during a process called **tubular secretion**. See Figure 15.7[7] for an illustration of the reabsorption and secretion that occur throughout this tubule. Each portion of the nephron has a different capacity to reabsorb and secrete water and specific solutes.

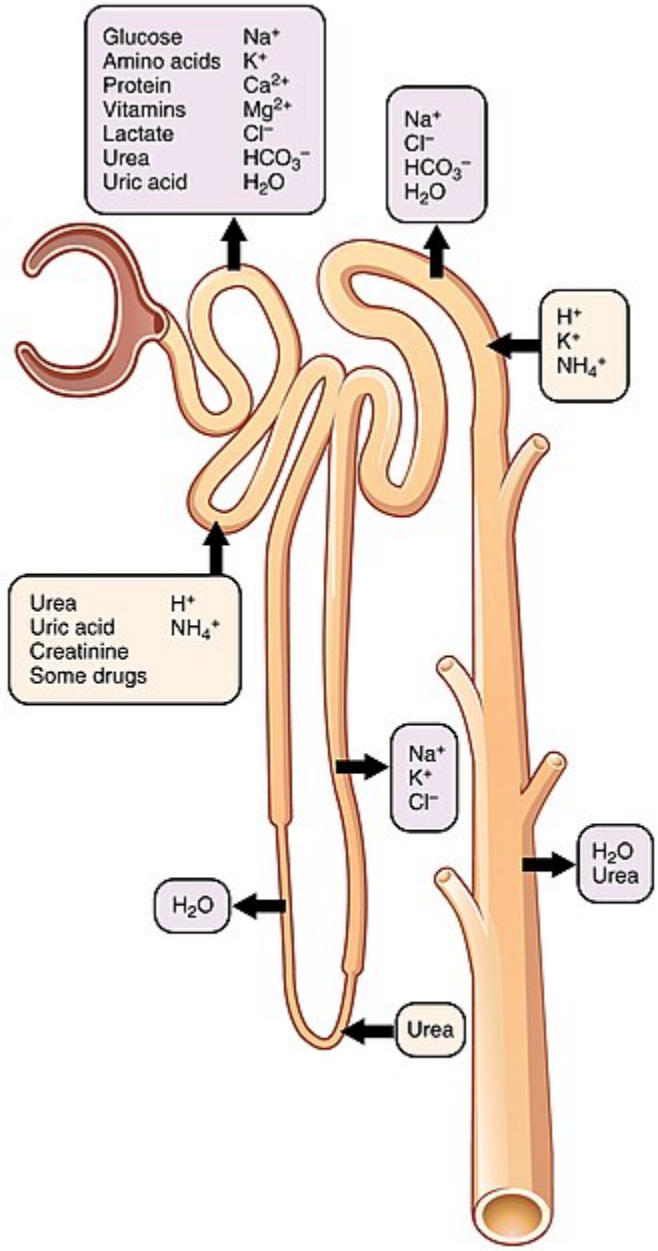


Figure 15.7 Locations of Secretion and Reabsorption in the Nephron

7. OpenStax. (2013). *2618 Nephron secretion reabsorption* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2618_Nephron_Secretion_Reabsorption.jpg.

Proximal Convoluted Tubule

The **proximal convoluted tubule (PCT)** is the first part of the renal tubule. It is called "convoluted" due to its coiled tube. Filtrate or filtered fluid collected by the glomerular capsule enters the proximal convoluted tubule, where some substances are reabsorbed, and others are secreted. (Note that substances in the kidneys are "reabsorbed," compared to being initially "absorbed" in the digestive tract.) About 99% of the water and most of the solutes filtered by the nephron are reabsorbed. Water and substances are reabsorbed into the blood of the peritubular and vasa recta capillaries surrounding the nephron.

Nephron Loop (Loop of Henle)

The **nephron loop** (also known as the loop of Henle) is a long single loop divided into descending and ascending portions. The descending and ascending portions of the loop are highly specialized to reabsorb much of the Na+ and water that were filtered out by the glomerulus. Some nephrons have short nephron loops that do not dip down beyond the cortex. These nephrons are called cortical nephrons. About 15% of nephrons have long nephron loops that extend deep into the medulla and are called juxtamedullary nephrons.

Distal Convoluted Tubule

The **distal convoluted tubule (DCT)** is the last part of the renal tubule. It connects the ascending nephron loop with the collecting duct. Approximately 80% of filtered water has been recovered by the time the filtrate enters the distal convoluted tubule. The distal convoluted tubule will recover another 10–15% before the filtrate enters the collecting ducts.

See Figure 15.8[8] for an illustration of the nephron structure, including the proximal convoluted tubule, the loop of Henle, and the distal convoluted tubule.

8. CNX OpenStax. (2016). *Biology: Figure 41-03-04* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Figure_41_03_04.jpg

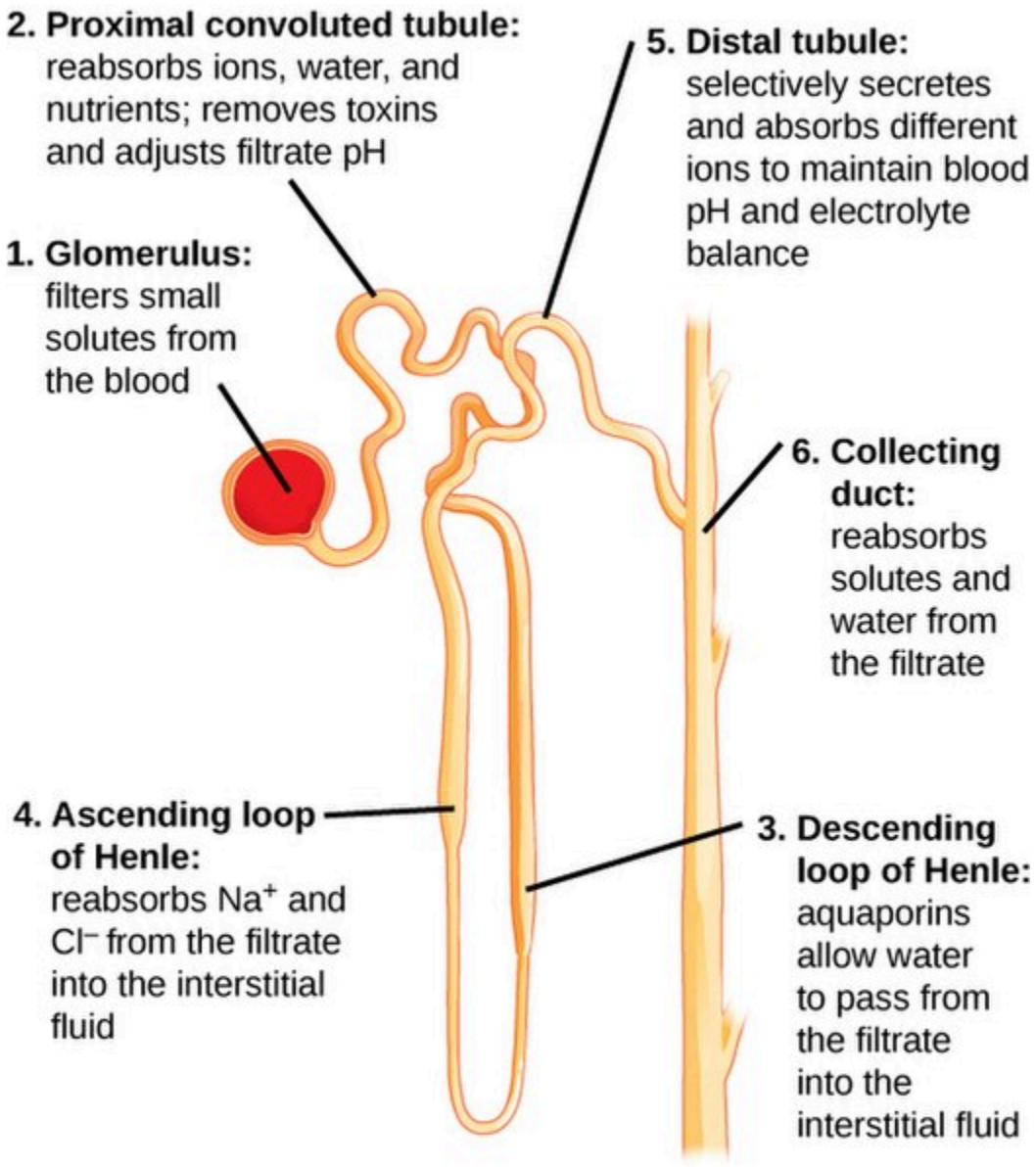


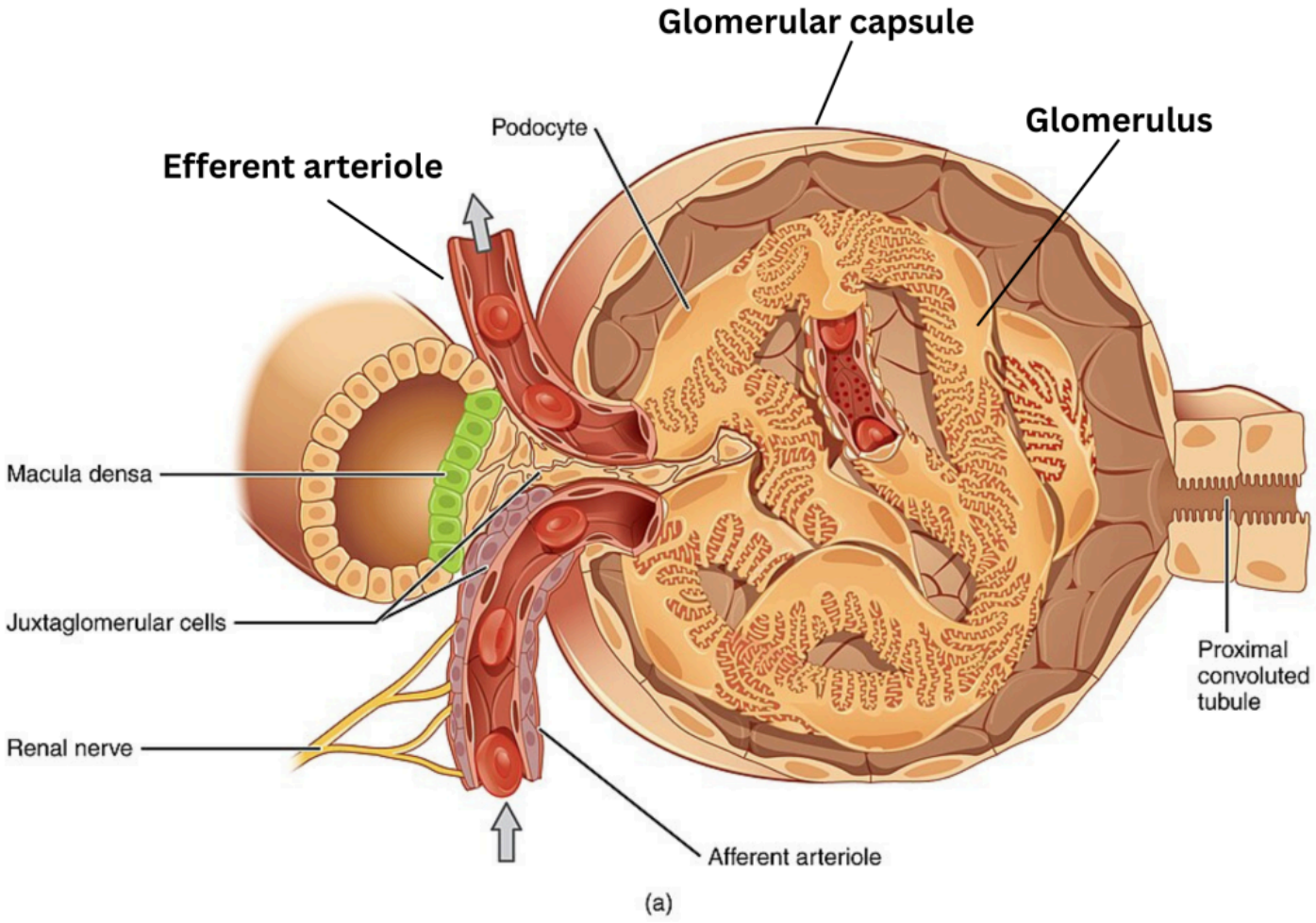
Figure 15.8 Nephron Structure

Juxtaglomerular Apparatus

Lying just outside the renal corpuscle is the **juxtaglomerular apparatus (JGA)**. See Figure 15.9[9] for an illustration of the juxtaglomerular apparatus. At the junction where the afferent and efferent arterioles enter and leave the glomerular capsule, the first part of the distal convoluted tubule (DCT) comes into direct contact with the arterioles. The

9. OpenStax. (2016). *2615 juxtaglomerular apparatus* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:2615_Juxtaglomerular_Apparatus.jpg

juxtaglomerular cells produce an enzyme called renin in response to decreased blood pressure or sympathetic nervous activity, which is an important part of a pathway called the renin-angiotensin-aldosterone system that increases blood pressure.



15.9 Juxtaglomerular Apparatus and Glomerulus

Collecting Ducts

The collecting ducts are continuous with the nephron but not technically part of it. Each collecting duct collects filtrate from several nephrons. Collecting ducts merge as they descend deeper into the medulla to empty at a renal papilla. Refer back to Figure 15.8 for an illustration of the collecting duct of a nephron.

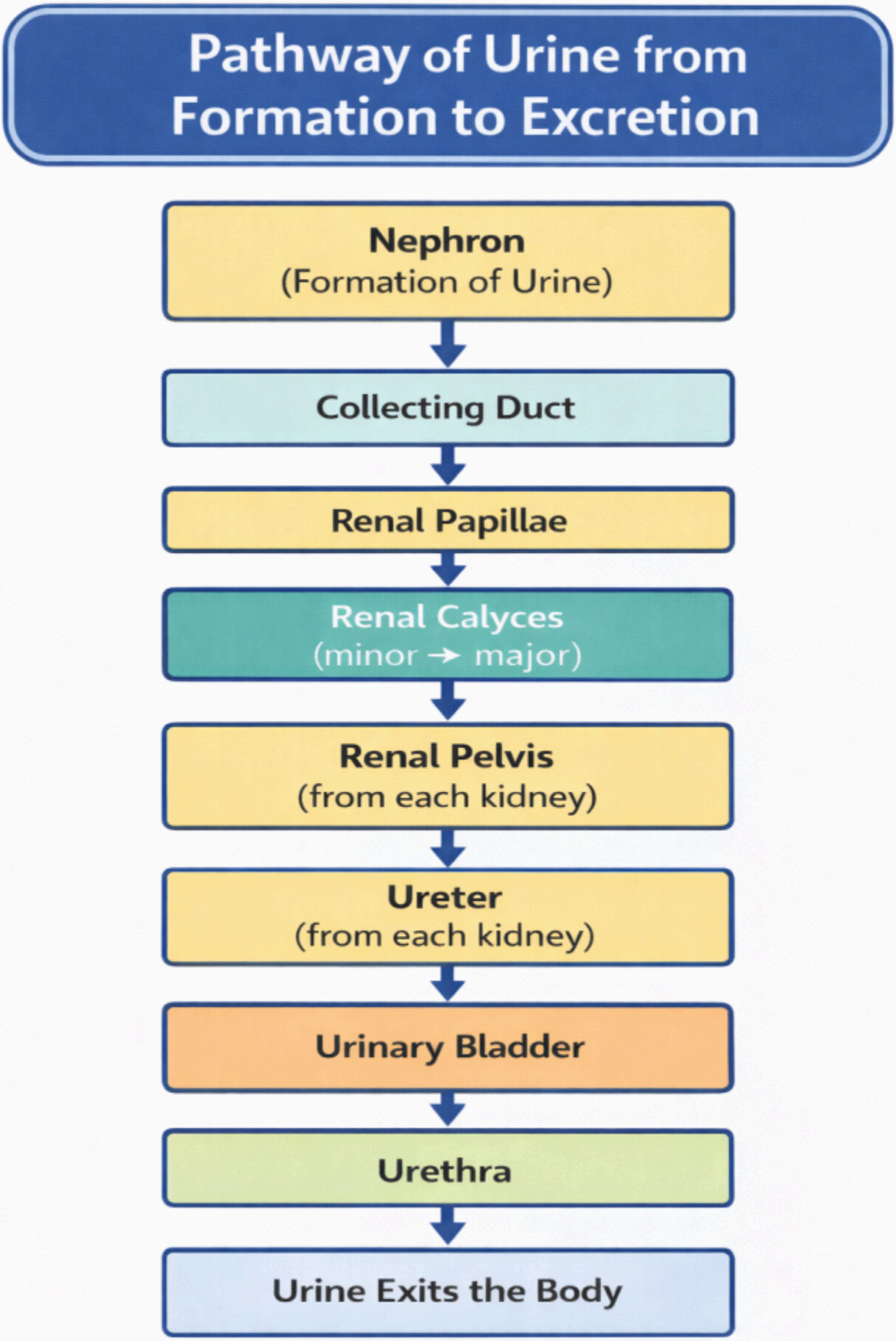
Renal Calyces and Renal Pelvis

Filtrate drains from the collecting ducts into hollow tubelike cavities called minor calyces (singular = calyx), which merge together to form larger cavities called the major calyces. The major calyces then merge together to form the funnel-shaped renal pelvis. The renal pelvis narrows to become the ureter of each kidney. Refer back to Figure 15.5 for an illustration of the calyces and the renal pelvis.

Pathway of Urine (Formation to Excretion)

The pathway of urine after it is formed from filtrate in the nephron is that it drains into the collecting duct and then into the renal papillae. From there, it drains into the minor and major calyces and then into the renal pelvis, the right and left ureters, the urinary bladder, the urethra, and is eventually eliminated outside of the body. See Figure 15.10[10] for an illustration of this pathway of urine from formation to excretion.

10. OpenAI. (2026, February 1). *Pathway of urine* [Large language model prompt]. ChatGPT. chatgpt.com


Pathway of Urine from Formation to Excretion
Nephron
(Formation of Urine)
Collecting Duct
Renal Papillae
Renal Calyces
(minor → major)
Renal Pelvis
(from each kidney)
Ureter
(from each kidney)
Urinary Bladder
Urethra
Urine Exits the Body

15.10 Urine Pathway System

Blood Supply of the Kidney

Oxygenated blood enters each kidney through the renal artery at the hilum. The **renal artery** divides into several branches of arteries that travel through the renal columns to reach the renal cortex. These arteries continue on to eventually branch into **afferent arterioles** that bring blood into the glomeruli of the 1.3 million nephrons in each kidney.

Blood leaves the glomeruli through the **efferent arterioles** and travels to the peritubular capillaries and vasa recta that surround the nephrons. **Peritubular capillaries** surround nephrons and parts of nephrons in the renal cortex, and **vasa recta** surround the nephron loop of juxtamedullary nephrons in the renal medulla. These capillaries connect to veins that continue to merge into the renal vein, which takes blood away from the kidney and back towards the heart.

See Figure 15.11[11] for an illustration of the blood supply to the kidney.

11. OpenStax. (2013). *2612 Blood flow in the kidneys* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2612_Blood_Flow_in_the_Kidneys.jpg

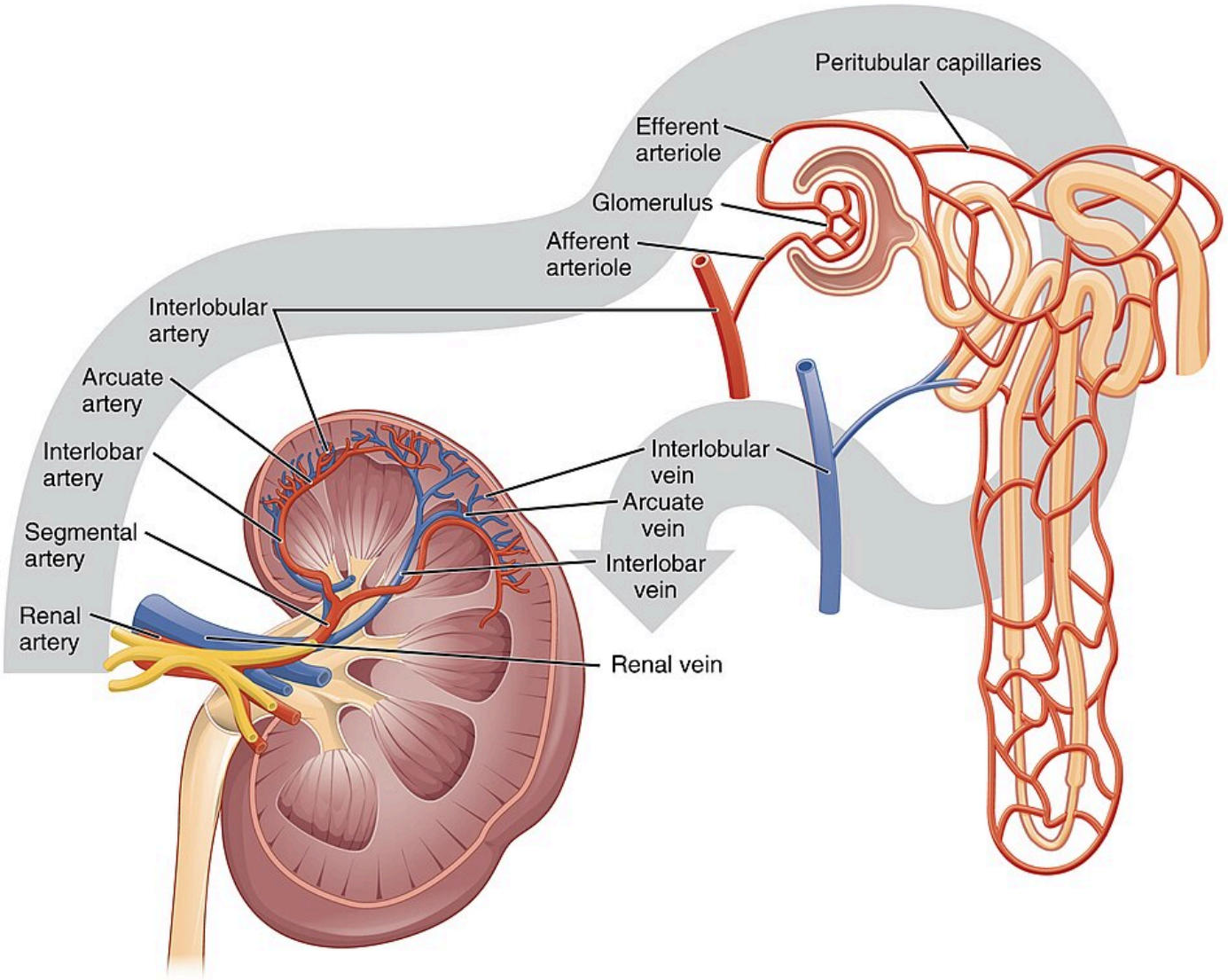


Figure 15.11 Blood Flow in the Kidney

Steps of Urine Formation

Nephrons take a simple filtrate of the blood and modify it into urine. Different parts of the nephron utilize specific processes to produce urine. These processes include glomerular filtration, tubular reabsorption, and tubular secretion.

Glomerular Filtration

Blood pressure pushes blood through the glomerulus, filtering out water, wastes, and other small solutes that can fit through the fenestrations (holes) in the glomerular

capillaries. These same fenestrations prevent the filtration of blood cells and large plasma proteins, as they cannot fit through. The filtrate is then collected by the glomerular capsule and funneled to the proximal convoluted tubule. Filtrate is mostly water but also contains amino acids, glucose, various ions, and wastes.

Glomerular Filtration Rate

The volume of filtrate formed by both kidneys per minute is called the **glomerular filtration rate (GFR)**. The heart pumps about 5 L of blood per minute under resting conditions. Approximately 20% or one liter of this blood enters the kidneys to be filtered. On average, this liter results in the production of about 125 mL/min filtrate produced in males (range of 90 to 140 mL/min) and 105 mL/min filtrate produced in females (range of 80 to 125 mL/min). This amount equates to a volume of about 180 L/day in males and 150 L/day in females. Ninety-nine percent of this filtrate is returned to the circulation by reabsorption, so that only about one to two liters of total urine are produced per day.

Estimated glomerular filtration rate (eGFR) is a blood test used to assess how well the kidneys are filtering waste and excess fluid from the blood. It is a calculated value based on creatinine level, age, and sex of the patient, and other factors. Clinically, eGFR is used to diagnose and monitor chronic kidney disease (CKD), as well as to calculate appropriate drug dosages based on a patient's kidney status.

Tubular Reabsorption

Many substances that were filtered out in the glomerulus are actually needed by the body. Most of these substances are reabsorbed into the blood from the proximal convoluted tubule. About 67% of the water, Na^+, and K^+ entering the nephron is reabsorbed in the PCT and returned to the circulation. Almost 100% of glucose, amino acids, and other organic substances, such as vitamins, are also reabsorbed here.

Water is reabsorbed by the process of osmosis and is directly affected by two hormones, aldosterone and ADH (antidiuretic hormone). **Aldosterone**, a hormone produced by the adrenal cortex, increases the reabsorption of Na^+, which then increases the reabsorption of water. **Antidiuretic hormone (ADH)**, a hormone released by the posterior pituitary gland, also increases the reabsorption of water. ADH exerts its effect farther along in the nephron at the distal collecting tubule and collecting duct. It influences how dilute or concentrated the final urine will be.

Tubular Secretion

Tubular secretion is the secretion of substances into the filtrate, which eventually becomes urine. For example, the cells of the proximal convoluted tubule actively secrete H^+ into the urine to raise pH if the pH is too low. Other ions commonly secreted into the filtrate include potassium (K^+) and ammonium (NH_4^+). Furthermore, some substances that need to leave the body may have been attached to proteins. Because proteins are too big to pass through the glomerular filtration membrane, they wouldn't have been removed from the blood yet.

Other Organs of the Urinary System

Ureters

The ureters are long tubular structures that connect the renal pelvis of the kidney to the urinary bladder. Urine moves through the ureters by waves of peristalsis. The ureters enter the bladder obliquely or at an angle. This is important because it creates a one-way valve that allows urine into the bladder but prevents it from backing up into the ureter. The ureters are approximately 11 inches (30 cm) long.

The ureter's inner mucosa is lined with **transitional epithelium** (also known as **urothelium**) and scattered goblet cells that secrete protective mucus. The muscular layer of the ureter consists of smooth muscle cells that generate peristaltic contractions, moving urine toward the bladder independently of gravity. Finally, a loose adventitial layer composed of collagen and fat anchors the ureters between the parietal peritoneum and the posterior abdominal wall. See Figure 15.12[12] for an illustration of the walls of the ureters.

12. OpenStax. (2016). *2607 ureter* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2607_Ureter.jpg

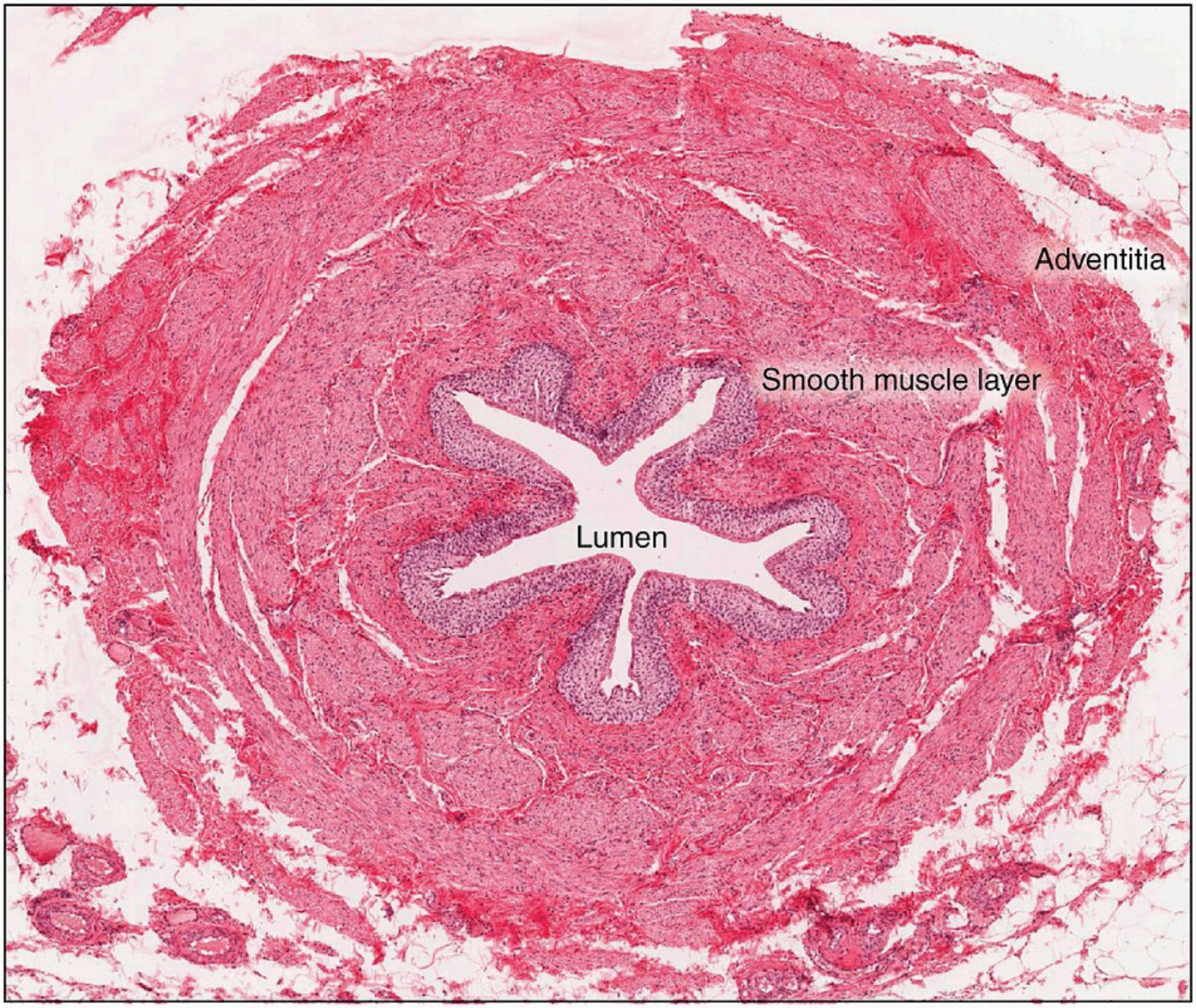


Figure 15.12 Ureter

Urinary Bladder

The urinary bladder collects urine from both ureters. The bladder lies anterior to the uterus in females and posterior to the pubic bone. During late pregnancy, its capacity is reduced due to compression by the enlarging uterus, resulting in increased frequency of urination. In males, the anatomy is similar, minus the uterus, and with the addition of the prostate inferior to the bladder. The bladder's "dome" distends superiorly when the bladder is filled with urine.

The bladder is a highly expandable organ. The interior surface is made of a transitional epithelium that is ideal for the large volume fluctuations of the bladder. When empty,

it resembles columnar epithelia, but when stretched, it "transitions" to a squamous appearance. Bladder volumes in adults can range from nearly zero to 500–600 mL.

See Figure 15.13[13] for an illustration of the urinary bladder and the bladder wall.

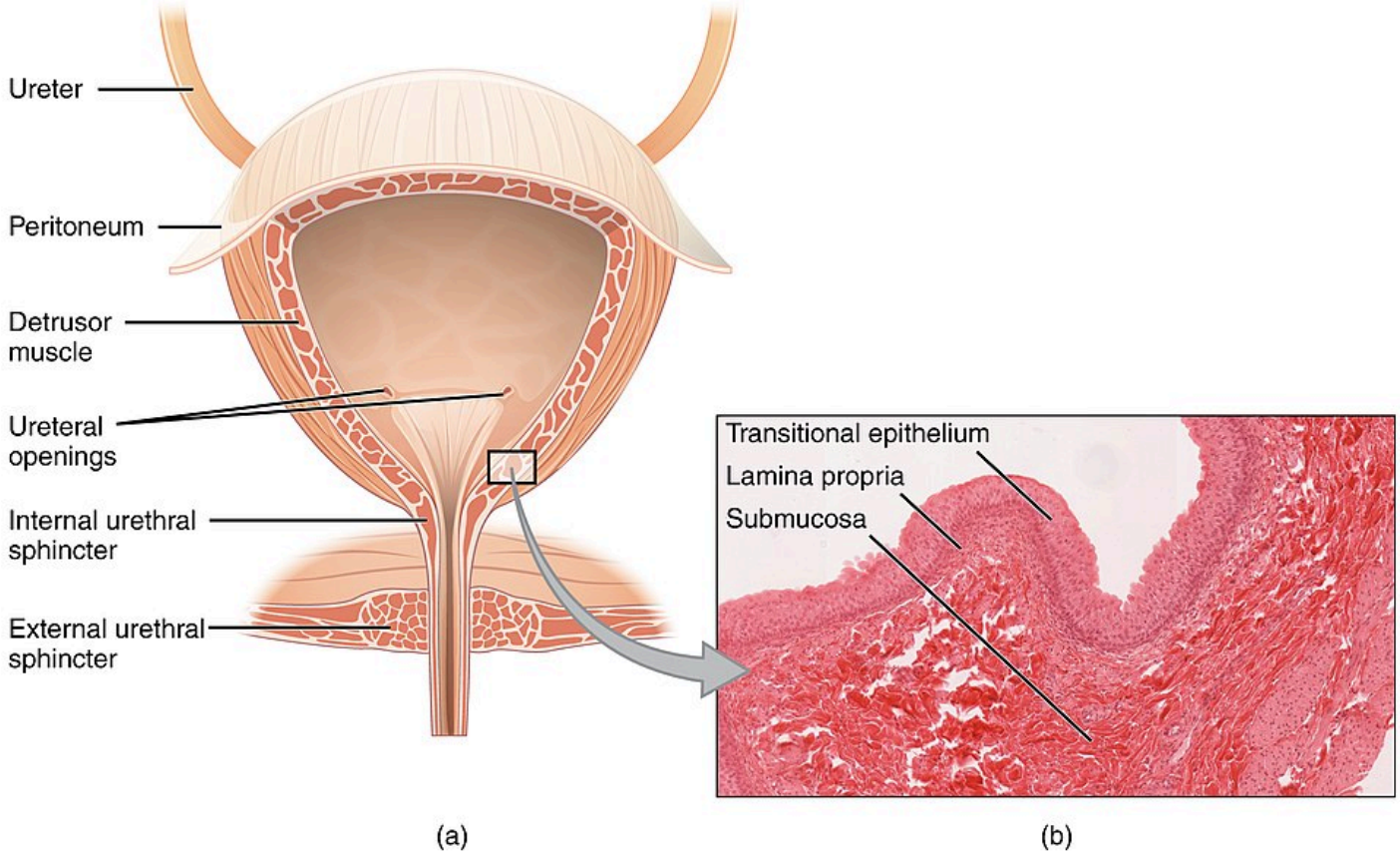


Figure 15.13 Bladder: (a) Anterior Cross Section of the Bladder and (b) Bladder Wall

Urethra

The **urethra** transports urine from the bladder to the outside of the body. The urethra is the only organ of the urinary system that shows any significant difference between males and females; all other urine transport structures are identical. In the female body, the external urethral orifice (opening) is anterior to the vaginal opening. Because the female urethra is relatively short—approximately 1.5 inches (4 cm)—it provides less of a barrier to bacteria compared to the longer male urethra, which helps explain the higher incidence of urinary tract infections (UTIs) in females. The male urethra passes through

13. OpenStax. (2013). *2605_The bladder* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2605_The_Bladder.jpg

the prostate gland immediately inferior to the bladder before passing through the penis. The length of the male urethra varies among individuals but averages 7.8 inches (20 cm) in length. See Figure 15.14[14] for an illustration of the female and male urethras.

Urinating (voiding) is regulated by an involuntary **internal urethral sphincter**, consisting of smooth muscle and a voluntary skeletal muscle that forms the **external urethral sphincter** inferior to it. Control over the external urethral sphincter is learned with toilet training.

14. OpenStax. (2021). *Female and male urethra* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Female_and_Male_Urethra.jpg

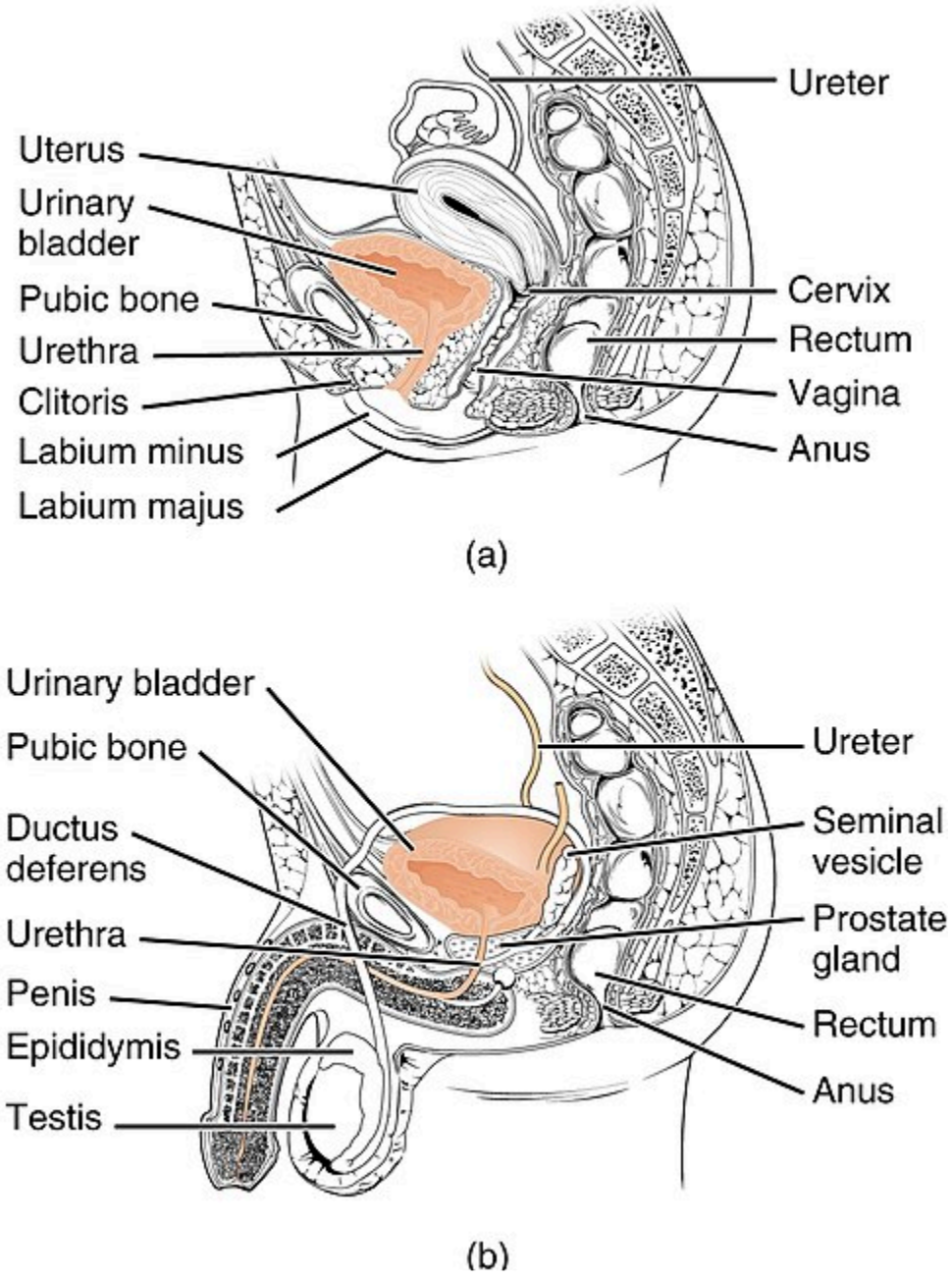


Figure 15.14 Female and Male Urethras: (a) Female Urethra (b) Male Urethra

Urine

Blood is filtered through the glomeruli of the nephrons, producing filtrate, which is transformed into urine at a relatively constant rate throughout the day. The amount of urine produced varies considerably, with the normal range from one to two liters per

day. The kidneys must produce a minimum urine volume of about 500 mL/day to rid the body of wastes.

The characteristics of urine are influenced by water intake, exercise, environmental temperature, nutrient intake, and other factors. Urine is mostly water, so some of the characteristics, such as color and odor, are rough indicators of the state of hydration. Typically, the darker in color that urine is, the less water it contains. For example, after exercise or working outside and sweating, urine may turn darker and produce a slight odor, even if plenty of water has been consumed. Urine also contains ions like sodium and chloride, waste products such as urea and creatinine, and a pigment called urobilinogen. See Table 15.1 for a summary of urine characteristics.

Table 15.1. Normal Urine Characteristics[15]

15. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e*. OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

Characteristic	Normal Values
Color	Pale yellow to deep amber
Odor	Odorless
Volume	750–2,000 mL/24 hours
pH	4.5–8.0
Specific Gravity	1.003–1.032
Osmolarity	40–1350 mOsmol/kg
Urobilinogen	0.2–1.0 mg/100 mL
White Blood Cells	0–2 HPF (per high-power field of microscope)
Leukocyte Esterase	None
Protein	None or trace
Bilirubin	<0.3 mg/100 mL
Ketones	None
Nitrites	None
Blood	None
Glucose	None

There are also substances that urine should not contain, and their presence can indicate illness. The glomeruli filter blood based on particle size, so large elements like blood cells, platelets, antibodies, and albumin do not enter the filtrate and should not be present in the urine. Glucose and amino acids, while in filtrate, are reabsorbed in the proximal convoluted tubule and should not be present in urine. Some normal bacteria may be found in the urine from the natural biome of the body or contamination, but large amounts of bacteria should not be present.

The presence of leukocytes (white blood cells) in urine may indicate a urinary tract infection (UTI). Furthermore, leukocyte esterase is released by leukocytes, and if detected in the urine, it can also be evidence of a UTI. Protein does not normally leave the glomerular capillaries, so only trace amounts of protein should be found in the urine. If excessive protein is detected in the urine, it usually means that the glomerulus is

damaged and is allowing protein to “leak” into the filtrate. The presence of red blood cells is abnormal in urine, although they may appear in female urine samples as a result of menstrual contamination. If red blood cells are present in urine, it can indicate a UTI or more serious conditions such as kidney stones, glomerulonephritis, trauma, or cancer.

Urine Color

The yellow color of urine is determined mostly by the breakdown products of red blood cell destruction and the hydration status of an individual. The “heme” of hemoglobin is converted by the liver and excreted indirectly into the urine, causing a yellow pigment called urochrome. If a person is well-hydrated, the diluted appearance may appear clear to light yellow, but as a person becomes more dehydrated and the urine is less dilute, this pigment causes a darker color of the urine. See Figure 15.15[16] for an illustration of a variety of urine colors.

16. OpenStax. (2016). *2601 Urine color chart* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2601_Urine_Color_Chart.jpg

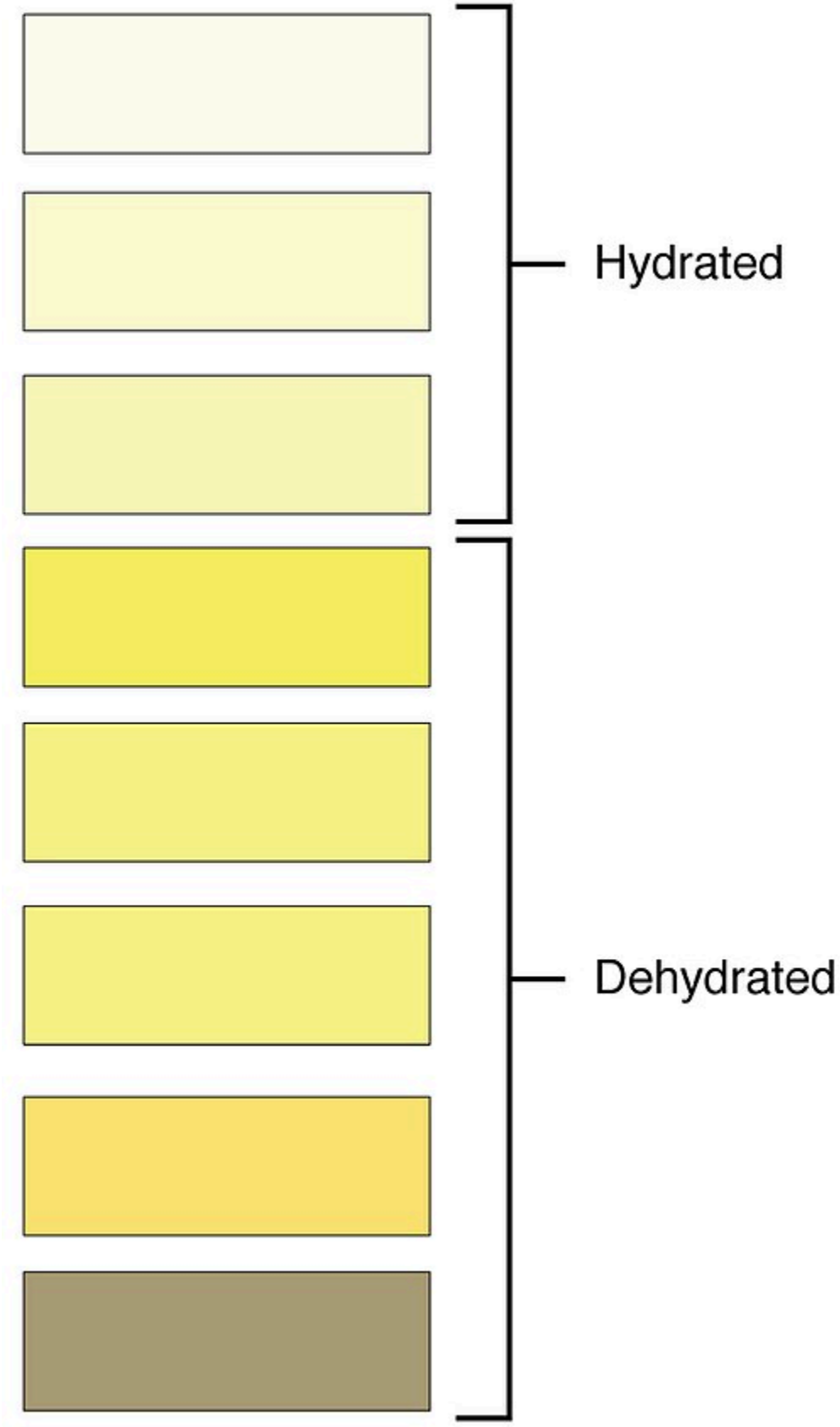


Figure 15.15 Urine Colors

Urine color is also affected by a variety of other factors. Urine color can be affected by the ingestion of certain foods like beets, berries, and fava beans. Bleeding from a kidney stone or cancer in the urinary tract may cause pink to bright red to brownish red urine. Small amounts of blood in the urine (called microscopic hematuria) won't visibly change the color of the urine. Liver disease or obstruction of bile drainage from the liver can cause a dark orange or brown "tea" or "cola" hue to the urine.

Dehydration produces darker, concentrated urine that may also possess a slight odor of ammonia. Most of the ammonia produced from protein breakdown is converted into urea by the liver, so ammonia is rarely detected in fresh urine. However, if urine is exposed to the environment for a period of time, bacteria break down urea into ammonia. Interestingly, about one in five people detect a distinctive odor in their urine after consuming asparagus; other foods, such as onions, garlic, and fish, can pass on their own aromas. These food-caused odors are harmless.

pH of Urine

The pH of the urine can vary from a normal low of 4.5 to a maximum of 8.0. Dietary intake can influence urinary pH, with meats lowering pH but citrus fruits, vegetables, and dairy products raising the pH. Chronically high or low pH can lead to disorders, such as the development of kidney stones and urinary tract infections.

Specific Gravity of Urine

Specific gravity is a measure of the number of solutes per unit volume of a solution and is traditionally easier to measure than osmolarity. Urine will always have a specific gravity greater than pure water (water = 1.000) due to the presence of solutes. Laboratories can now measure urine osmolarity directly, which is a more accurate indicator of urinary solutes than specific gravity. Remember that osmolarity is the number of osmoles or milliosmoles per liter of fluid (mOsmol/L). Urine osmolarity ranges from a low of 50–100 mOsmol/L to as high as 1,200 mOsmol/L H_2O.

Ketones

Ketones are produced when the body burns fat. Ketones in the urine suggest that the body is using fat as an energy source instead of glucose. For example, ketones may appear in the urine if a person has a severe lack of carbohydrate intake or is experiencing

starvation. Individuals with type 1 diabetes mellitus may also have excessive ketones in their urine. When their pancreas does not produce insulin, their cells cannot use the glucose in their bloodstream. The cells are forced to use fat as their energy source, which produces ketones as a byproduct. Consequently, glucose will likely be present in the urine as well.

Urinalysis

Urinalysis is a diagnostic lab test used to analyze the composition of urine and check for abnormalities that could indicate infection or disease.

Micturition

Micturition is the medical term for urination (voiding) or emptying the bladder. The bladder can hold up to 500–600 mL of urine. When bladder volume reaches about 150 mL, an urge to void is sensed. As the bladder continues to fill, subsequent urges become harder to ignore. Voluntary control of urination relies on consciously preventing relaxation of the external urethral sphincter to maintain urinary continence. Incontinence is a loss of control of urination. Read more about incontinence in the "**Disorders of the Urinary System**" section.

Video

*]:pointer-events-auto [content-visibility:auto] supports-[content-visibility:auto]:[contain-intrinsic-size:auto_100lvh] R6Vx5W_threadScrollVars scroll-mb-[calc(var(--scroll-root-safe-area-inset-bottom,0px)+var(--thread-response-height))] scroll-mt-[calc(var(--header-height)+min(200px,max(70px,20svh)))]" dir="auto" data-turn-id="request-69f3891f-cad4-8328-be35-d4d3dbd28b71-80" data-testid="conversation-turn-152" data-scroll-anchor="false" data-turn="assistant">
Watch the video "Excretory System and the Nephron" below to learn how the

kidneys filter blood and how the nephron functions in waste removal and fluid balance.[17]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Body Fluid Balance

Our body composition is mostly water, ranging from about 75% of body mass in infants to about 50 to 60% in adults, to as low as 45% in older adults. The percent of body water changes with the body's development because the proportions of the body given to each organ and to muscles, fat, bone, and other tissues change from infancy to adulthood. The brain and kidneys have the highest water content, with water making up 80–85% of their total mass. In contrast, teeth have the lowest proportion of water, with about 8–10% water. See Figure 15.16[18] for an illustration of the body's water content.

17. Amoeba Sisters. (2022, August 10). *Excretory system and the nephron* [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=q5qaGHfdmYM

18. OpenStax. (2013). *2701 water content in the body 01* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2701_Water_Content_in_the_Body-01.jpg

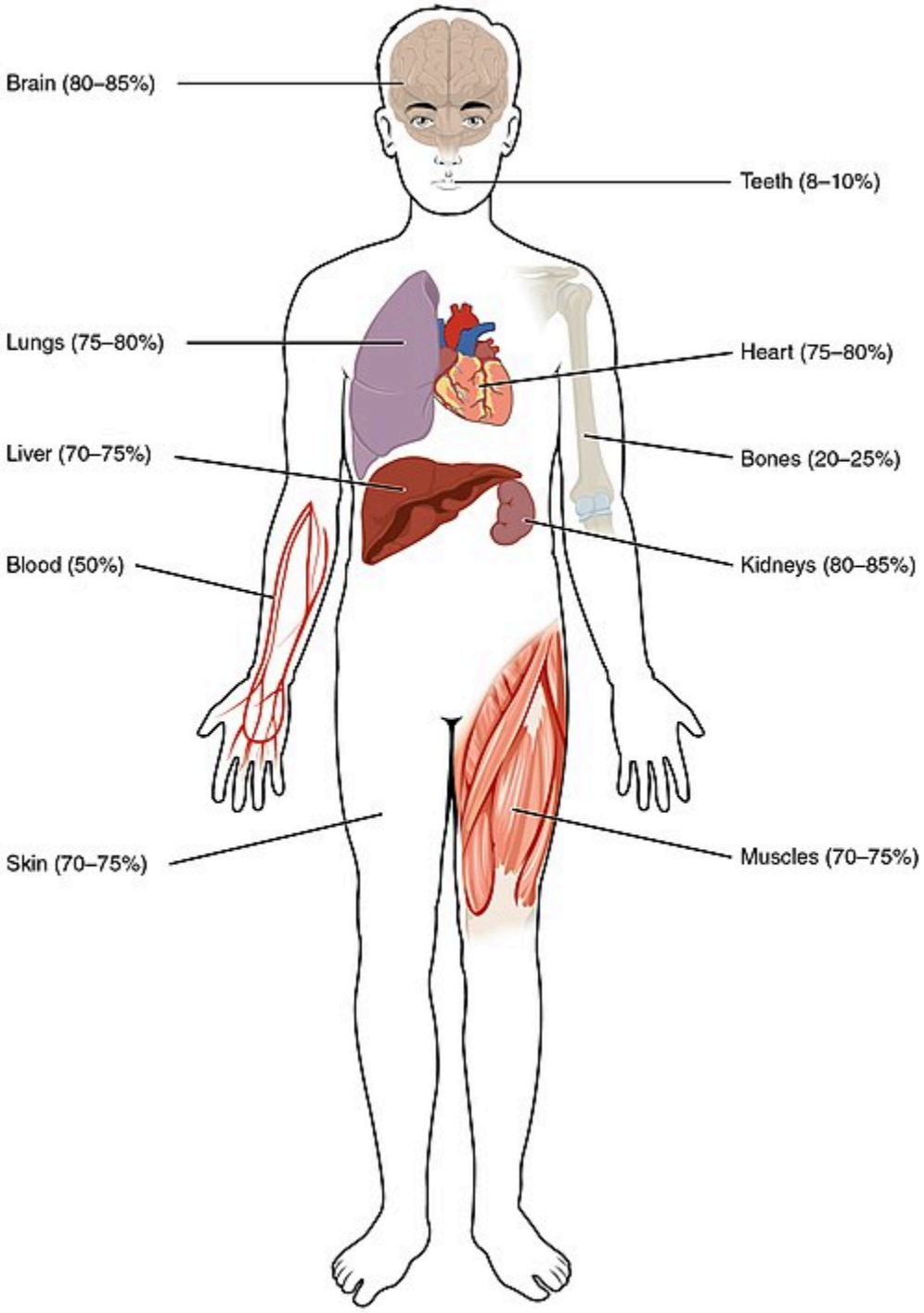


Figure 15.16 Water Content of the Body's Organs and Tissues

Fluid Intake and Output

On a typical day, an average adult takes in about 2,500 milliliters (mL) of fluids (equal to about 3 quarts). Although most of the intake is absorbed from fluids and foods in the

digestive tract, about 230 mL (8 ounces) per day is generated metabolically in the last step of aerobic respiration.

About the same volume (2,500 mL) of water leaves the body daily, with most eliminated as urine. This amount is called **sensible water loss** because a person is aware of it, and the amount can be measured. Water is also lost through the skin by sweating, and a small amount is eliminated through feces and menstruation. Some water is also lost through water vapor in the air exhaled from the lungs. These types of water loss are called **insensible water loss** because a person is unaware of it.

To maintain homeostasis in the body, the amount of fluid intake must equal fluid output. If adequate fluids are not consumed or if too many fluids are lost from the body, **dehydration** can occur. A person who repeatedly vomits or has diarrhea may also become dehydrated. Infants, because their body mass is so low, can become dangerously dehydrated very quickly. Other populations at a higher risk of dehydration include the elderly, those with altered mental states, and individuals with significant medical conditions. Dehydration can be a medical emergency as blood volume and blood pressure decrease, impacting blood flow to vital organs. A severely dehydrated person may lose consciousness, become comatose, or die if their body is not rehydrated quickly.

Acid-Base Balance

The pH of human blood normally ranges from 7.35 to 7.45. Homeostatic mechanisms normally keep the pH of blood within this narrow range. This is critical because fluctuations—either too acidic or too alkaline—can be life-threatening.

Buffers

Buffers in the human body maintain a normal range of pH of body fluids. A **buffer** is a substance that resists a change in pH when a small amount of acid or base is added to it. The three major buffers used by the body include proteins (hemoglobin and albumin), phosphates, and bicarbonate. The bicarbonate buffer is the primary buffering system of the blood and interstitial fluid in tissues throughout the body. It is a very powerful and fast-acting buffer that is produced and reabsorbed by the kidneys. Additionally, nearly all proteins can function as buffers and account for two-thirds of the buffering power of the blood and most of the buffering within cells. Lastly, the phosphate buffer system has

a high concentration of phosphates in the intracellular fluid to resist pH changes inside the cells.

Acidosis

A person whose blood pH is below 7.35 is considered to be in **acidosis**. Acidosis depresses the central nervous system and has several symptoms, including headache, confusion, lethargy, and fatigue. A sustained blood pH below 7.0 can be fatal.

Common causes of acidosis are respiratory disorders and situations that impair breathing, resulting in the buildup of CO_2 (and H^+) in the bloodstream. Acidosis can also be caused by metabolic problems that promote the production of acids or reduce the function of buffers that act as bases. For example, people with undiagnosed or poorly managed type 1 diabetes mellitus don't have enough insulin for their cells to use glucose, and, therefore, produce ketones as their body breaks down fats for energy instead. As ketones build up in their blood, a life-threatening condition called diabetic ketoacidosis can develop. Kidney failure can also cause metabolic acidosis when the kidneys lose their ability to eliminate H^+ ions and produce bicarbonate. People with severe diarrhea can lose excessive amounts of bicarbonate, allowing acids to build up in body fluids.

Alkalosis

A person with a blood pH above 7.45 is considered to be in **alkalosis**. Alkalosis overstimulates the nervous system, and symptoms include cognitive impairment (which can progress to unconsciousness), tingling or numbness in the extremities, muscle twitching and spasm, and nausea and vomiting. A blood pH above 7.8 is fatal.

Respiratory alkalosis is commonly caused by hyperventilation, resulting in the excessive release of carbon dioxide by the lungs and reduced concentration of H^+ ions in the blood. Metabolic alkalosis can be caused by prolonged, severe vomiting due to a loss of hydrogen ions (as components of HCl acid). Medications such as diuretics can also cause alkalosis, as increased urination causes the body to lose excessive potassium ions. Antacids, too, can potentially cause alkalosis if a person takes them in excessive amounts for persistent heartburn or an ulcer.

See Figure 15.17[19] for an illustration of the symptoms of acidosis and alkalosis.

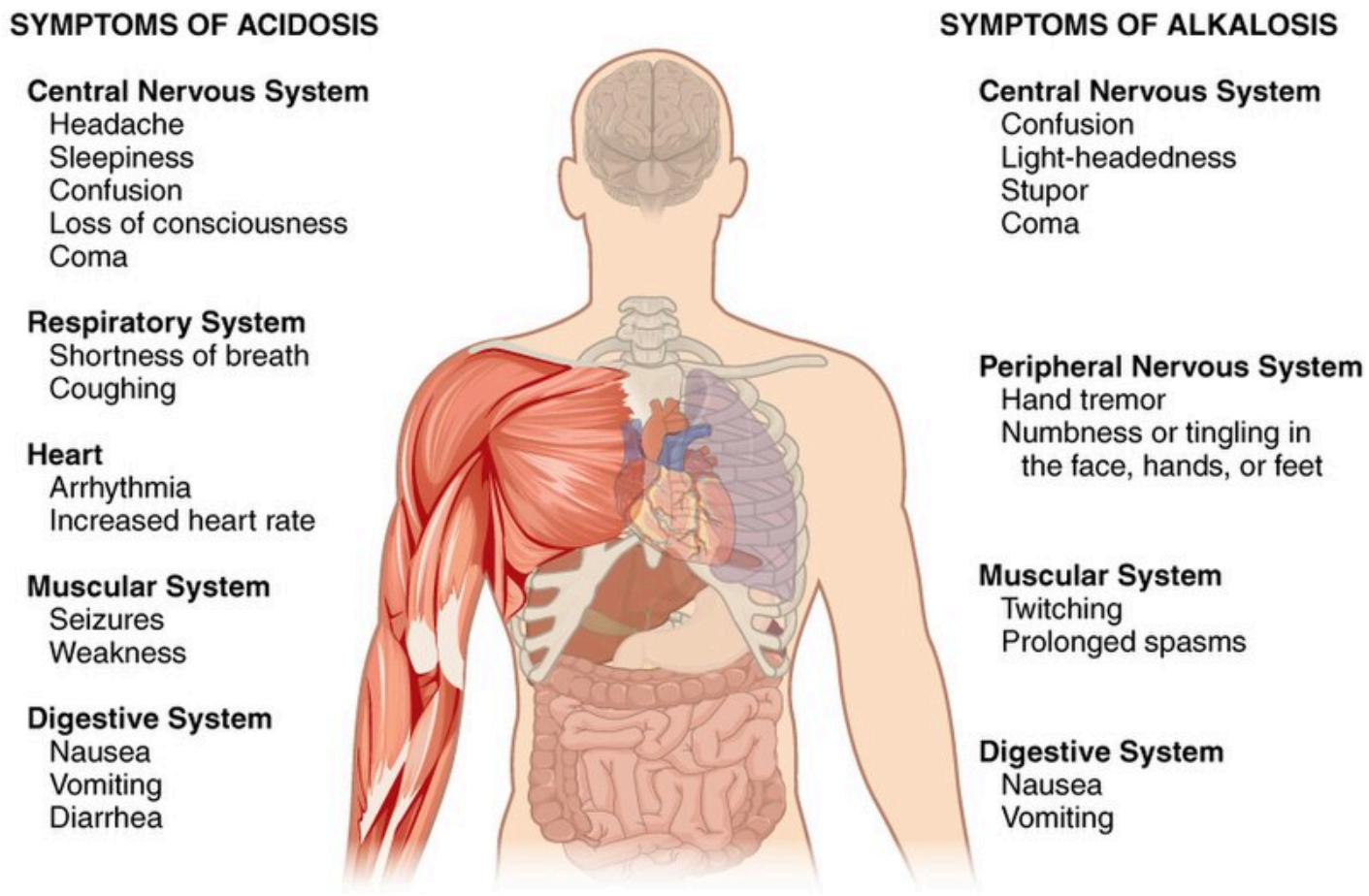


Figure 15.17 Symptoms of Acidosis and Alkalosis

19. OpenStax. (2013). *2716 Symptoms of acidosis alkalosis* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:2716_Symptoms_of_Acidosis_Alkalosis.jpg

15.4 Disorders of the Urinary System

Acute Kidney Failure

Acute kidney failure is the rapid (less than two days) loss of kidney function. There are many possible causes of acute kidney failure, including the following:

- Acute tubular necrosis (damage to the renal tubules)
- Autoimmune kidney disease
- Decreased blood flow to the kidneys due to very low blood pressure, which can result from dehydration, hemorrhage, serious illness or injury, or surgery
- Disorders that cause clotting within the kidney's blood vessels
- Infections that directly injure the kidney, such as acute pyelonephritis (severe infection of the kidneys)
- Pregnancy complications, including placental abruption (separation of the placenta from the uterine wall) or placenta previa (placenta blocking the cervix)
- Urinary tract blockage
- Illicit drugs such as cocaine and heroin
- Medicines, including nonsteroidal anti-inflammatory drugs (NSAIDs), certain antibiotics, and blood pressure medicines, intravenous contrast (dye), HIV medications, and some types of cancer

Acute kidney failure is diagnosed through blood and urine tests that measure creatinine, urea nitrogen, and protein levels in the blood and urine. Acute kidney failure is typically treated with dialysis and medications.[1]

1. A.D.A.M. Medical Encyclopedia [Internet]. (2024). *Acute kidney failure.* https://medlineplus.gov/ency/article/000501.htm

Bladder Cancer

Bladder cancer is the most common malignancy affecting the urinary system. Symptoms of bladder cancer are hematuria, urinary frequency, urgency, dysuria, and nocturia. Treatment and prognosis are based on the severity of the disease and whether the cancer has metastasized. If cancer has not invaded the bladder muscle tissue, treatment typically includes removal of the tumor followed by chemotherapy administered directly into the bladder. Muscle-invasive bladder cancer is treated with radical cystectomy, meaning removal of the bladder and regional lymph nodes. In males, radical cystectomy also includes the removal of the prostate and seminal vesicles. When a patient's bladder is removed, urinary flow must be redirected, referred to as urinary diversion conduits. Clients with metastatic cancer are typically treated with chemotherapy, immunotherapy, or targeted therapies.[2]

Chronic Kidney Disease

Chronic kidney disease (CKD) is a condition in which the kidneys become progressively damaged and don't filter blood effectively, causing fluids, electrolytes, and toxins to remain in the body instead of being appropriately eliminated in the urine. People with early stages of CKD may not feel ill, but blood and urine tests indicate elevated levels of creatinine and/or protein. Symptoms of later stages of CKD include urinating less frequently; edema (swelling) from fluid retention; shortness of breath from fluid buildup in the lungs; fatigue from anemia due to decreased production of erythropoietin; nausea; vomiting; or itchy skin from electrolyte imbalances and toxin buildup.

CKD usually gets worse over time, though treatment has been shown to slow progression. Chronic kidney disease can cause complications affecting multiple organ systems, including cardiovascular disease, mineral and bone disorders, metabolic acidosis, and neurological issues. As the disease progresses, these complications become more severe. When the kidneys stop functioning, it is called chronic kidney failure or **end-stage renal disease**. **Dialysis** (artificial cleaning of the blood) or a kidney transplant is needed for survival.[3]

2. Lerner, S. (2023). Overview of the initial approach and management of urothelial bladder cancer. *UpToDate*. https://www.uptodate.com/contents/overview-of-the-initial-management-of-urothelial-carcinoma-of-the-bladder

3. Centers for Disease Control. (2024). *Chronic kidney disease basics.* https://www.cdc.gov/kidney-disease/about/index.html

Diabetes Insipidus

Diabetes insipidus (DI) is a condition where the body produces abnormally large amounts of dilute urine, leading to dehydration and excessive thirst. DI occurs due to deficient levels of antidiuretic hormone (ADH) released by the posterior pituitary gland or a lack of response by the kidneys to ADH. DI is caused by head injuries, infections, or surgery near the pituitary gland, kidney disease, or as a side effect of certain medications. DI is typically treated with medications to stimulate ADH production or help the kidneys respond to it better, while also treating dehydration and the underlying causes of the condition. Note that diabetes insipidus is not related to diabetes mellitus, but the elevated levels of blood glucose that can occur in diabetes mellitus can also cause excessive urination.[4]

Glomerulonephritis

Glomerulonephritis is inflammation of the glomeruli (the small blood vessels in the kidneys that filter blood), causing them to lose their ability to filter wastes and excessive water. Protein and red blood cells may leak into the urine while toxins that are normally removed by the kidneys are retained in the bloodstream. A common cause of acute (sudden) glomerulonephritis is the immune system's overreaction to infection, especially those caused by *Streptococcus* (commonly known as "strep throat"), *Pneumococcus*, the varicella virus (commonly known as chicken pox), and malaria (a type of parasite). Chronic (long-term) glomerulonephritis can be caused by genetic disorders, autoimmune disease, or exposure to hydrocarbon solvents.

How long glomerulonephritis lasts depends on its cause and the severity of kidney damage. When glomerulonephritis follows an infection, it typically resolves within weeks to months. For example, children who develop glomerulonephritis following a strep infection typically recover completely. In other cases, glomerulonephritis becomes a chronic condition that lasts for years and can eventually lead to kidney failure.

Mild cases of glomerulonephritis may not cause any symptoms and may only be discovered if protein or blood is found in the urine during a routine urine test. In other cases, the first symptom of glomerulonephritis may be high blood pressure. Other symptoms may include edema in the feet, lower legs, and eyes; shortness of breath due

4. Endocrine Society. (2022). *Diabetes insipidus.* https://www.endocrine.org/patient-engagement/endocrine-library/diabetes-insipidus

to fluid buildup in the lungs; reduced frequency of urination; and dark-colored urine due to the presence of red blood cells. High levels of protein in the urine can also cause it to appear foamy. Complications of glomerulonephritis include severe chronic kidney disease and kidney failure that may require lifelong treatment with dialysis or a kidney transplant.[5]

Kidney Stones

Kidney stones are clusters of crystals that form from substances in the urine that can cause severe pain as they pass through the urinary tract. **Urolithiasis** refers to stones present anywhere in the urinary tract.

Urine has various substances like minerals, acids, and salts dissolved in it. When there is too much of a certain substance in a small amount of fluid, crystals can begin to form that attract other elements, which then join together to form a solid. In most people, having enough water in the urine flushes these crystals out of the urinary tract. Some people have chemicals in their urine that prevent stones from forming. After it is formed, a kidney stone may stay in the kidney and continue to grow larger or travel down the urinary tract into the ureter. In mild cases, tiny stones the size of sand move out of the body in the urine without causing much pain. However, larger stones can cause severe pain and a back-up of urine in the urethra, bladder, ureter, or kidney, affecting the kidney's ability to filter and possibly causing damage to the kidneys. See Figure 15.18[6] for an image of a variety of kidney stones.

5. LeWine, H. E. (2024). *Glomerulonephritis.* Harvard Health Publishing. https://www.health.harvard.edu/diseases-and-conditions/glomerulonephritis-a-to-z

6. Jakupica (2015). *Kidney stones (renal calculi)* [Photograph]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Kidney_stones_%28_renal_calculi_%29,_%D0%91%D1%83%D0%B1%D1%80%D0%B5%D0%B6%D0%BD%D0%B8_%D0%BA%D0%B0%D0%BC%D0%B5%D1%9A%D0%B0_15.jpg



Figure 15.18 Kidney Stones

Common symptoms of kidney stones include severe pain in the lower back, abdomen, or flank (side of the back); blood in the urine; nausea or vomiting; fever and chills; inability to urinate or frequent urination; or urine that smells bad or looks cloudy.

There are four types of kidney stones: calcium oxalate, uric acid, struvite, and cystine. Calcium-based stones are the most common type of kidney stones. They can form when a person eats high-oxalate or low-calcium foods and doesn't drink enough fluids. Uric acid stones can form from eating animal proteins such as beef, poultry, pork, eggs, and fish. Bacterial infections can cause struvite stones. Cystine stones are formed when two cysteine amino acids bind together due to an inherited condition.

People with small kidney stones may be prescribed pain medications while waiting for the stone(s) to pass through their urine. It can take as long as three weeks for kidney stones to pass on their own, and even some small stones can cause extreme pain as they

pass through the urinary tract. Larger kidney stones often require pain medication and medical treatment to break them up and remove them from the urinary tract.[7,8]

Nocturnal Enuresis (Bedwetting)

Passing urine without conscious control while sleeping is called nocturnal enuresis, commonly known as bedwetting. Nocturnal enuresis occurs in more than five million people in the United States. Most children by the age of five can control their bladder during the day and night. However, bedwetting occurs in approximately 10% of six-year-olds, 5% of 10-year-olds, and 1% of teenagers and young adults.

Bedwetting is slightly more common in boys than in girls, and it is more common in children who have coexisting behavioral or psychiatric disorders. As children age and spend more nights away from home at sleepovers with friends and at camps, bedwetting can cause social anxiety, isolation from peers, and depression. Bedwetting can often be treated successfully with a combination of lifestyle modifications, such as fluid restriction before bedtime, voiding schedules throughout the day, a nighttime wakening schedule, and moisture-sensitive alarms that wake the child when bedwetting occurs. If these modifications are not successful, medications may be prescribed.[9]

Polycystic Kidney Disease

Polycystic kidney disease (PKD) is a genetic disorder that causes numerous cysts that are filled with fluid to grow in the kidneys. These cysts can enlarge the kidneys and damage the surrounding tissue, reducing kidney function and possibly leading to kidney failure. See Figure 15.19[10] for an image of PKD.

7. National Kidney Foundation. (n.d.). *Kidney stones.* https://www.kidney.org/kidney-topics/kidney-stones
8. Cleveland Clinic. (2024). *Kidney stones.* https://my.clevelandclinic.org/health/diseases/15604-kidney-stones
9. Urology Care Foundation. (2022). *Nocturnal enuresis (bedwetting).* https://www.urologyhealth.org/urologic-conditions/bed-wetting-(enuresis)
10. Dr. Edwin P. Ewing, Jr. (1972). *Polycystic kidneys, gross pathology CDC PHIL* [Photograph]. Centers for Disease Control. Public Domain. https://commons.wikimedia.org/wiki/File:Polycystic_kidneys,_gross_pathology_CDC_PHIL.png

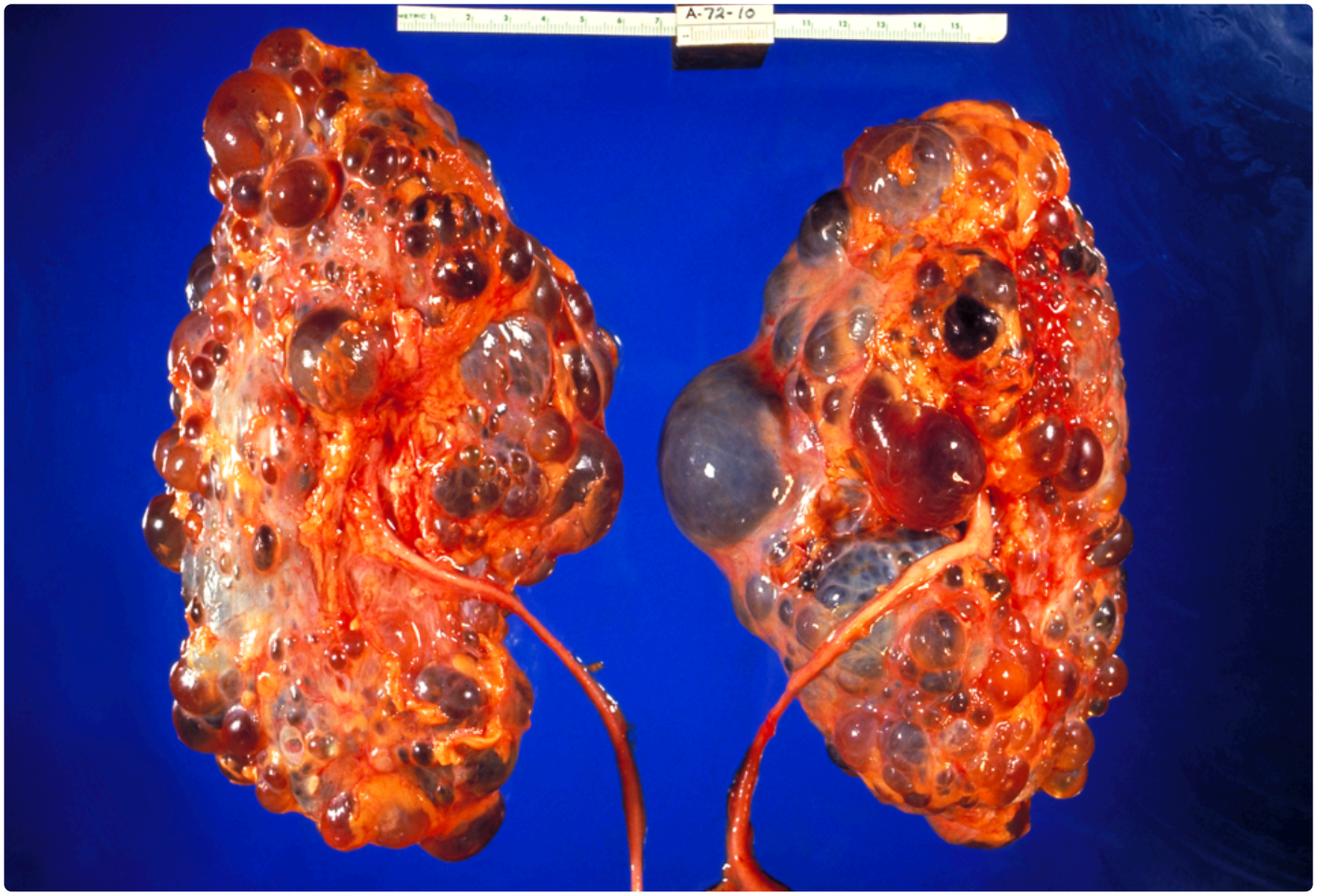


Figure 15.19 Polycystic Kidney Disease

In the United States, about 600,000 people have polycystic kidney disease, which is the fourth leading cause of kidney failure. Men and women are equally at risk for the disease. Most people do not develop symptoms until they are 30 to 40 years old.

Symptoms of PKD can vary but may include high blood pressure, abdominal or back pain, blood in the urine, and a swollen abdomen. About 25% of people with PKD have a coexisting defective valve in their heart that causes symptoms of heart fluttering or pounding, as well as chest pain. These symptoms may be the first clue that someone has polycystic kidney disease.

There is no cure for PKD, but medications may be prescribed to slow the growth of cysts, or surgery may be performed to drain or remove large cysts. In severe cases, a kidney transplant may be required.[11]

11. National Kidney Foundation. (n.d.). *Polycystic kidney disease.* https://www.kidney.org/kidney-topics/polycystic-kidney-disease

Urinary Incontinence

Urinary incontinence is the involuntary loss or leakage of urine that can range from a small annoyance to significantly affecting a person's quality of life. There are several types of urinary incontinence with different causes and treatments, including, but not limited to, the following:

- Stress incontinence occurs when pressure is placed on the bladder, such as when coughing, sneezing, laughing, or exercising.
- Urge incontinence occurs when a sudden, intense urge to urinate leads to involuntary leakage.
- Overflow incontinence is caused by the bladder not emptying completely, causing frequent or constant leaking.
- Functional incontinence is caused by physical or mental limitations that prevent an individual from reaching the toilet in time.

Women are at higher risk for urinary incontinence due to the effects of pregnancy, childbirth, and menopause. Men are more likely to develop overflow incontinence with age because of normal prostate enlargement that prevents complete emptying of the bladder.

Treatment is based on the type of urinary incontinence and may include pelvic floor exercises, timed voiding, bladder training, medications, and surgery.[12]

Urinary Tract Infection

A **urinary tract infection (UTI)** is a common type of infection that occurs when bacteria enter the urethra and infect the urinary tract. Urinary tract infections include cystitis (bladder infections) and pyelonephritis (kidney infections).

Urinary tract infections are more common in females because their urethras are shorter and closer to the rectum and anus, making it easier for bacteria to enter the urinary tract. Other risk factors for urinary tract infections include a previous history of UTI, sexual activity, pregnancy, age (older adults and young children are more likely to

12. National Institute of Diabetes and Digestive and Kidney Diseases. (2021). *Definition & facts for bladder control problems (urinary incontinence).* https://www.niddk.nih.gov/health-information/urologic-diseases/bladder-control-problems/definition-facts

get UTIs), structural problems in the urinary tract (such as an enlarged prostate gland), and poor hygiene (such as in children who are toilet training).

Symptoms include burning during urination, frequent or urgent urination, and cloudy or foul-smelling urine. In severe cases, fever, chills, or back pain may also be present. UTIs are treated with antibiotics, as well as lifestyle changes to prevent future UTIs, such as staying hydrated, wiping from front to back, and urinating frequently.[13,14]

Pyelonephritis (Kidney Infection)

Pyelonephritis, commonly called a kidney infection, is a severe urinary tract infection that causes inflammation in the kidneys. Most kidney infections are caused by bacteria that first infect the bladder and then move up the ureters to one or both of the kidneys. Kidney infections lead to about 250,000 office visits and 200,000 hospital admissions in the United States each year.

Symptoms of pyelonephritis include fever; pain in the back, side, or groin; painful urination; cloudy or foul-smelling urine; and nausea or vomiting. Pyelonephritis is treated with antibiotics for 7 to 14 days. If not treated properly, pyelonephritis can cause chronic kidney disease.[15,16]

13. Centers for Disease Control. (2024). *Urinary tract infection basics.* https://www.cdc.gov/uti/about/index.html
14. Yale Medicine. (n.d.). *Cystitis.* https://www.yalemedicine.org/conditions/cystitis
15. National Institute of Diabetes and Digestive and Kidney Diseases. (2024). *Kidney infection (pyelonephritis).* https://www.niddk.nih.gov/health-information/urologic-diseases/kidney-infection-pyelonephritis
16. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e.* OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

15.5 Career Connections Related to the Urinary System

The urinary system includes the kidneys, ureters, urinary bladder, and urethra. It helps remove waste products from the blood, regulates fluid and electrolyte balance, and produces urine. When the urinary system is affected by disease, injury, infection, or kidney failure, many professionals may help with testing, treatment, patient care, and support. Careers related to the urinary system can include dialysis technicians, medical assistants, registered nurses, nursing assistants, and medical laboratory technicians.

Dialysis Technician

Dialysis technicians, also called hemodialysis technicians, work with the health care team to care for patients whose kidneys are no longer able to effectively filter waste and extra fluid from the blood. They may prepare dialysis equipment, monitor patients during treatment, record information, follow infection prevention procedures, and report patient concerns to licensed health care professionals.

Medical Assistant

Medical assistants work in clinics and other health care settings where they support patient care and office procedures. In nephrology, urology, primary care, or dialysis-related settings, medical assistants may help room patients, collect health information, record symptoms, prepare patients for examinations, assist with basic procedures, support documentation, and communicate follow-up instructions.

Registered Nurse

Registered nurses provide patient care, education, and support in hospitals, clinics, long-term care facilities, home health, and dialysis settings. This career connects to the urinary system because nurses may care for patients with urinary tract infections,

kidney disease, kidney failure, fluid imbalance, or after urinary system procedures. They may monitor symptoms, administer medications, provide patient education, support infection prevention, and coordinate care with other health professionals.

Nursing Assistant

Nursing assistants provide basic care and help patients with daily activities under the supervision of licensed nursing staff. This career connects to the urinary system because nursing assistants may help patients with toileting, catheter care, fluid intake, hygiene, comfort measures, vital signs, and reporting changes in urine output or symptoms.

Medical Laboratory Technician

Medical laboratory technicians perform laboratory tests on blood, urine, and other body fluids that help providers diagnose and monitor disease. This career connects to the urinary system because urine and blood tests can provide important information about kidney function, hydration, infection, electrolyte balance, and other urinary system conditions.

Take a Closer Look

Explore careers related to the human body's urinary system on these websites.

- Dialysis technician from the National Association of Nephrology Technicians/Technologists
- Certified clinical hemodialysis technician from the Nephrology Nursing Certification Commission
- Medical assistant from the American Association of Medical Assistants
- Registered nurse from the American Nurses Association
- Nursing assistant and orderly careers from the U.S. Bureau of Labor Statistics
- Clinical laboratory technologists and technicians from the U.S. Bureau of Labor Statistics

- Urology careers from the American Urological Association

15.6 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

15.7 Glossary

Acidosis: Low pH. (Chapter 15.2, Chapter 15.3)

Adipose capsule: A shock-absorbing layer of adipose tissue. (Chapter 15.3)

Afferent arterioles: Small blood vessels that carry blood into the glomeruli (filtering units) of the kidney's nephrons. (Chapter 15.3)

Aldosterone: The main mineralocorticoid hormone that helps balance sodium and potassium levels and controls blood pressure and volume. (Chapter 15.3)

Alkalosis: Elevated pH. (Chapter 15.2, Chapter 15.3)

Antidiuretic hormone (ADH): A hormone released by the posterior pituitary that helps the body retain water when blood osmolality is high, such as during dehydration. (Chapter 15.3)

Bladder cancer: The most common cancer of the urinary system, causing symptoms like blood in urine, frequent urination, painful urination, and nighttime urination. (Chapter 15.4)

Buffer: A substance that resists changes in pH when small amounts of acid or base are added, helping maintain stable body chemistry. (Chapter 15.3)

Calcitriol: The active form of vitamin D that increases calcium absorption from the intestines and helps regulate calcium and phosphate levels in the blood. (Chapter 15.2)

Calcium pyrophosphate arthritis (pseudogout): An inflammatory joint disease similar to gout but caused by calcium phosphate crystal buildup rather than uric acid. (Chapter 15.4)

Chronic kidney disease (CKD): A progressive condition where damaged kidneys cannot effectively filter blood, causing harmful substances to build up in the body. (Chapter 15.4)

Dehydration: A condition that occurs when fluid intake is less than fluid output, leading to insufficient body water levels. (Chapter 15.3)

Diabetes insipidus (DI): A condition causing excessive production of dilute urine and extreme thirst due to insufficient ADH hormone or kidney unresponsiveness to ADH. (Chapter 15.4)

Dialysis: An artificial process that cleans the blood when the kidneys can no longer filter waste and excess fluid from the body. (**Chapter 15.4**)

Dialysis technician: A dialysis technician or hemodialysis technician works with the healthcare team to provide patient care to people with end-stage renal disease (permanent kidney failure). (**Chapter 15.5**)

Distal convoluted tubule (DCT): The final coiled section of the kidney tubule that connects the nephron loop to the collecting duct and fine-tunes urine composition. (**Chapter 15.3**)

Edema: Swelling caused by excess fluid trapped in the body's tissues, often occurring in the hands, feet, ankles, or legs. (**Chapter 15.2**)

Efferent arterioles: Small blood vessels that carry blood away from the glomeruli to the capillaries surrounding the nephrons. (**Chapter 15.3**)

End-stage renal disease: The final stage of chronic kidney disease, when the kidneys stop functioning, and dialysis or transplant is needed for survival. (**Chapter 15.4**)

Erythropoietin: A hormone produced primarily by the kidneys that stimulates the production of red blood cells in the bone marrow. (**Chapter 15.2**)

Estimated glomerular filtration rate (eGFR): A blood test that calculates how well the kidneys are filtering waste based on creatinine levels, age, and sex to diagnose kidney disease. (**Chapter 15.3**)

External urethral sphincter: A voluntary skeletal muscle below the internal sphincter that provides conscious control over urination. (**Chapter 15.3**)

Glomerular capsule: Surrounds the glomerulus and captures the filtrate being pushed out of the glomerular capillaries; also known as Bowman's capsule. (**Chapter 15.3**)

Glomerular filtration rate (GFR): The volume of filtrate produced by both kidneys per minute, normally about 125 mL/min in males and 105 mL/min in females. (**Chapter 15.3**)

Glomerulonephritis: Inflammation of the glomeruli (the kidney's filtering units) that damages their ability to filter waste and excess water from the blood. (**Chapter 15.4**)

Glomerulus: A ball of capillaries at the beginning of each nephron that begins the filtration of blood. (**Chapter 15.3**)

Gout: A form of arthritis caused when uric acid crystals (a waste product from nucleic acid breakdown) are deposited in a body joint. (**Chapter 15.4**)

Insensible water loss: Water loss from the body that a person is unaware of, such as through breathing, sweating, and skin evaporation. (**Chapter 15.3**)

Internal urethral sphincter: An involuntary smooth muscle that automatically controls the release of urine from the bladder. (**Chapter 15.3**)

Juxtaglomerular apparatus (JGA): A specialized structure in the kidney where blood vessels and tubules meet that produces renin to help regulate blood pressure. (**Chapter 15.3**)

Ketones: Substances produced when the body burns fat for energy instead of glucose, detected in urine during conditions like diabetes or fasting. (**Chapter 15.3**)

Kidney lobe: A unit of the kidney, consisting of a central renal pyramid, the overlying cortex, and half of the adjacent renal columns on either side. (**Chapter 15.3**)

Kidney stones: Crystal clusters formed from substances in urine that cause severe pain when passing through the urinary tract. (**Chapter 15.4**)

Micturition: The medical term for urination or emptying the bladder, which begins when bladder volume reaches about 150 mL. (**Chapter 15.3**)

Nephrologist: A physician who specializes in diagnosing and treating kidney diseases and conditions. (**Chapter 15.4**)

Nephrology: The study of the anatomy and physiology of the kidneys and kidney diseases. (**Chapter 15.1**)

Nephron loop (loop of Henle): A U-shaped portion of the kidney tubule with descending and ascending parts that reabsorbs sodium and water from filtered urine. (**Chapter 15.3**)

Nephrons: Functional units of the kidney that filter blood and convert the filtrate into urine. (**Chapter 15.3**)

Peritubular capillaries: Tiny blood vessels that surround nephrons in the kidney's outer region (cortex) for the exchange of substances. (**Chapter 15.3**)

Polycystic kidney disease (PKD): A genetic disorder causing fluid-filled cysts to grow in the kidneys, potentially enlarging them and damaging tissue, leading to kidney failure. (**Chapter 15.4**)

Proximal convoluted tubule (PCT): The first, coiled section of the kidney's renal tubule where initial filtration and reabsorption of substances from urine occurs. (**Chapter 15.3**)

Pyelonephritis: A severe kidney infection caused by bacteria that spread from the bladder up through the ureters, causing inflammation in the kidneys. (**Chapter 15.4**)

Renal artery: A blood vessel that branches off from the abdominal aorta and supplies oxygen-rich blood to the kidneys. (Chapter 15.3)

Renal capsule: A tough, fibrous outer covering of the kidney that protects it from trauma and infection. (Chapter 15.3)

Renal columns: Extensions of cortical tissue that separate renal pyramids in the medulla, divide the kidney into lobes, and support blood vessels entering and exiting the cortex. (Chapter 15.3)

Renal corpuscle: A structure composed of two parts: the glomerulus and the glomerular capsule. (Chapter 15.3)

Renal cortex: The outer region of the kidney. (Chapter 15.3)

Renal fascia: A layer of connective tissue that anchors the kidneys to surrounding structures and helps maintain their position in the abdominal cavity. (Chapter 15.3)

Renal hilum: The slight indentation on the medial side of each kidney where blood vessels, nerves, lymphatic vessels, and the ureters connect. (Chapter 15.3)

Renal pyramids: Six to eight cone-shaped tissues in the medulla of each kidney. (Chapter 15.3)

Sensible water loss: Water loss from the body that a person is aware of and can measure, mainly through urine production. (Chapter 15.3)

Specific gravity: A measure of the concentration of dissolved substances in urine compared to pure water, indicating how concentrated the urine is. (Chapter 15.3)

Transitional epithelium (also known as urothelium): A type of epithelium that can stretch and change shape. (Chapter 15.3)

Tubular reabsorption: The process by which the nephron returns water and solutes from the filtrate back into the blood. (Chapter 15.3)

Tubular secretion: The process by which substances are moved from the blood into the filtrate in the kidney tubules to be eliminated in urine. (Chapter 15.3)

Urethra: The tube that carries urine from the bladder to the outside of the body, with structural differences between males and females. (Chapter 15.3)

Urinalysis: A diagnostic laboratory test that examines urine composition to detect infections, diseases, or other health abnormalities. (Chapter 15.3)

Urinary incontinence: Involuntary loss or leakage of urine that can range from minor to significantly impacting quality of life. (Chapter 15.4)

Urinary tract infection (UTI): A common bacterial infection of the urinary tract that can affect the bladder (cystitis) or kidneys (pyelonephritis). (**Chapter 15.4**)

Urolithiasis: The presence of stones anywhere in the urinary tract, including the kidneys, ureters, bladder, or urethra. (**Chapter 15.4**)

Urology: The study of male and female urinary systems, as well as the male reproductive system. (**Chapter 15.1**)

Urothelium (also known as transitional epithelium): A specialized, stratified tissue layer lining most of the urinary tract, including the renal pelvis, ureters, bladder, and urethra

Vasa recta: Straight blood vessels that surround the nephron loops in the kidney's inner region (medulla). (**Chapter 15.3**)

PART XVI

CHAPTER 16 REPRODUCTIVE SYSTEM

16.1 Introduction to the Reproductive System

Chapter Competency

Analyze how components of the reproductive systems function in the body.

Learning Objectives

- Identify the gross and microscopic structural components of the male and female reproductive systems.
- Correlate the structural components of the male and female reproductive system with their functions.
- Identify the secretions of the male and female reproductive systems and their functions.
- Summarize the functions of the reproductive systems.

Imagine you are working as a diagnostic medical sonographer preparing to perform an ultrasound exam related to the reproductive system. Depending on the patient's needs, you may be asked to visualize structures such as the ovaries, uterus, testes, or associated ducts and glands. To obtain accurate images and communicate findings clearly with the care team, you must understand the location, structure, and function of reproductive organs, as well as how hormones influence reproductive processes.

Reproduction is the process of forming a new organism. In humans, reproduction involves the male and female reproductive systems. These systems produce specialized sex cells, secrete sex hormones, and support the processes that allow genetic information to be passed from one generation to the next.

Humans are considered **diploid** organisms because most body, or somatic, cells contain 23 pairs of chromosomes, for a total of 46 chromosomes. One set of chromosomes is inherited from each parent. Of these 23 pairs, 22 pairs are **autosomal chromosomes**, which carry thousands of genes that influence body structure and

function. The 23rd pair are the **sex chromosomes**, which help determine biological sex. Typically, individuals with two X chromosomes develop female reproductive structures, while individuals with one X chromosome and one Y chromosome develop male reproductive structures. The presence of a Y chromosome usually triggers the development of male reproductive anatomy, while its absence usually results in the development of female reproductive anatomy.

A **gamete** is a specialized sex cell. In males, the gamete is called a **spermatozoon** (plural = spermatozoa), or sperm. In females, the gamete is called an **ovum** (plural = ova), or egg. Sperm and ova are **haploid** cells, meaning they contain one set of 23 chromosomes, or half the number found in most somatic cells. During fertilization, a sperm and an ovum combine their chromosomes to form a new diploid cell called a **zygote**.

Because sperm are haploid, each sperm carries either an X chromosome or a Y chromosome. The ovum carries an X chromosome. If a sperm carrying an X chromosome fertilizes an ovum, the resulting zygote typically has XX sex chromosomes. If a sperm carrying a Y chromosome fertilizes an ovum, the resulting zygote typically has XY sex chromosomes. In this way, the chromosome carried by the sperm determines the chromosomal sex of the zygote.

In this chapter, you will explore the structure and function of the reproductive systems. You will learn about the anatomy of the male reproductive system, including the testes, ducts, glands, and external genitalia, as well as the processes of puberty and spermatogenesis. You will also study the female reproductive system, including the ovaries, uterine tubes, uterus, vagina, external genitalia, and mammary glands. In addition, you will examine female puberty, the ovarian cycle, the menstrual cycle, and common reproductive system diseases and disorders.

By mastering these concepts, you will gain a deeper understanding of how reproductive structures support gamete production, hormone secretion, reproductive cycles, and reproductive health. This foundation will help you connect reproductive anatomy and physiology to patient education, imaging, assessment, hormonal regulation, fertility, menstrual health, and disorders affecting the reproductive system.

16.2 Functions of the Reproductive System

The major functions of the reproductive system are regulating sexual development and producing offspring to ensure the survival of the species. These functions include producing hormones, creating and transporting reproductive cells called gametes (sperm and eggs), and, in females, nurturing a developing fetus during pregnancy.[1]

The structures and specific functions of the male and female reproductive systems are described in more detail in the following sections.

1. National Cancer Institute SEER Training Modules. (n.d.). *Introduction to the reproductive system*. National Institutes of Health. https://training.seer.cancer.gov/anatomy/reproductive/

16.3 Male Reproductive System Anatomy

The structures of the male reproductive system include the scrotum, testes, epididymis, vas deferens, accessory glands, penis, and urethra.[1]

See Figure 16.1[2] for an illustration of the structures of the male reproductive system.

1. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e.* OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction
2. OpenStax. (2013). *Figure_28_01_01.jpg* [Diagram]. Wikimedia Commons. CC BY 3.0. https://en.wikipedia.org/wiki/File:Figure_28_01_01.jpg

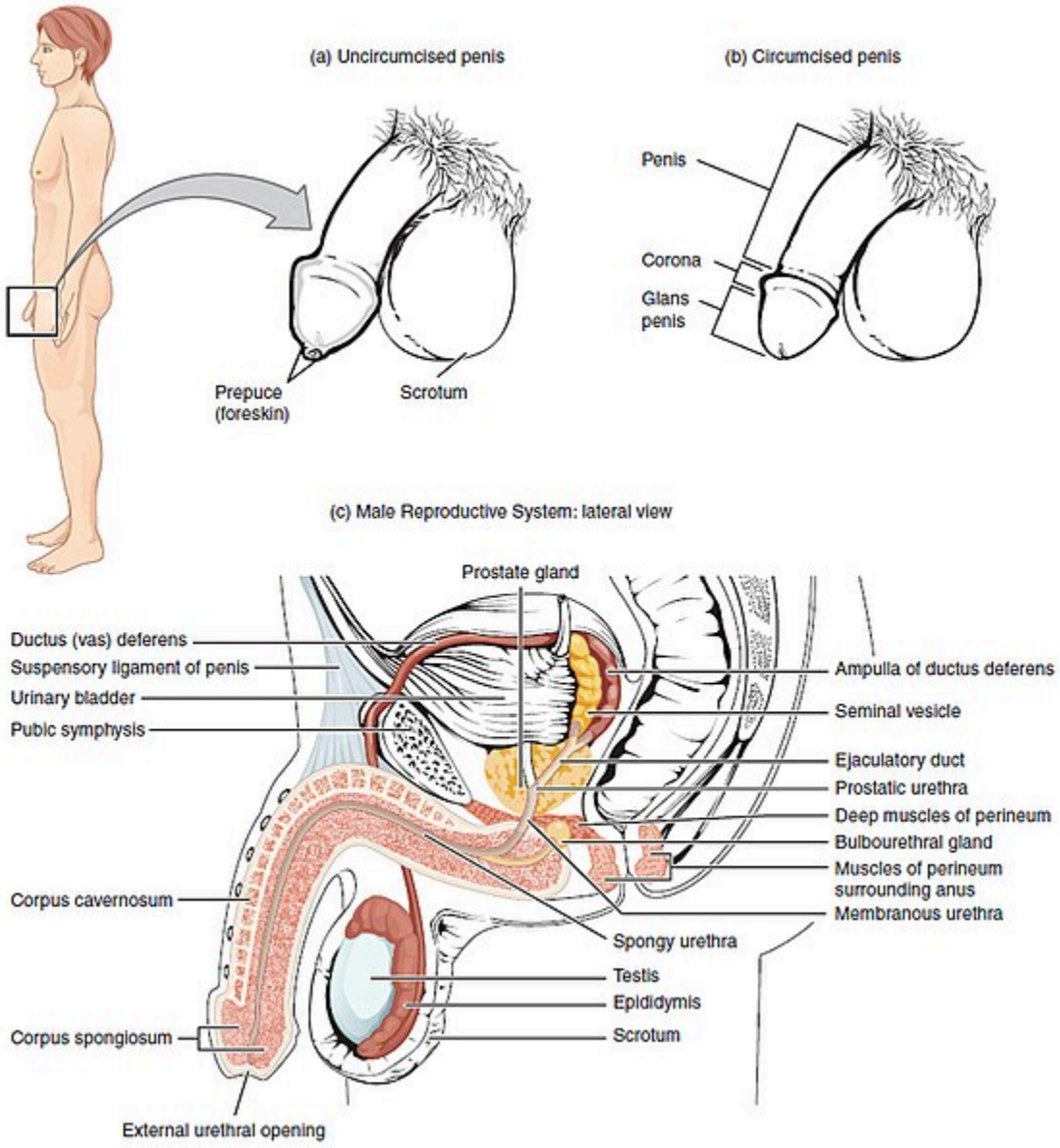


Figure 16.1 Male Reproductive System

Scrotum

The **scrotum** is a muscular sac that contains the testes (singular = testis). It hangs slightly away from the body, posterior to the penis. This location is important as viable sperm production in the testes requires a temperature 2 to 4°C below core body temperature.

The **dartos muscle** makes up the muscle layer of the scrotum. It continues internally to make up the **scrotal septum**, a wall that divides the scrotum into two compartments, each housing one testis.

Two **cremaster muscles** cover each testis like a muscular netting. By contracting simultaneously, the dartos and cremaster muscles can elevate the testes when cold, moving the testes closer to the body and decreasing the surface area of the scrotum to retain heat. Alternatively, as temperature increases, the scrotum relaxes, moving the testes farther from the body and increasing scrotal surface area, which promotes heat loss. Externally, the scrotum has a raised medial thickening on the surface called the **raphe**.

See Figure 16.2[3] for an illustration of the scrotum.

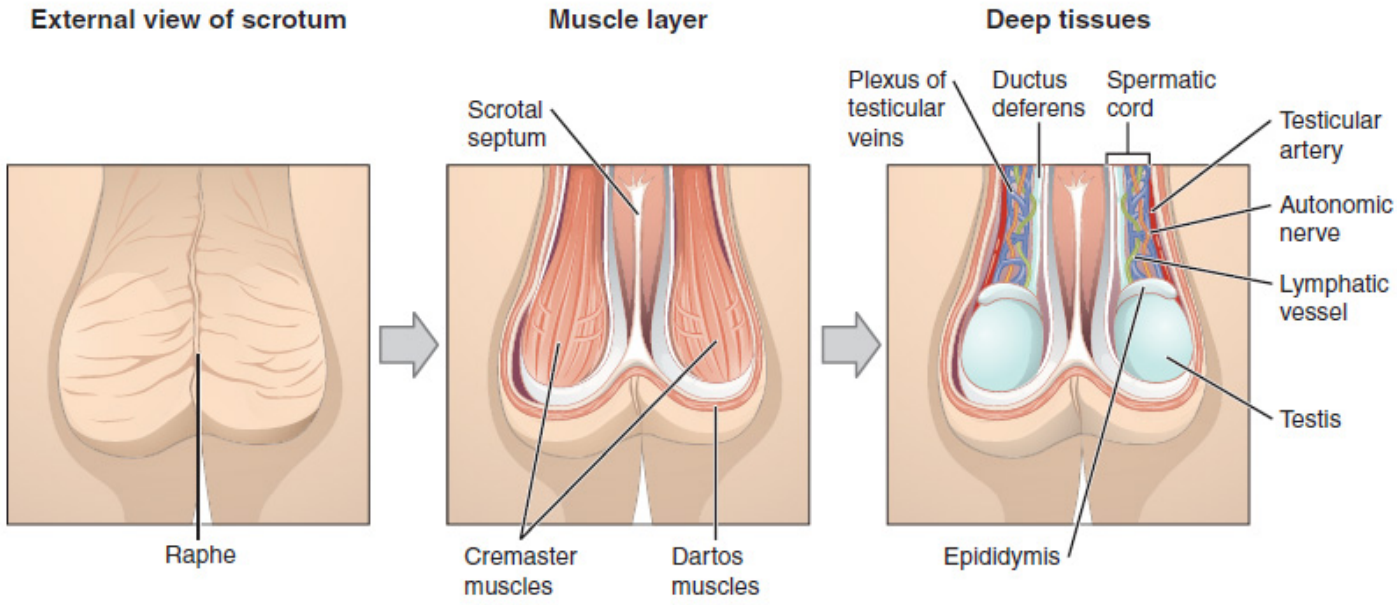


Figure 16.2 Scrotum

Testes

The **testes** (singular = testis) are the male reproductive organs or gonads. They produce both sperm and hormones, such as testosterone, and are active from puberty until death. The two adult testes are each approximately 4 to 5 cm in length and are housed within the scrotum.

Very long and tightly coiled **seminiferous tubules** form the interior of each testis. The seminiferous tubules are composed of Sertoli cells that contain developing sperm.

3. OpenStax. (2013). *Figure_28_01_02* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Figure_28_01_02.JPG

These immature sperm are released into the lumen or hollow center of the seminiferous tubules and make their way to the epididymis.

See Figure 16.3[4] for an illustration of the anatomy of the testes.

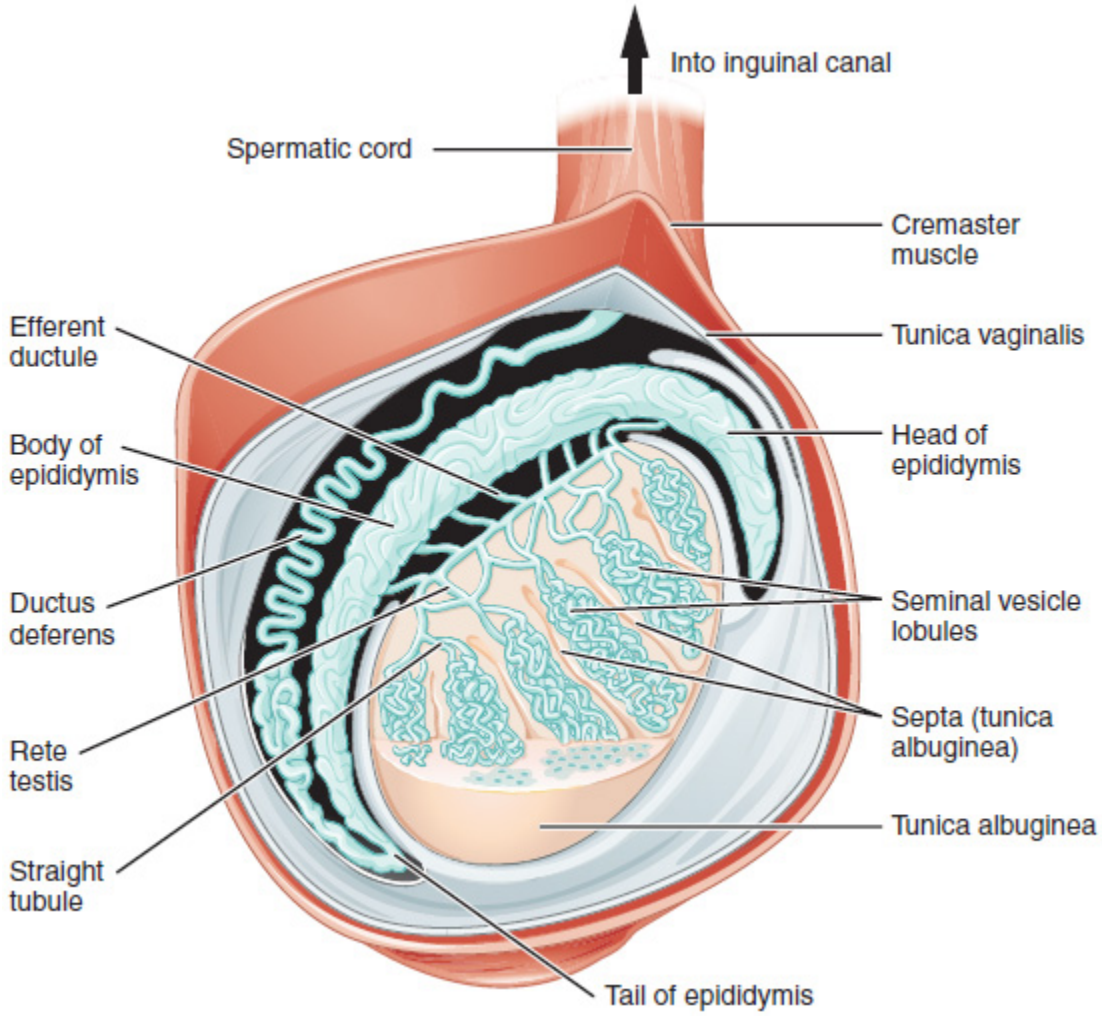


Figure 16.3 Anatomy of the Testis

Cells of the Testes

There are many different cells found within the testes, including **spermatogonia**, sperm cells, Sertoli cells, and Leydig cells.

4. OpenStax. (2013). *Figure_28_01_03.JPG* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Figure_28_01_03.JPG

Spermatogonia and Sperm

The least mature cells in the testes are the spermatogonia (singular = spermatogonium). Spermatogonia are the stem cells of the testis, which means that they are able to differentiate into sperm.

Spermatogonia divide via mitosis into two cells. One is retained as a spermatogonium, and the other cell differentiates into a primary spermatocyte. The primary spermatocyte undergoes meiosis I to form two haploid secondary spermatocytes. These two cells undergo Meiosis II to form four spermatids, which then develop into mature sperm. The process that begins with spermatogonia and ends with mature sperm is called **spermatogenesis**. More information on spermatogenesis can be found in Chapter 16.4 under Spermatogenesis. See Figure 16.4[5] for an illustration of spermatogenesis.

5. OpenStax. (2013). *Figure_28_01_04* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Figure_28_01_04.jpg

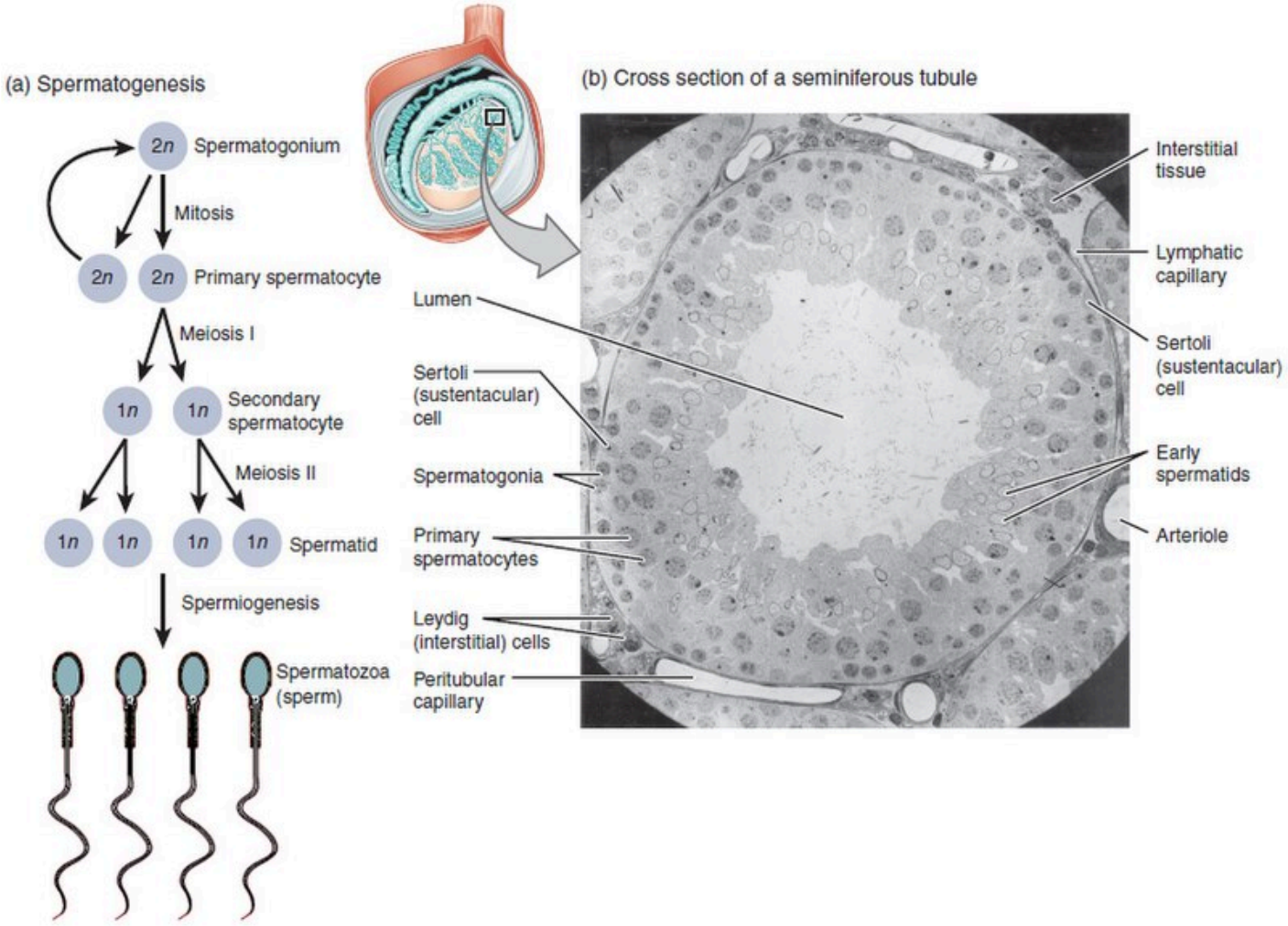


Figure 16.4 Spermatogenesis

Sertoli Cells

Surrounding the developing sperm cells are Sertoli cells. **Sertoli cells** (or sustentacular cells) are a type of supporting cell that are typically found in epithelial tissue. Sertoli cells promote sperm production and can control whether sperm live or die. Tight junctions between these sustentacular cells create the **blood–testis barrier**, which protects developing sperm from the individual's immune system. Refer back to Figure 16.4 for an illustration of Sertoli cells.

Leydig Cells

A fourth type of cell found in the testes is the **Leydig cell**, which produces the

hormone testosterone. The alternate term for Leydig cells is **interstitial endocrine cells**, which reflects their location between the seminiferous tubules in the testes. Refer back to Figure 16.4 for an illustration of Leydig cells.

Epididymis

From the lumen of the seminiferous tubules, the sperm are surrounded by testicular fluid and moved to the **epididymis** (plural = epididymides), a coiled tube attached to the testis where newly formed sperm continue to mature.

Though the epididymis does not take up much room due to its tightly coiled shape, it would be approximately 6 m (20 feet) long if straightened. It takes an average of 12 days for sperm to move through the coils of the epididymis. As sperm move through the epididymis, the sperm further mature and acquire the ability to move on their own. The more mature sperm are then stored in the tail of the epididymis (the final section) until ejaculation occurs. Refer back to Figure 16.3 illustrating the anatomy of a testis to view the epididymis.

Vas (Ductus) Deferens

During ejaculation, sperm exit the tail of the epididymis and are pushed by smooth muscle contraction through the **vas deferens** (also called the ductus deferens). The vas deferens are two thick, muscular tubes that are bundled together inside the scrotum with connective tissue, blood vessels, lymphatic vessels, muscle, and nerves into a structure called the **spermatic** cord. Refer back to Figures 16.1 and 16.2 to view an illustration of the vas (ductus) deferens.

From each epididymis, each vas deferens extends superiorly into the abdominal cavity through the **inguinal canal** in the abdominal wall. From here, the vas deferens continues into the pelvic cavity, ending posterior to the bladder, where it dilates in a region called the ampulla (meaning “flask”).

Because the vas deferens is physically accessible within the scrotum, surgical sterilization to prevent sperm delivery can be performed by cutting and sealing a small section of the vas deferens. This procedure is called a vasectomy, and it is an effective form of birth control. However, it may be possible to reverse a **vasectomy**, clinicians consider the procedure permanent.

Accessory Glands

Sperm make up only 5 percent of **semen**, the thick, milky fluid that is ejaculated. The normal volume of semen varies from 1.5 to 5.0 milliliters per ejaculation, with sperm count varying from 20 to 150 million sperm per milliliter.[6]

Most of the semen is produced by the accessory glands of the male reproductive system: the seminal vesicles, the prostate gland, and the bulbourethral glands. Semen has an alkaline pH. This is important to help neutralize the acidity of the vagina so that some sperm survive.

Seminal Vesicles

As sperm pass through the ampulla of each vas deferens at ejaculation, they mix with fluid from the **seminal vesicle (or seminal gland)**. The paired seminal vesicles are glands that contribute approximately 60 percent of the semen volume. Seminal vesicle fluid contains prostaglandins to help with sperm motility and large amounts of fructose, which is used by the sperm mitochondria as an energy source to generate ATP to produce movement through the female reproductive tract.

The fluid, now containing both sperm and seminal vesicle secretions, moves into the **ejaculatory duct**, a short structure formed from the ampulla of the vas deferens and the duct of the seminal vesicle. The paired ejaculatory ducts transport the seminal fluid into the prostate gland.

Refer back to Figure 16.1 for an illustration of the seminal vesicles and the ejaculatory duct.

Prostate Gland

The **prostate gland** sits inferior to the bladder, surrounding the **prostatic urethra** (the portion of the urethra that travels through the prostate). About the size of a walnut, the prostate gland is formed of both muscular and glandular tissues. It adds an alkaline, milky fluid to the semen that is important to first coagulate (thicken) and then de-coagulate the semen following ejaculation. The temporary thickening of semen helps retain it within the female reproductive tract, providing time for sperm to utilize the

6. Medline [Internet]. (2024). *Semen analysis*. https://medlineplus.gov/ency/article/003627.htm

fructose provided by seminal vesicle secretions. The semen then liquifies so sperm can pass further into the female reproductive tract. Refer back to Figure 16.1 for an illustration of the prostate gland. The prostate gland also adds citric acid, an important nutrient, and seminalplasmin, a natural antibiotic, to the semen.[7]

Prostate-specific antigen (PSA) is a protein produced by both cancerous and noncancerous tissue in the prostate. Prostate-specific antigen is mostly found in semen, but small amounts of PSA also circulate in the blood. The **PSA test** is a blood test used primarily to screen for prostate cancer. The test measures the amount of prostate-specific antigen in the blood and can detect high levels of PSA that may indicate the presence of prostate cancer. However, many other conditions, such as an enlarged or inflamed prostate, can also increase PSA levels.[8]

Bulbourethral Glands

The final addition to semen is made by two **bulbourethral glands** (also known as **Cowper's glands**). The bulbourethral glands release a thick, salty fluid that lubricates the end of the urethra and the vagina and helps to clean urine residues from the penile urethra. The fluid from these accessory glands is released after the male becomes sexually aroused and shortly before the release of the semen. It is sometimes called pre-ejaculate. Refer back to Figure 16.1 for an illustration of the bulbourethral glands.

Video

Watch the MedlinePlus health video to learn how sperm move through the male reproductive system during ejaculation[9]

- Open the MedlinePlus sperm release pathway health video webpage

7. Shivaji S. (1988). Seminalplasmin: A protein with many biological properties. *Bioscience Reports, 8*(6), 609–618. https://doi.org/10.1007/BF01117340
8. Mayo Clinic. (2025). *PSA test.* https://www.mayoclinic.org/tests-procedures/psa-test/about/pac-20384731
9. MedlinePlus. (2025, October 5). Sperm release pathway [Video]. U.S. National Library of Medicine. All rights reserved. Link: https://medlineplus.gov/ency/anatomyvideos/000121.htm

Penis

The **penis** is the male copulatory (sex) organ. It is soft for non-sexual actions such as urination, and swollen and rod-like with sexual arousal. Three columns of erectile tissue make up most of the volume of the penis. When erect, the stiffness of the penis allows it to penetrate into a female's vagina and deposit semen into the reproductive tract.

Shaft of Penis

The shaft of the penis is composed of three column-like chambers of erectile tissue. Each of the two larger lateral chambers is called a **corpus cavernosum** (plural = corpora cavernosa). Together, these make up the bulk of the penis. The **corpus spongiosum**, which can be felt as a raised ridge on the erect penis, is a smaller chamber that surrounds the spongy, or penile, urethra and makes up the head (or glans) of the penis.

See Figure 16.5[10] for illustrations of a flaccid and erect penis.

10. OpenStax. (2013). *Figure_28_01_06* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Figure_28_01_06.jpg

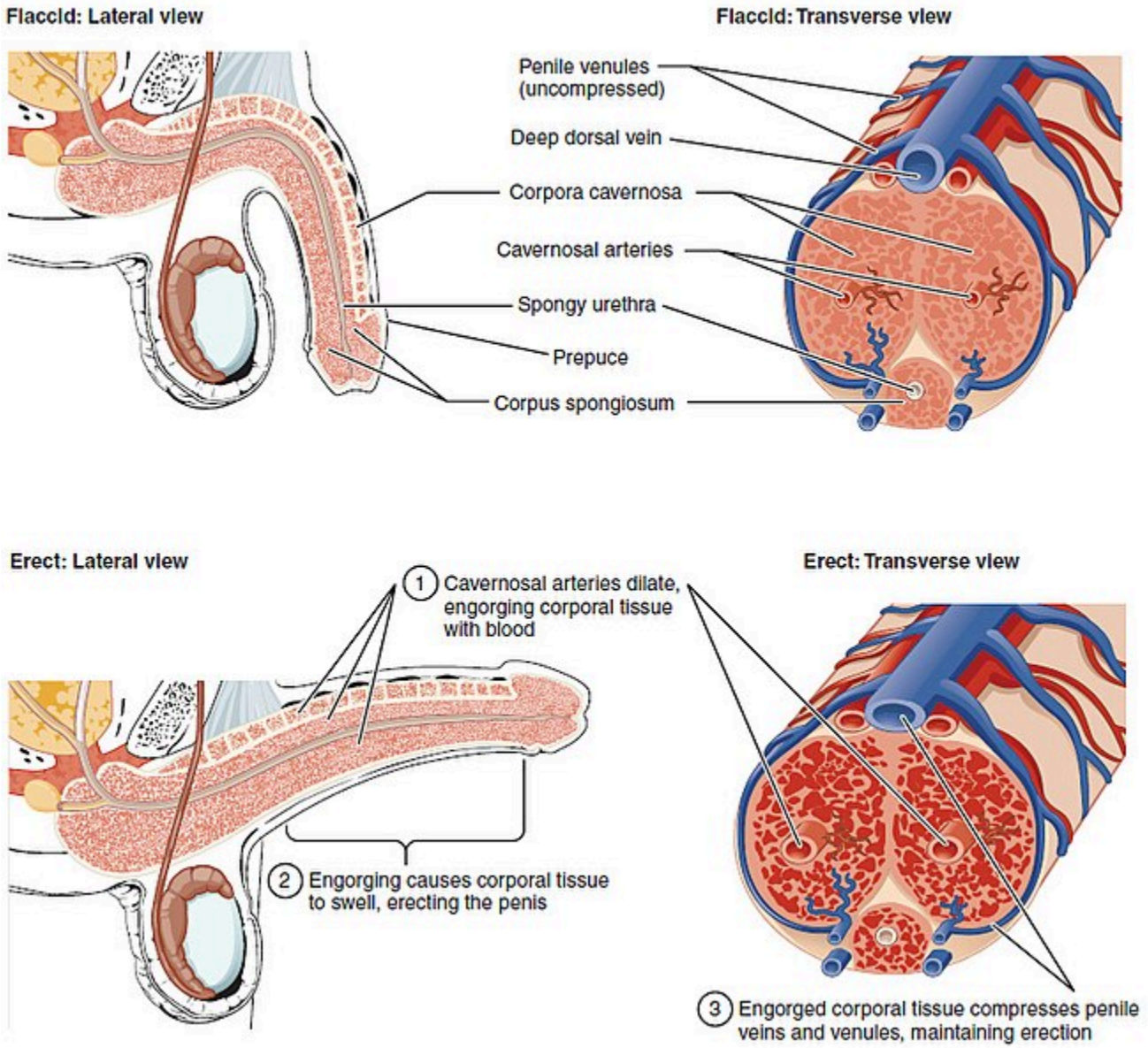


Figure 16.5 Penis

Glans Penis

The end of the penis, called the **glans penis**, has a high concentration of nerve endings, resulting in very sensitive skin. The skin from the shaft extends down over the glans and forms a covering called the **prepuce** (also known as the **foreskin**). The prepuce also contains a dense concentration of nerve endings, and both lubricates and protects the sensitive skin of the glans penis. A surgical procedure called **circumcision**, often performed for religious or social reasons, removes the prepuce, typically within days of birth.

Both sexual arousal and REM sleep (during which dreaming occurs) can cause an erection. Erections are the result of **vasocongestion**, or engorgement of the tissues because more arterial blood is flowing into the penis than is leaving. Depending on the flaccid dimensions of a penis, it can increase in size slightly or greatly during erection, with the average length of an erect penis measuring approximately 6 inches (15 cm).

Urethra

The penis contains the urethra that carries both urine and semen out of the body. The urethra has three regions, including the prostatic urethra, the membranous urethra, and the spongy (or penile) urethra.

The **prostatic urethra** passes through the prostate gland. During sexual intercourse, it receives sperm via the ejaculatory ducts and secretions from the seminal vesicles. The bulbourethral glands produce and secrete mucus into the urethra to buffer urethral pH during sexual stimulation. The mucus neutralizes the usually acidic environment and lubricates the urethra, decreasing the resistance to ejaculation. The short **membranous urethra** passes through the deep muscles of the perineum between the prostate gland and the penis. The **spongy (or penile) urethra** is located within the corpus spongiosum (giving it the name "spongy urethra") and is the longest section. It passes through the length of the penis and exits at the tip of the penis through an opening called the **external urethral orifice**. See Figure 16.6[11] for an illustration of the three regions of the male urethra.

11. CFCF. (2013). *Penis lateral cross section* [Diagram]. Wikimedia Commons. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Penis_lateral_cross_section.jpg#/media/Fichier:Penis_lateral_cross_section.jpg

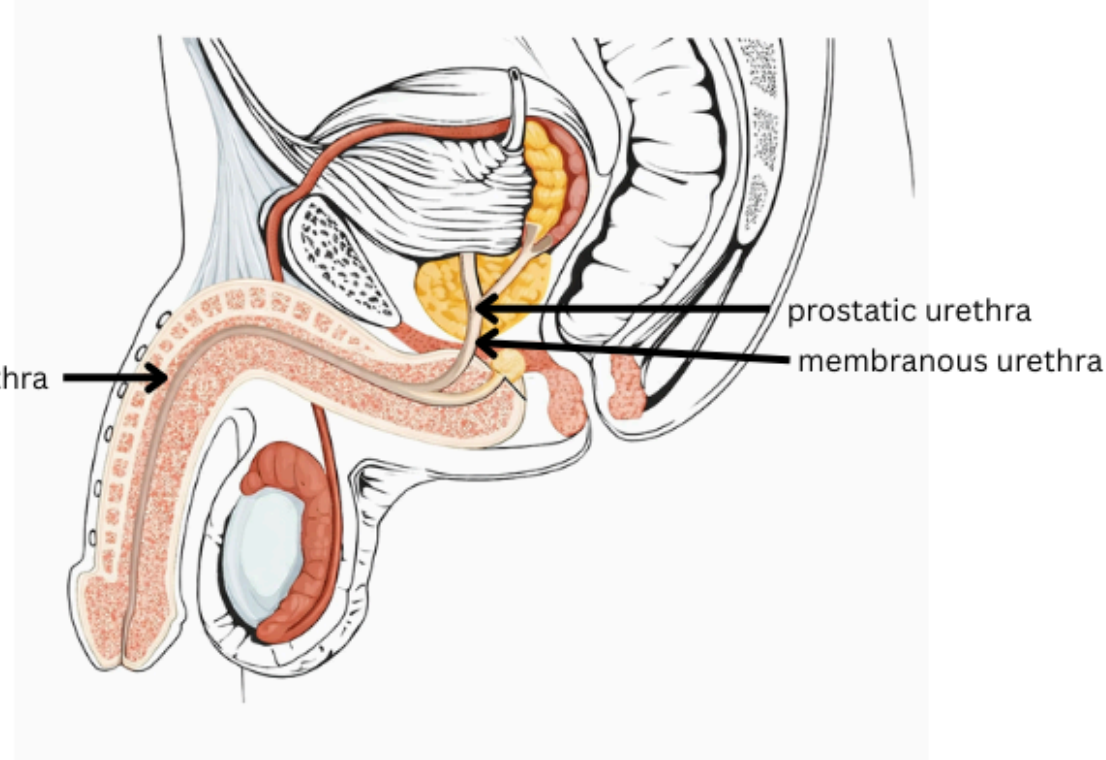


Figure 16.6 Parts of the Urethra

16.4 Male Puberty and Spermatogenesis

Puberty is the stage of development when individuals become sexually mature. Though the outcomes of puberty for males and females are very different, the hormonal control of the process is very similar. In addition, though the timing of these events varies between individuals, the sequence of changes that occur is predictable for adolescents.

Male Reproductive Hormones

The onset of puberty is controlled by hormones. The hypothalamus begins to secrete a hormone called gonadotropin-releasing hormone (GnRH). This hormone stimulates the anterior pituitary gland to secrete follicle-stimulating hormone (FSH) and luteinizing hormone (LH). The first changes begin around the age of eight or nine when the production of LH becomes detectable. The release of LH occurs primarily at night during sleep and precedes the physical changes of puberty by several years.

As an individual approaches puberty, the levels of LH and FSH slowly increase and lead to the enlargement and maturation of the testes. LH stimulates the Leydig cells to secrete higher levels of testosterone, and FSH stimulates the Sertoli cells to begin spermatogenesis (sperm production).

Secondary Sex Characteristics

The increasing levels of testosterone also cause the development of secondary sex characteristics. In males, the growth of the testes is typically the first physical sign of the beginning of puberty, which is followed by growth and increased pigmentation of the scrotum and growth of the penis. The next step is the growth of hair, including armpit, pubic, chest, and facial hair. Testosterone stimulates the growth of the larynx and thickening and lengthening of the vocal folds, which causes the voice to deepen or drop in pitch. The first fertile ejaculations typically appear at approximately 15 years of age, but this age can vary widely across individuals. The male growth spurt occurs throughout

puberty, at approximately age 11 to 13, and height can increase as much as four inches in a year. In some individuals, pubertal development can continue through the early 20s.

In addition to age, multiple factors can affect the age of onset of puberty, including genetics, environment, psychological stress, and nutrition. Some studies indicate a link between puberty onset and the amount of stored fat in an individual. This effect is more pronounced in females but has been documented in both sexes.

See Figure 16.7[1] for an illustration of the hormones of puberty.

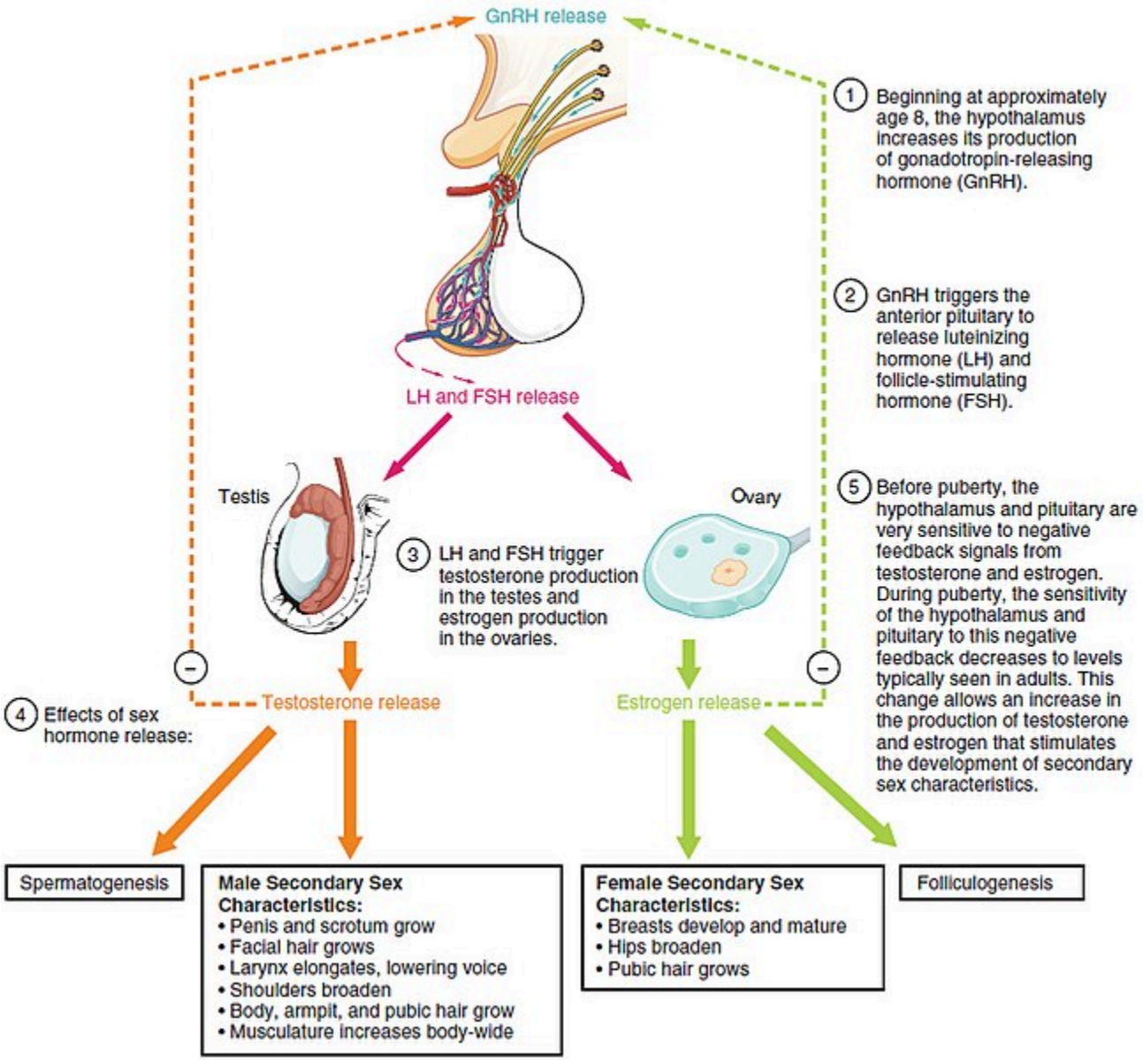


Figure 16.7 Hormones of Puberty

1. OpenStax. (2013). *Figure_28_03_01* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Figure_28_03_01.jpg

Spermatogenesis

Spermatogenesis, the production of sperm, occurs in the seminiferous tubules. Spermatogenesis begins at puberty and continues throughout life. The production of sperm from a spermatogonium to a mature sperm takes approximately 64 days. The number of sperm produced per day varies from 100,000 to 300,000. Sperm counts slowly decline after the age of 35, and some studies suggest that smoking can lower sperm counts at any age.

The process of spermatogenesis uses two types of cell division, mitosis and meiosis. **Mitosis** is the division of a somatic cell (all the cells in the body except the sperm and ovum) into two identical daughter cells, each with 46 chromosomes.

Meiosis is a special type of cell division that occurs only in the sperm and ovum. It requires two rounds of division (prophase, anaphase, metaphase, and telophase) with no interphase between round one (Meiosis I) and round two (Meiosis II). An exchange of genes between chromosomes called "crossing over" occurs during Prophase I, the beginning of meiosis, resulting in a new combination of genes. The two rounds of division result in four genetically unique daughter cells with 23 chromosomes in each cell.

Step I: Mitosis of the Spermatogonia

The process of spermatogenesis begins with mitosis of the spermatogonia (sperm-producing stem cells). Because spermatogonia are diploid (2n), they have 46 total chromosomes arranged in 23 pairs of chromosomes. A copy of these chromosomes is made during interphase so that when the spermatogonia divide, the new cells will have the same number of chromosomes as the original cell. The division of the spermatogonia by mitosis results in two identical diploid spermatogonium cells, each with 46 chromosomes.

One of these two cells remains a spermatogonium, and the other **differentiates** or passes through the blood-testis barrier and becomes a **primary spermatocyte**.

Step II: Meiosis I

DNA is replicated again during interphase in a primary spermatocyte, so the cell starts Meiosis I with 46 chromosomes and a copy of those 46 chromosomes. The primary

spermatocyte goes through Prophase I, Metaphase I, Anaphase I, and Telophase I to divide, resulting in two cells called **secondary spermatocytes**. Each secondary spermatocyte now has half the number of chromosomes, or 23 chromosomes, and is genetically unique. No replication of DNA occurs between Meiosis I and Meiosis II, and the two secondary spermatocytes go directly into Meiosis II.

Step III: Meiosis II

The two secondary spermatocytes begin Meiosis II with 23 total chromosomes in each cell. They both go through Prophase II, Metaphase II, Anaphase II, and Telophase II to divide, resulting in four haploid cells with 23 chromosomes in each cell. Each of these new haploid cells is called a **spermatid**.

See Figure 16.8[2] for an overview of spermatogenesis.

2. OpenStax. (2013). *Figure_28_01_04* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Figure_28_01_04.jpg

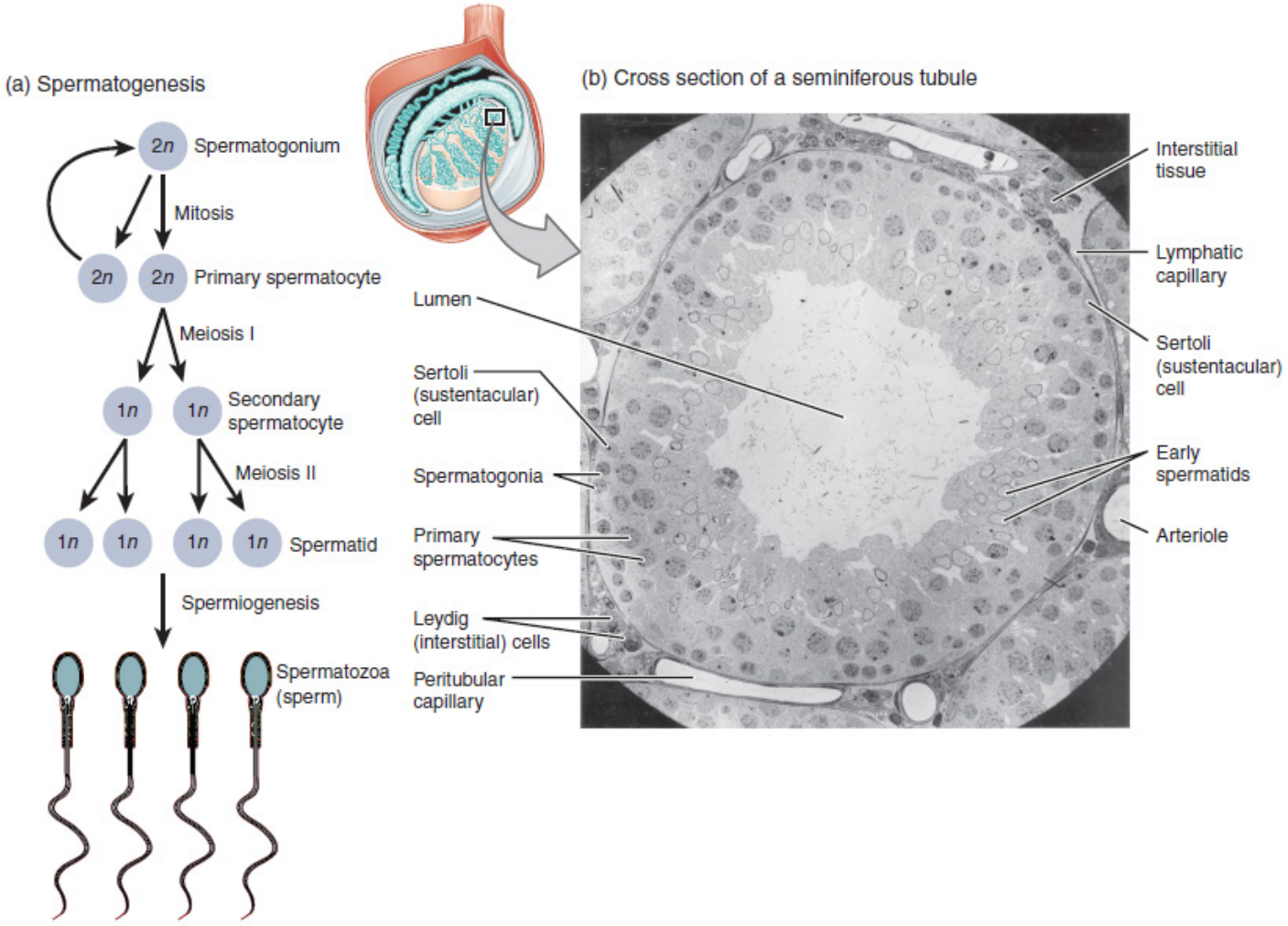


Figure 16.8 Spermatogenesis: (a) Mitosis and Meiosis Produce Four Spermatids and (b) Seminiferous Tubule with Spermatocytes and Spermatids

Spermiogenesis

A process called **spermiogenesis** transforms these early spermatids, beginning the formation of the parts of a true sperm. **Spermatozoa**, or formed sperm, are the end result of this process. Eventually, the sperm are released into the lumen and travel to the epididymis to mature.

Sperm

Sperm are smaller than most cells in the body; in fact, the size of a sperm cell is 85,000 times smaller than that of the ovum. Sperm have a distinctive head, midpiece, and tail region.

The head of the sperm contains the nucleus and DNA. A structure called the **acrosome** covers most of the head of the sperm cell as a "cap" that is filled with lysosomal enzymes important for the sperm to penetrate an egg. Mitochondria fill the midpiece of the sperm. ATP produced by these mitochondria will power the **flagellum**, which extends from the midpiece through the tail of the sperm, enabling it to move the entire sperm cell. See Figure 16.9[3] for an illustration of the structure of a sperm cell.

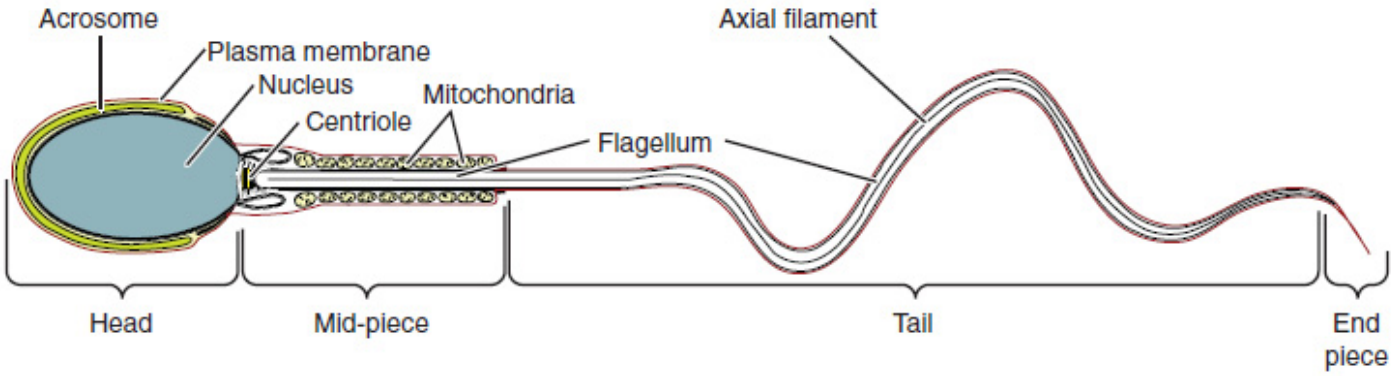


Figure 16.9 Structure of Sperm

3. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Structure of sperm* [Diagram]. OpenStax. CC-BY-NC-SA 4.0. https://openstax.org/books/anatomy-and-physiology-2e/pages/27-1-anatomy-and-physiology-of-the-testicular-reproductive-system

16.5 The Female Reproductive System

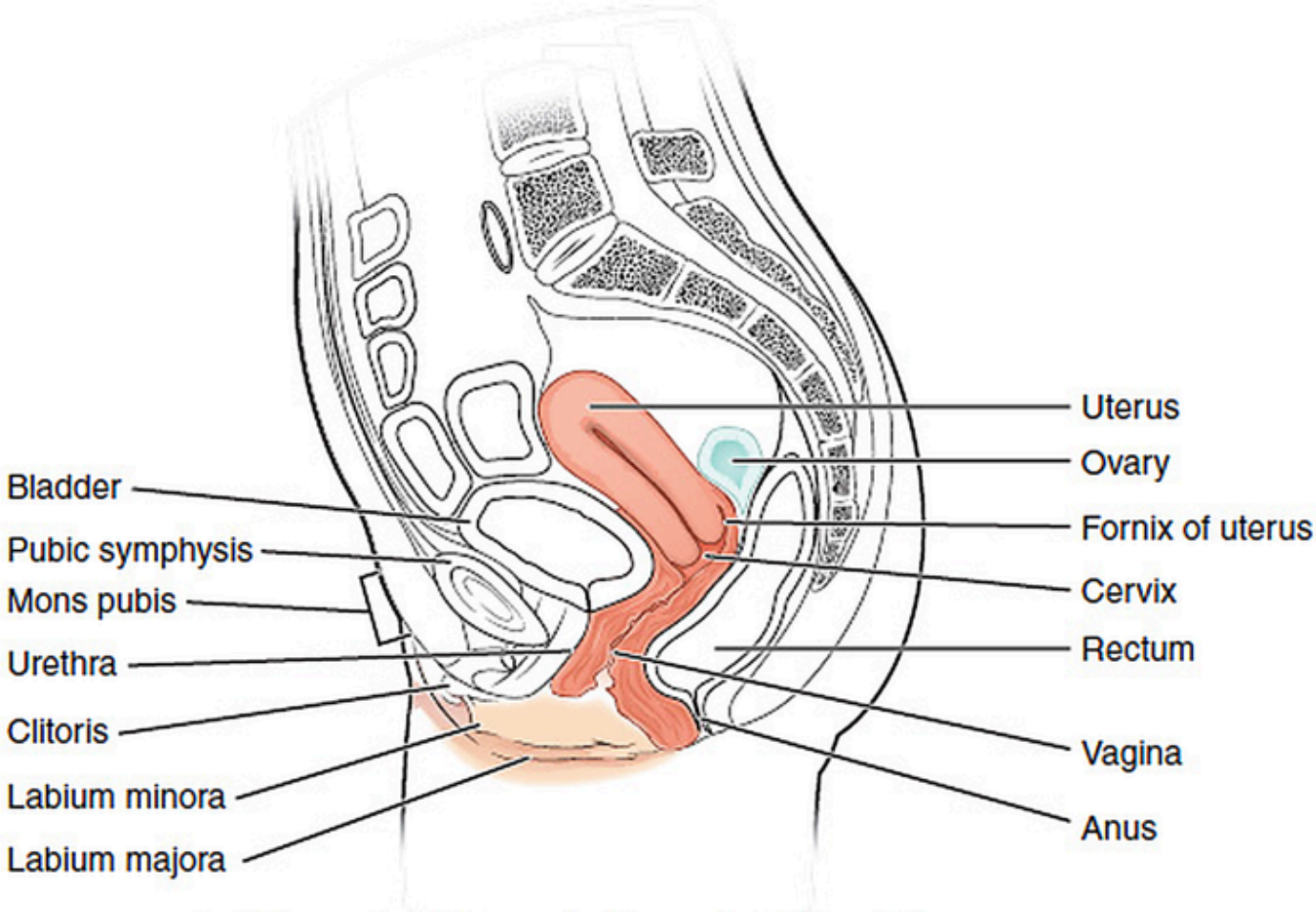
The female reproductive system produces reproductive hormones and ova (singular = ovum), also known as oocytes or eggs. It also supports and nourishes a developing fetus and delivers it to the outside world. The female reproductive system is located primarily inside the pelvic cavity.

The female reproductive system comprises internal and external structures. Key internal structures include the ovaries, Fallopian tubes, uterus, and cervix. The vulva (external genitalia) includes the mons pubis, labia majora, labia minora, clitoris, and vaginal opening.[1]

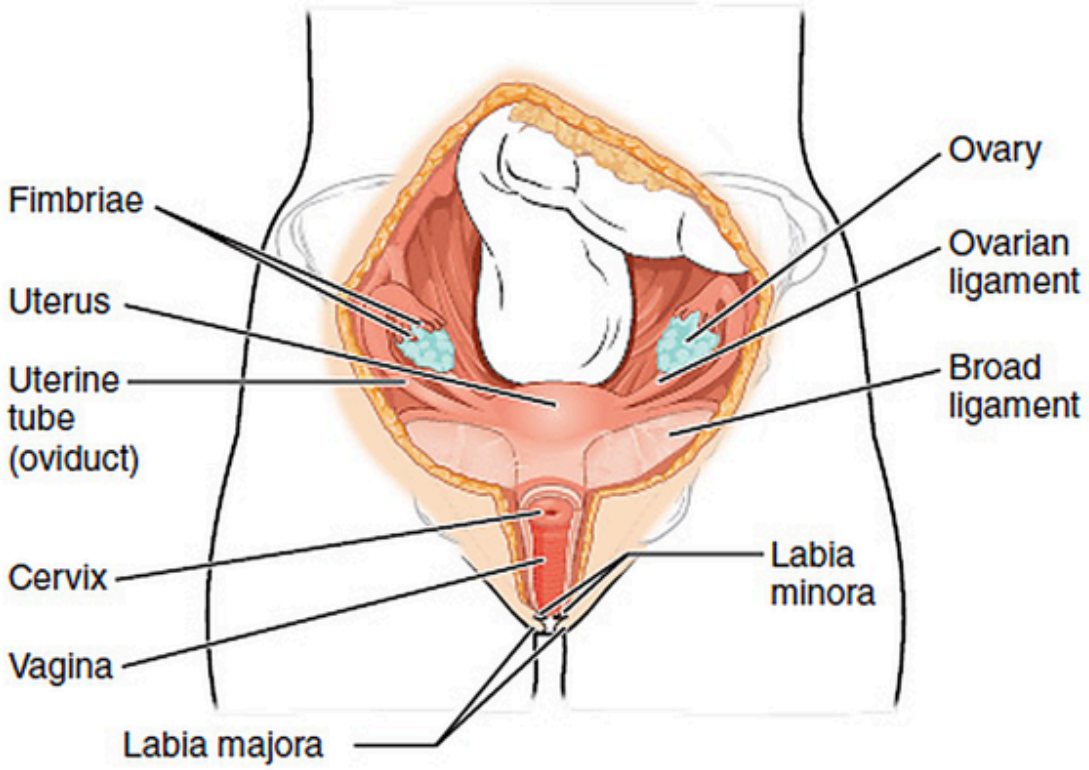
See Figure 16.10[2] for an illustration of the female reproductive system.

1. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e.* OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

2. OpenStax. (2013). *Figure_28_02_01* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Figure_28_02_01.JPG



(a) Human female reproductive system: lateral view



(b) Human female reproductive system: anterior view

Figure 16.10 Human Female Reproductive System: (a) Lateral and (b) Anterior View

Ovaries

The female gonads are the **ovaries**, a pair of small glands about the size of an almond. The ovaries are located within the pelvic cavity and are anchored to the uterus by the **ovarian ligaments**. The cortex makes up most of the adult ovary, and oocytes and follicles develop within this outer layer. Deep to the cortex is the inner ovarian medulla, which contains blood vessels, lymph vessels, and nerves. Refer back to Figure 16.9 for an illustration of the ovaries.

A **follicle** contains one oocyte and its supporting cells. The ovaries contain numerous follicles in different stages of development. Follicles grow and develop in a process called folliculogenesis, which typically leads to ovulation of one follicle approximately every 28 days. In addition, follicles produce estrogens and progesterone, which help to prepare the endometrium for a possible pregnancy. See the "Folliculogenesis" subsection in the "Female Puberty, Ovarian Cycle, and Menstrual Cycle" section for more information.

Fallopian Tubes

The **Fallopian tubes** (also called uterine tubes or oviducts) carry the ovulated oocyte to the uterus. Each of the two Fallopian tubes is close to, but not directly connected to, the ovary. The Fallopian tubes are divided into sections. The wide distal **infundibulum** flares out with slender, finger-like projections called **fimbriae** that sweep the egg into the Fallopian tube. The middle region of the Fallopian tube is called the **ampulla** and is where fertilization often occurs. The **isthmus** is the narrow medial end of the Fallopian tube that is connected to the uterus.

The Fallopian tubes also have three layers: an outer serosa, a middle smooth muscle layer, and an inner mucosal layer. In addition to its mucus-secreting cells, the inner mucosa contains ciliated cells that beat towards the direction of the uterus to move the oocyte to it. The Fallopian tubes also use peristalsis to move the oocyte towards the uterus. See Figure 16.11[3] for an illustration of the Fallopian tubes.

3. OpenStax. (2013). *Figure_28_02_06* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Figure_28_02_06.JPG

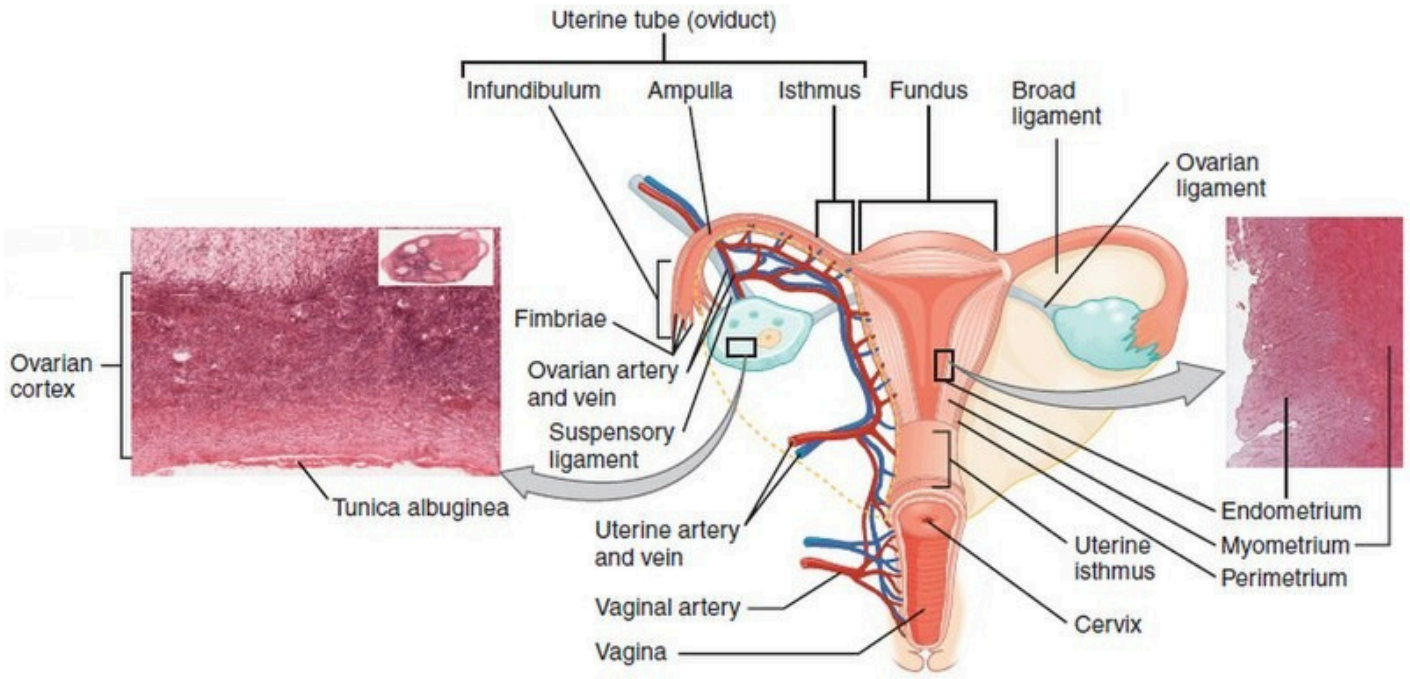


Figure 16.11 Ovaries, Fallopian Tubes, and Uterus

Uterus

The **uterus** is a muscular organ that nourishes and supports a growing embryo and fetus. The lay term for this organ is the womb. Its average size is approximately 5 cm wide by 7 cm long (approximately 2 inches by 3 inches) when the individual is not pregnant and can grow to up to 500 times its size during the full term of a pregnancy. The uterus has three sections. The portion of the uterus superior to the opening of the uterine tubes is called the **fundus**. The middle section of the uterus is called the **body (or corpus)**. The **cervix** is the narrow inferior portion of the uterus that projects into the vagina.

Several ligaments maintain the position of the uterus within the pelvic cavity. The **broad ligament** serves as a primary support for the uterus, extending laterally from both sides of the uterus and attaching it to the pelvic wall. The **round ligament** attaches to the uterus near the Fallopian tubes and extends to the labia majora. The **uterosacral ligament** stabilizes the uterus posteriorly by its connection from the cervix to the pelvic wall.

The wall of the uterus is made up of three layers: the perimetrium, the myometrium, and the endometrium. The most superficial layer is the **perimetrium**, a serous membrane that covers the outside of the uterus. The **myometrium** is the middle smooth muscular layer that makes up most of the uterus and is responsible for uterine

contractions. The muscle fibers run horizontally, vertically, and diagonally to create the powerful contractions that occur during labor and the less powerful contractions (or cramps) that occur during a menstrual period.

The innermost layer of the uterus is called the **endometrium**. The endometrium has a rich blood supply and consists of two sublayers: the stratum basalis and the stratum functionalis. The **stratum basalis** (or basal layer) is the deeper layer that creates the more superficial stratum functionalis. The **stratum functionalis (or functional layer)** grows and thickens in response to increased levels of estrogen and progesterone in preparation for a potential pregnancy. If fertilization does not occur, the stratum functionalis is shed during menstruation.

Cervix

The **cervix** is the narrow inferior portion of the uterus that projects into the vagina. The opening at the inferior end of the cervix is called the external os. The cervix produces mucus that changes in consistency throughout the menstrual cycle. Normally, the mucus is thick to prevent sperm from entering the uterus. However, during ovulation, the mucus will become thin and stretchy to allow sperm to move through the reproductive tract.

Refer back to Figure 16.10 for an illustration of the uterus and cervix.

Vagina

The **vagina** is the female copulatory (sex) organ. It is a muscular canal approximately 4 inches (10 cm) long that serves as the entrance to the reproductive tract. It also serves as the exit from the uterus for menstruation and childbirth. The walls of the vagina are able to expand to accommodate intercourse and childbirth.

The **hymen** is a thin membrane that sometimes partially covers the entrance to the vagina. An intact hymen is not an indication of virginity. Even at birth, this is only a partial membrane, as menstrual fluid and other secretions must be able to exit the body, regardless of penile–vaginal intercourse. The hymen can be ruptured with strenuous physical exercise, inserting things into the vagina, and childbirth.

The vagina has a normal population of microorganisms that protect against infection by harmful organisms that can enter the vagina. In a healthy person, the most predominant type of vaginal bacteria is from the genus *Lactobacillus*. This family of

beneficial bacterial flora secretes lactic acid and, thus, protects the vagina by maintaining an acidic pH (less than 4.5). Potential pathogens are less likely to survive in these acidic conditions. Lactic acid, in combination with other vaginal secretions, makes the vagina a self-cleansing organ.

Douching—or washing out the vagina with fluid—can disrupt the normal balance of healthy microorganisms and actually increase risk for infections and irritation. The American College of Obstetricians and Gynecologists recommends that people not douche and that they allow the vagina to maintain its normal, healthy population of protective microbial flora.

Refer back to Figure 16.10 for an illustration of the vagina.

External Female Anatomy

The external female reproductive structures are referred to collectively as the **vulva**. The vulva includes the mons pubis, labia majora and minora, clitoris, and vestibule.

The **mons pubis** is a pad of fat that is located superficial to the pubic bone. After puberty, it becomes covered in pubic hair. The **labia majora** (*labia* = "lips"; *majora* = "larger") are folds of hair-covered skin that begin just posterior to the mons pubis. The thinner and more pigmented **labia minora** (*labia* = "lips"; *minora* = "smaller") are medial to the labia majora and do not have hair. Although they naturally vary in shape and size from person to person, the labia minora serve to protect the urethra and the vaginal orifice.

The superior, anterior portions of the labia minora come together to encircle the **clitoris** (or glans clitoris), an organ that originates from the same cells as the glans penis. The clitoris has abundant nerves that make it important in sexual sensation and orgasm. The **vestibule** is the area between the labia minora where the external urethral orifice and vaginal orifice are located. The two **Bartholin's (or greater vestibular) glands** are located lateral to the vaginal orifice. They produce mucus that adds lubrication to the vagina.

See Figure 16.12[4] for an illustration of the vulva.

4. OpenStax. (2013). *Vulva Figure 28_02_02* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Vulva_Figure_28_02_02.jpg

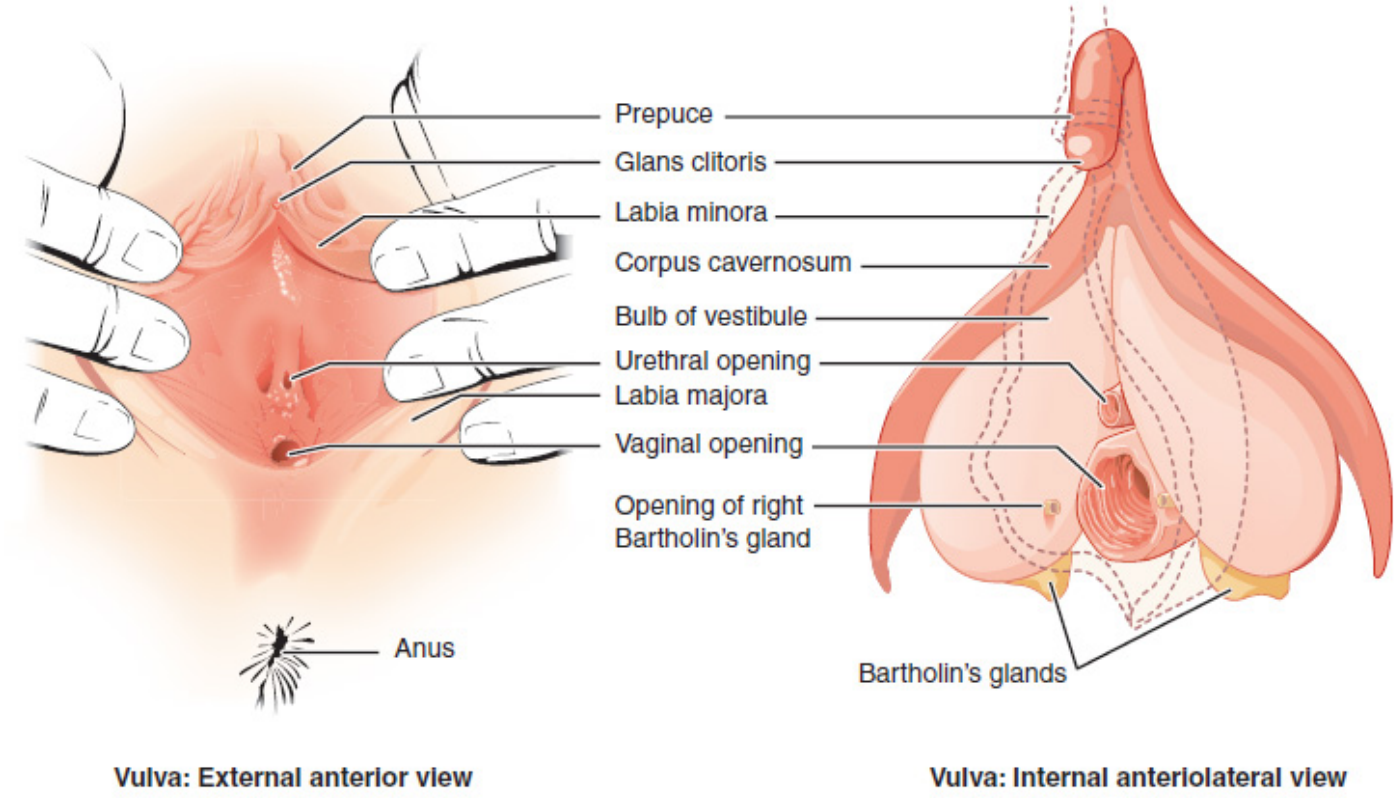


Figure 16.12 The Vulva

Perineum

In both females and males, the area between the genitals and the anus is called the **perineum**. The muscles in the perineum are important for urination in both sexes, ejaculation in males, and vaginal contraction in females. The pelvic floor muscles support the pelvic organs; resist intra-abdominal pressure; and work as sphincters for the urethra, rectum, and vagina.

Breasts and Mammary Glands

The **breasts** are considered accessory organs of the female reproductive system. They are located anterior to the pectoralis major muscles of the chest. The breast includes a nipple surrounded by a pigmented **areola**. The areola is typically circular in shape and can vary in size from 1 to 4 inches (25 to 100 mm) in diameter, which may become darker in color during pregnancy. The areolar region is characterized by small, raised areolar glands that secrete lubricating fluid during lactation to protect the nipple from chafing.

The breasts contain adipose tissue, which determines the size of the breasts. Breast size differs between individuals and does not affect the amount of milk that can be produced. Supporting the breasts are multiple bands of connective tissue called **suspensory ligaments** that connect the breast tissue to the dermis of the overlying skin.

During the normal hormonal fluctuations in the menstrual cycle, breast tissue responds to changing levels of estrogen and progesterone, which can lead to swelling and breast tenderness in some individuals. If pregnancy occurs, the increase in hormones leads to further development of the mammary tissue and enlargement of the breasts.

See Figure 16.13[5] for an illustration of the anatomy of the breast.

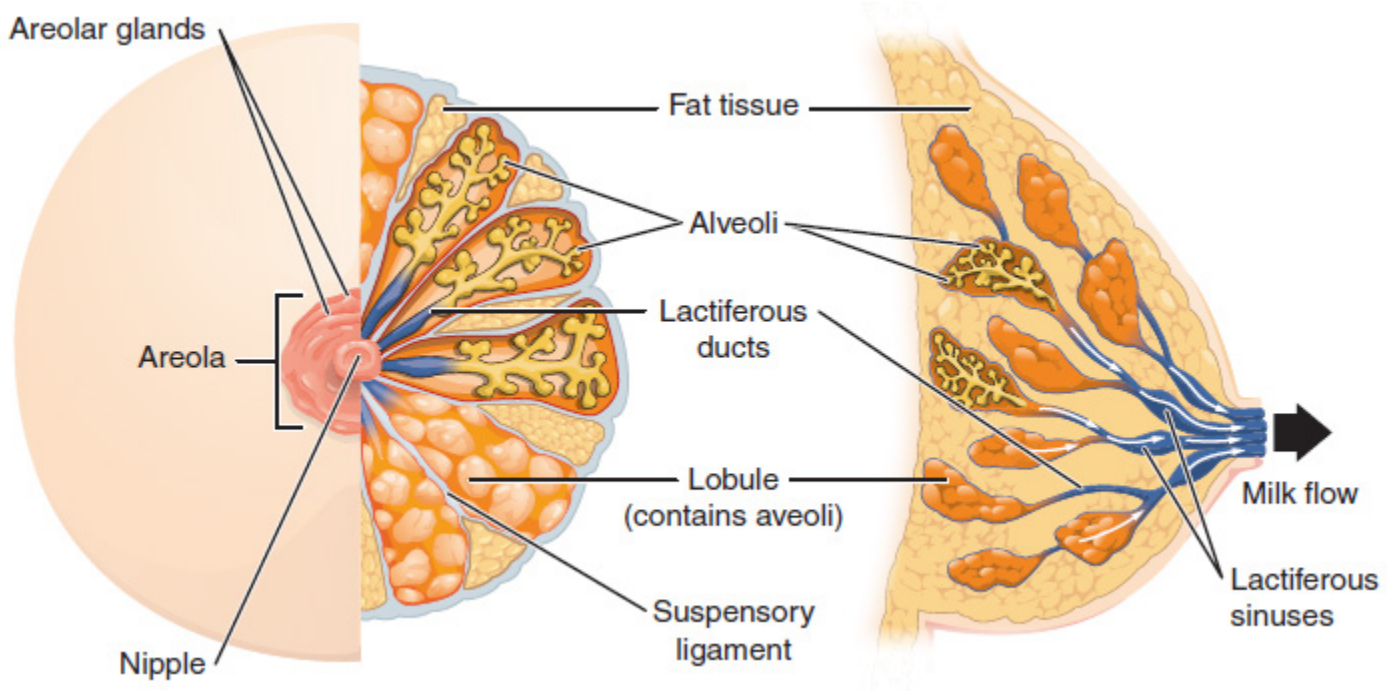


Figure 16.13 Anatomy of the Breast

The function of the breasts is to produce and supply milk to an infant in a process called **lactation**. Breast milk is produced by the **mammary glands**, which are modified sweat glands. The hormone **prolactin (PRL)** promotes lactation. During pregnancy, it contributes to the development of the mammary glands, and after birth, it stimulates the mammary glands to produce breast milk. The effects of prolactin rely on the permissive effects of estrogens, progesterone, and other hormones. In non-pregnant

5. OpenStax. (2013). *Figure_28_02_09* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Figure_28_02_09.jpg

individuals, prolactin secretion is inhibited by prolactin-inhibiting hormone (PIH). Only during pregnancy do prolactin levels rise in response to prolactin-releasing hormone (PRH) from the hypothalamus.

When a baby nurses, the entire areolar region is taken into the mouth. Milk leaves the breast through the nipple via 15 to 20 lactiferous ducts that open to the surface of the nipple. The baby withdraws milk from the breast by suckling. The hormone **oxytocin** is necessary for the milk ejection reflex (commonly referred to as "letdown") for the baby to get milk. As the baby begins suckling, sensory receptors in the nipples transmit signals to the hypothalamus. In response, oxytocin is secreted and released into the bloodstream. Within seconds, cells in the milk ducts contract, ejecting milk into the infant's mouth.

16.6 Female Puberty, Ovarian Cycle, and Menstrual Cycle

Much of the development of the reproductive system occurs during female puberty and is marked by the appearance of sex-specific characteristics in adolescents. Multiple factors influence the onset of puberty, including genetics, environment, and psychological stress. Historical data show the effect of improved nutrition on the age of **menarche** (the start of menstruation) in the United States, which decreased from an average age of 17 in 1860 to 12.75 years in 1960, where it remains today. Body fat appears to have a strong role in determining menarche, likely due to the high metabolic needs of pregnancy and lactation in the human body. In fact, adolescent females who are extremely lean and highly active, such as gymnasts, often experience a delay in the onset of puberty.

Secondary Sex Characteristics

Female **secondary sex characteristics** are physical characteristics that are influenced by estrogen and are important for reproductive function. As a female reaches puberty, the first change usually visible is the development of the breasts. The reproductive organs will also grow at this time, axillary (armpit) and pubic hair will appear, and the hips will widen. A growth spurt normally starts around the age of 9 to 11 and may last two years or more. During this time, height can increase up to three inches in a year.

Female Reproductive Hormones

Puberty is initiated by the **gonadotropin-releasing hormone (GnRH)**, a hormone secreted by the hypothalamus. GnRH stimulates the anterior pituitary to secrete **follicle stimulating hormone (FSH)** and **luteinizing hormone (LH)**. FSH targets the ovaries to stimulate follicular development (these follicles then secrete estrogens) and egg maturation. LH triggers ovulation, as well as the production of estrogens and progesterone by the ovaries.

The primary hormones produced by the ovaries are estrogens, which include

estradiol, estriol, and estrone, and progesterone. **Estrogens** play an important role in many physiological processes, including the development of the reproductive system, regulation of the menstrual cycle, development of secondary sex characteristics, and the maintenance of pregnancy. **Progesterone** helps regulate the menstrual cycle and prepare for and maintain pregnancy.

Ovarian Cycle

The ovarian cycle is the development of oocytes and ovarian follicles within the ovary. During the reproductive years, it is a roughly 28-day cycle that occurs simultaneously with the menstrual (uterine) cycle (see below). The ovarian cycle includes two related processes: oogenesis (the production of an ovum) and folliculogenesis (the growth and development of ovarian follicles).

Oogenesis

The production of an ovum (egg) is called **oogenesis**. The process begins with ovarian stem cells called **oogonia**. Oogonia are formed during fetal development and divide via mitosis, much like spermatogonia in the testis. However, unlike spermatogonia, oogonia form millions of **primary oocytes** in the fetal ovaries prior to birth. These primary oocytes then stop at this stage of Meiosis I and resume meiosis years later at puberty and continue until close to **menopause** (the ending of a female's reproductive functions). The number of primary oocytes present in the ovaries is approximately one to two million in an infant, which declines to approximately 400,000 at puberty and to zero by the end of menopause. See Figure 16.14[1] for an overview of oogenesis.

1. OpenStax. (2013). *Figure_28_02_03* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Figure_28_02_03.JPG

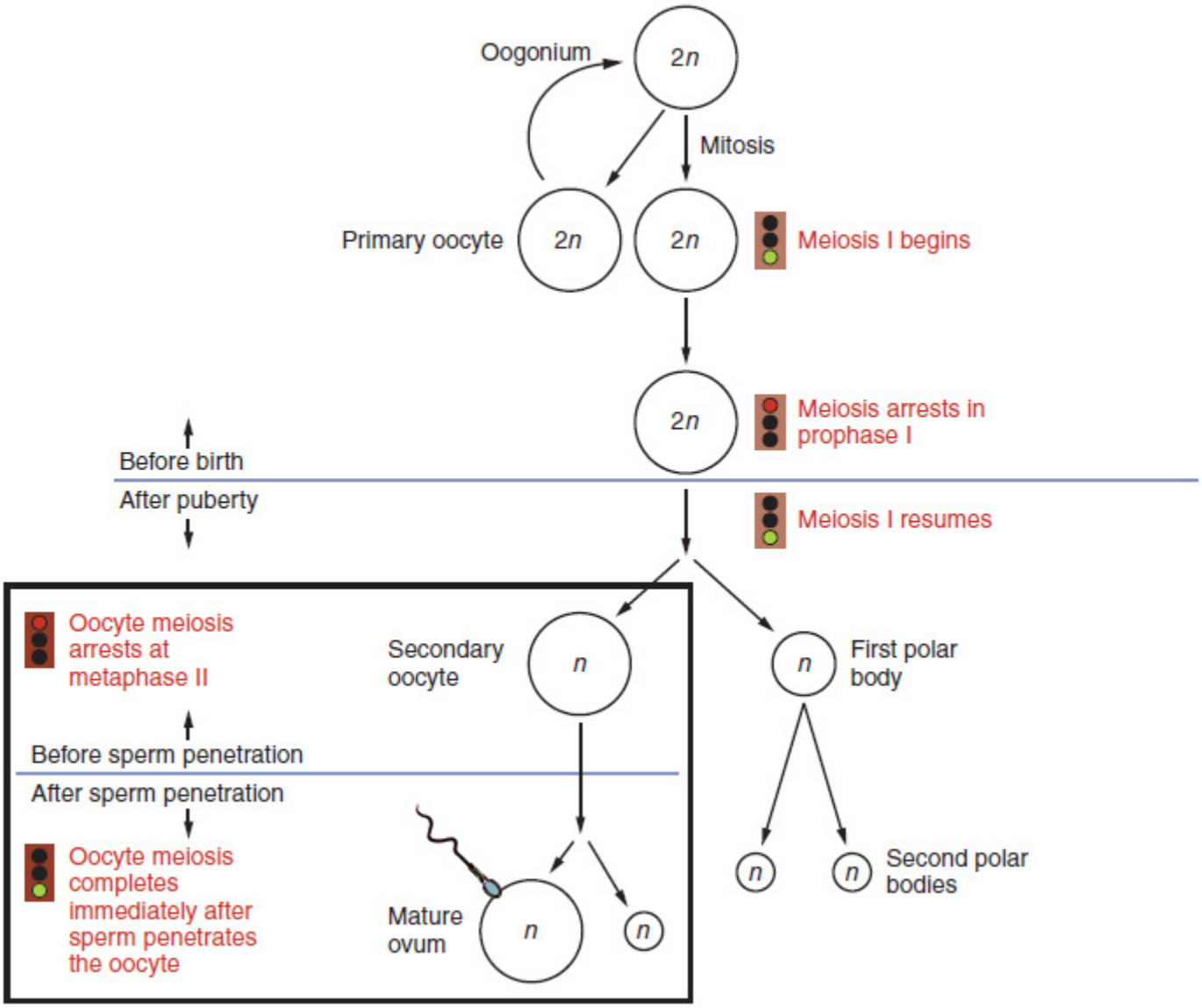


Figure 16.14 Oogenesis

The initiation of **ovulation**—the release of an oocyte from the ovary—marks the transition from puberty into reproductive maturity. From then on, throughout the reproductive years, ovulation occurs approximately once every 28 days.

Just prior to ovulation, a surge of luteinizing hormone (LH) triggers the restarting of meiosis in a primary oocyte. This initiates the transition from primary to **secondary oocyte**. However, this cell division does not result in two identical cells. These cells have half the number of chromosomes as the primary oocyte. Also, the cytoplasm is divided unequally, and one daughter cell is much larger than the other. This larger cell, the secondary oocyte, eventually leaves the ovary during ovulation. The smaller cell, called the first **polar body**, may or may not divide again, but in either case, it eventually

disintegrates. Therefore, even though oogenesis produces up to four cells, only one survives. Only if fertilization by a sperm occurs will the secondary oocyte ever finish meiosis by dividing into an ovum and a second polar body (which disintegrates).

Folliculogenesis

After puberty, follicles grow and develop in a process called **folliculogenesis**, which typically leads to ovulation of one oocyte approximately every 28 days, along with the death of multiple other follicles. The death of ovarian follicles is called **atresia** and can occur at any point during follicular development.

Folliculogenesis begins with follicles in a resting state. These small **primordial follicles** are present in female newborns and are the most common type of follicle in the adult ovary. Primordial follicles have a single flat layer of support cells, called **granulosa cells**, that surround the oocyte, and they can stay in this resting state for years—some until right before menopause.

Some primordial follicles will grow in response to the hormone FSH to become **primary follicles**. Primary follicles start with the same single layer of granulosa cells, but they become active, increase in size, and proliferate.

As the granulosa cells divide, the follicles, now called **secondary follicles**, increase in diameter, adding a new outer layer of connective tissue, blood vessels, and **theca cells**—cells that work with the granulosa cells to produce estrogens. Within the growing secondary follicle, the primary oocyte creates a thin acellular membrane called the **zona pellucida**. A thick fluid, called follicular fluid, collects in a space called the **antrum**.

Follicles with a large and fully formed antrum are considered tertiary follicles (also known as Graafian follicles). Most follicles don't make it to this point. Usually, only one follicle reaches the tertiary stage when it will release its secondary oocyte during ovulation. The rest of the developing follicles undergo atresia. Roughly 99% of the follicles in the ovary will undergo atresia, which can occur at any stage of folliculogenesis. After ovulation, the empty follicle is now called the **corpus luteum**. It will continue secreting progesterone and estrogens for the second half of the menstrual cycle (and longer if pregnancy happens that cycle).

See Figure 16.15[2] for an illustration of folliculogenesis.

2. OpenStax. (2013). *Figure_28_02_04* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Figure_28_02_04.JPG

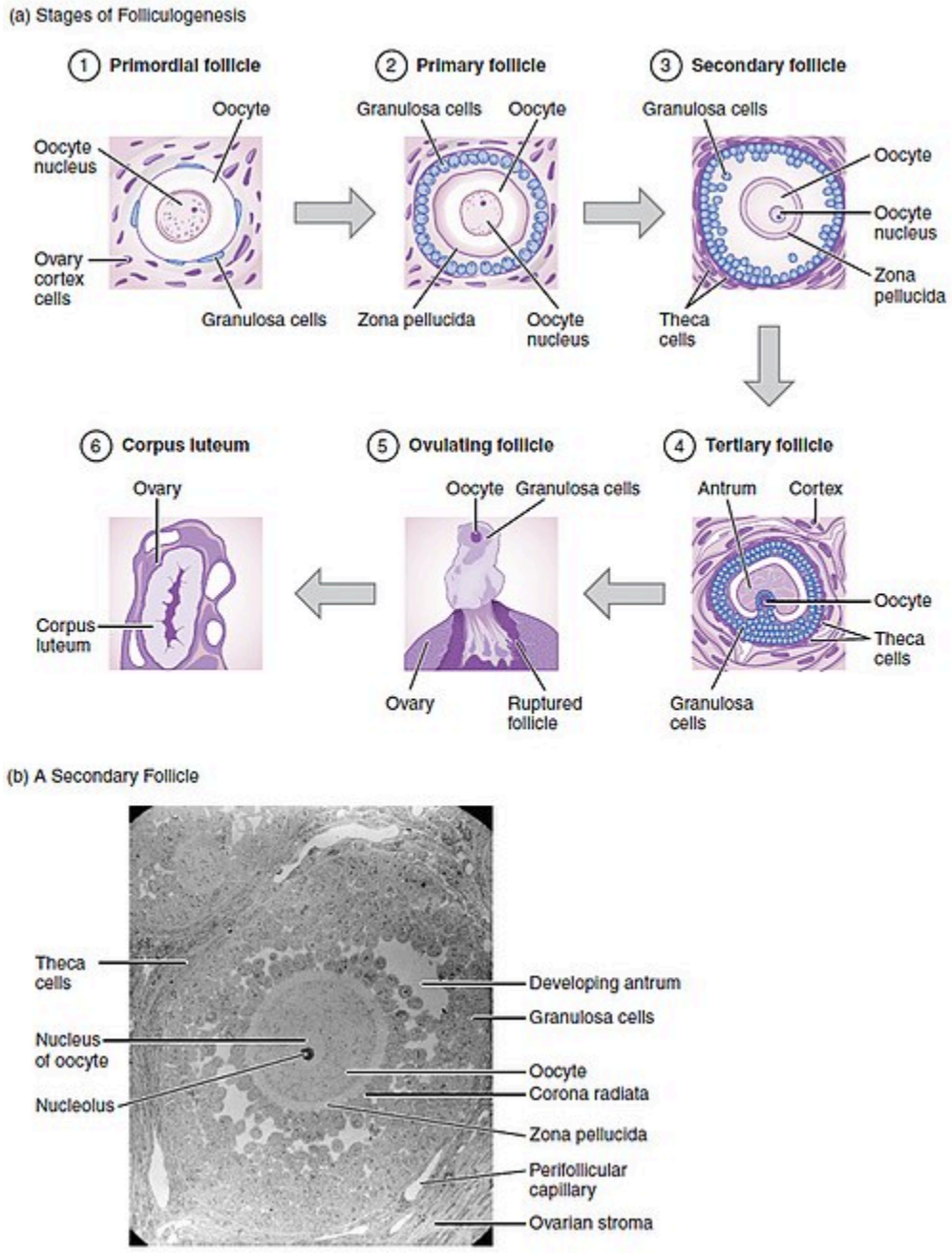


Figure 16.15 Folliculogenesis: (a) Stages of Folliculogenesis and (b) Secondary Follicle

The process of development just described, from primordial follicle to early tertiary follicle, takes approximately two months in humans. The final stages of follicular development, ending with ovulation of a secondary oocyte, occur over a course of approximately 28 days.

Phases of the Ovarian Cycle

The ovarian cycle can be divided into three steps: the follicular phase, ovulation, and the luteal phase.

Follicular Phase

FSH stimulates the follicles to grow (hence the name “follicle-stimulating hormone”). The release of LH also stimulates the granulosa and theca cells of the follicles to produce estrogen. This phase of the ovarian cycle, when the follicles are growing and secreting estrogen, is known as the **follicular phase**. In this phase, the tertiary (antral) follicles (ovarian follicles with a primary or secondary oocyte, multiple layers of granulosa cells, and a fully formed antrum) are growing and secreting estrogen. The more granulosa and theca cells a follicle has (that is, the larger and more developed it is), the more estrogen it will produce in response to LH stimulation.

As a result of these large follicles producing large amounts of estrogen, systemic plasma estrogen concentrations increase. Following a classic negative feedback loop, the high concentrations of estrogen will stimulate the hypothalamus and anterior pituitary gland to reduce the production of GnRH, LH, and FSH. Because the large tertiary follicles require FSH to grow and survive at this point, this decline in FSH caused by negative feedback causes most of them to die (atresia).

Typically, only one follicle, now called the dominant follicle, will survive this reduction in FSH. This remaining follicle will be the one that releases an oocyte. Scientists have studied many factors that lead to a particular follicle becoming dominant. The size, the number of granulosa cells, and the number of FSH receptors on those granulosa cells all contribute to a follicle becoming the one surviving dominant follicle.

Ovulation

When only one dominant follicle remains in the ovary, it again begins to secrete estrogen. It produces more estrogen than all of the developing follicles did together before the negative feedback occurred. It produces so much estrogen that the normal negative feedback doesn’t occur. Instead, these extremely high concentrations of systemic plasma estrogen trigger a regulatory switch in the anterior pituitary that responds by secreting large amounts of LH and FSH into the bloodstream. The positive

feedback loop by which more estrogen triggers the release of more LH and FSH only occurs at this point in the cycle.

It is this large burst of LH (called the LH surge) that leads to ovulation of the dominant follicle. The LH surge induces many changes in the dominant follicle, including stimulating the resumption of meiosis of the primary oocyte to a secondary oocyte. As noted earlier, the polar body that results from unequal cell division simply degrades. The LH surge also triggers proteases (enzymes that cleave proteins) to break down structural proteins in the ovarian wall on the surface of the bulging dominant follicle. This degradation of the wall, combined with pressure from the large, fluid-filled antrum, results in the expulsion of the oocyte surrounded by granulosa cells into the peritoneal cavity. This release is ovulation.

The surge of LH also stimulates a change in the granulosa and theca cells that remain in the follicle after the oocyte has been ovulated. This change is called luteinization (recall that the full name of LH is luteinizing hormone), and it transforms the collapsed follicle into a new, temporary endocrine structure called the **corpus luteum**, a term meaning "yellowish body." Instead of estrogen, the luteinized granulosa and theca cells of the corpus luteum begin to produce large amounts of the sex steroid hormone progesterone, a hormone that is critical for the establishment and maintenance of pregnancy. Progesterone triggers negative feedback at the hypothalamus and pituitary, which keeps GnRH, LH, and FSH secretions low, so no new dominant follicles develop at this time.

Luteal Phase

The postovulatory phase of progesterone secretion is known as the luteal phase of the ovarian cycle. If pregnancy does not occur within 10 to 12 days, the corpus luteum will stop secreting progesterone and degrade into the corpus albicans, a nonfunctional "whitish body" that will disintegrate in the ovary over a period of several months. During this time of reduced progesterone secretion, FSH and LH are once again stimulated, and the follicular phase begins again with a new cohort of early tertiary follicles beginning to grow and secrete estrogen.

Video

Watch the video "How Does the Ovarian Cycle Work?" below to learn how

hormonal changes regulate the phases of the ovarian cycle, including follicle development, ovulation, and the formation of the corpus luteum.[3]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

See Figure 16.16[4] for an illustration of the hormonal regulation of ovulation.

3. Visible Body. (2023, October 23). How does the ovarian cycle work? [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=l6IQyVIFA7w

4. OpenStax. (2013). *Figure_28_02_05* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Figure_28_02_05.jpg

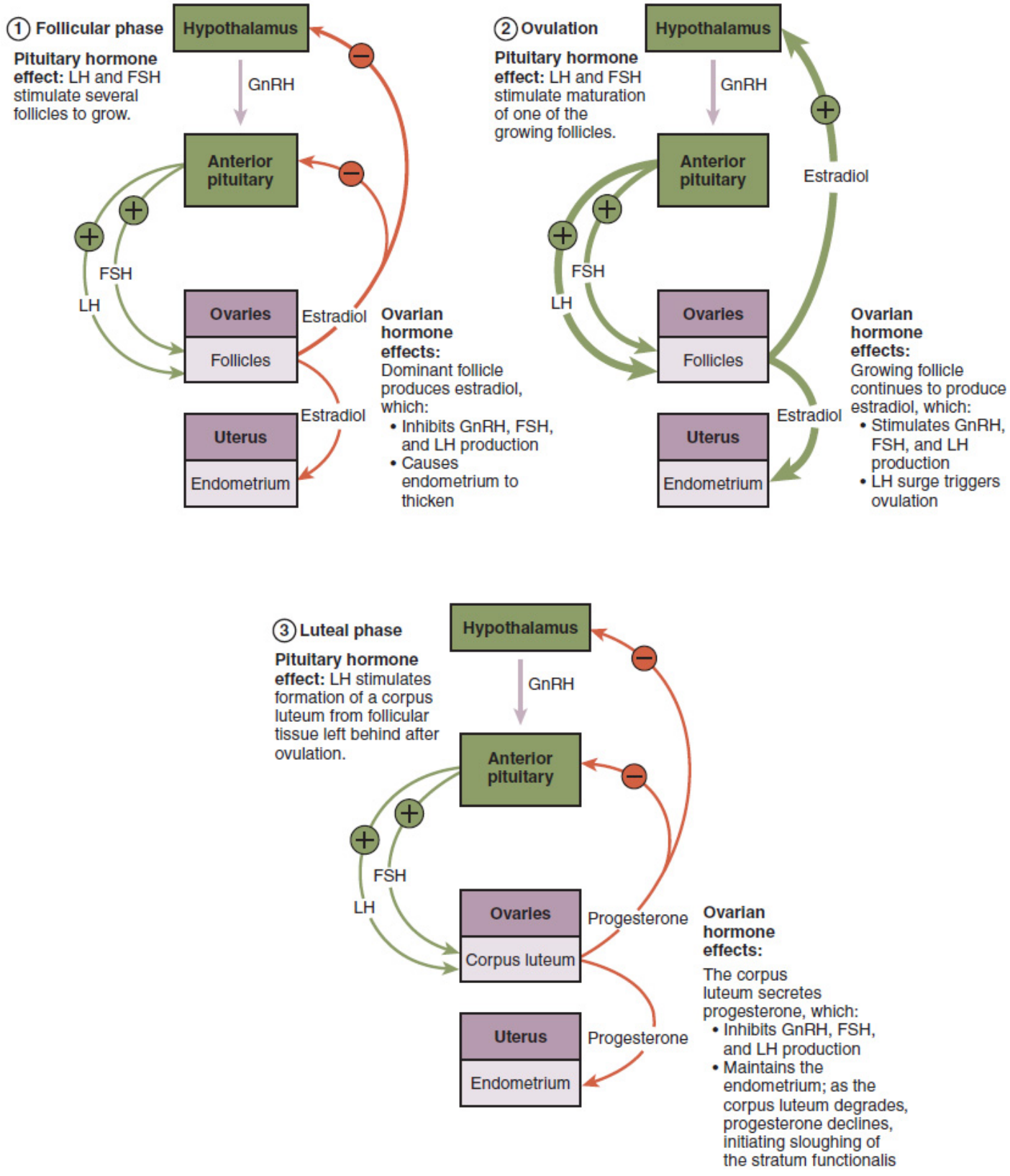


Figure 16.16 Hormonal Regulation of Ovulation

Menstrual (Uterine) Cycle

The **menstrual (uterine) cycle** starts with the first day of menstruation, referred to as day one of the menstrual cycle. The average length of a menstrual cycle is 28 days, but this varies between individuals and even in the same person from one cycle to the next, typically lasting anywhere from 21 to 32 days. There are three distinct phases of the menstrual cycle: the menstrual phase, the proliferative phase, and the secretory phase. These phases happen in the uterus while the oocyte is developing simultaneously in the ovaries.

Menstrual (Menses) Phase

The **menstrual phase** of the menstrual cycle is when the stratum functionalis of the uterus is shed, also known as menstruation. Menstruation occurs for an average of about five days but can last from two to seven days, or even longer.

The menses phase occurs during the early days of the follicular phase of the ovarian cycle, when progesterone, estrogen, FSH, and LH levels are low. These low levels of hormones cause tiny arterioles in the uterus to constrict, cutting off oxygen to the stratum functionalis. The stratum functionalis then dies and is shed as the menstrual period.

Proliferative Phase

Once menstrual flow stops, the endometrium begins to grow (proliferate) again, marking the beginning of the **proliferative phase** of the menstrual cycle. FSH and LH stimulate the growth of several follicles in the ovaries, and the follicles begin to secrete increased amounts of estrogen, stimulating the endometrial lining to rebuild. Ovulation marks the end of the proliferative phase.

Secretory Phase

In the secretory phase, the hormone progesterone (secreted by the corpus luteum) finishes maturing the endometrial lining for the possible implantation of a fertilized egg. Spiral arteries develop and provide blood to the thickened stratum functionalis. The endometrial glands secrete a glycogen-rich fluid that will nourish an embryo if

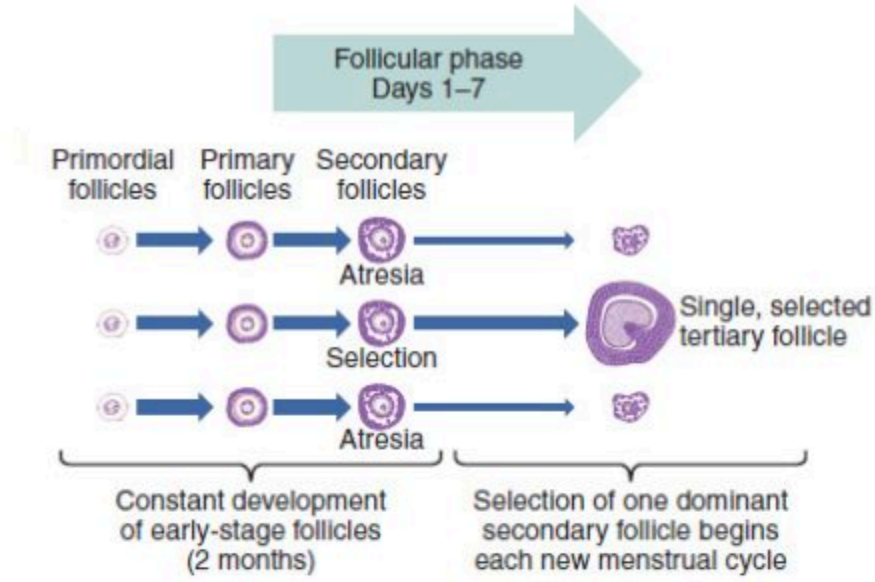
fertilization occurs. High levels of estrogen increase Fallopian tube contractions to help move the ovulated oocyte toward the uterus. Estrogen also decreases the acidity of the vagina, making it more hospitable to sperm.

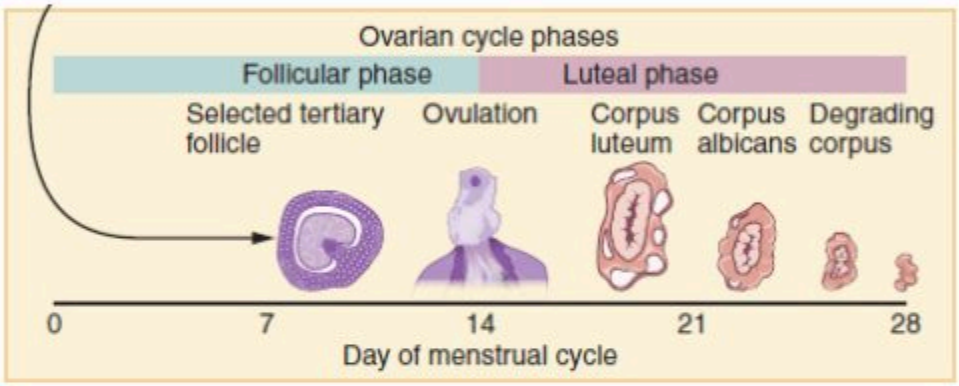
If fertilization does not occur, the corpus luteum will degenerate into the **corpus albicans** and will no longer be able to secrete hormones to sustain the stratum functionalis. The levels of both estrogen and progesterone will fall. Prostaglandins will be secreted, causing constriction of the spiral arteries. This reduces the oxygen supply to the stratum functionalis layer, which will die and is shed, resulting in menstruation, or the first day of the next cycle.

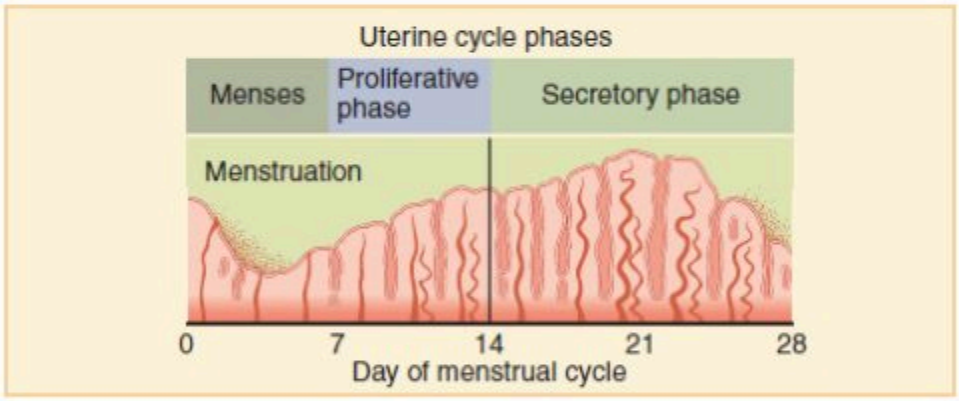
See Figures 16.17[5] and 16.18[6] for illustrations of hormone levels in the ovarian and menstrual cycles.

5. OpenStax. (2013). *Figure_28_02_07* [Diagram]. Wikimedia Commons. CC BY 3.0. https://commons.wikimedia.org/wiki/File:Figure_28_02_07.jpg

6. Isometrik, Kaldari, Begoon, & Marnanel. (2013). *Menstrual cycle* [Diagram]. CC BY-SA 3.0. https://commons.wikimedia.org/wiki/File:Menstrual_cycle.svg


Follicular phase
Days 1–7
Primordial follicles
Primary follicles
Secondary follicles
Atresia
Single, selected tertiary follicle
Selection
Atresia
Constant development of early-stage follicles (2 months)
Selection of one dominant secondary follicle begins each new menstrual cycle


Ovarian cycle phases
Follicular phase
Luteal phase
Selected tertiary follicle
Ovulation
Corpus luteum
Corpus albicans
Degrading corpus
0
7
14
21
28
Day of menstrual cycle


Uterine cycle phases
Menses
Proliferative phase
Secretory phase
Menstruation
0
7
14
21
28
Day of menstrual cycle

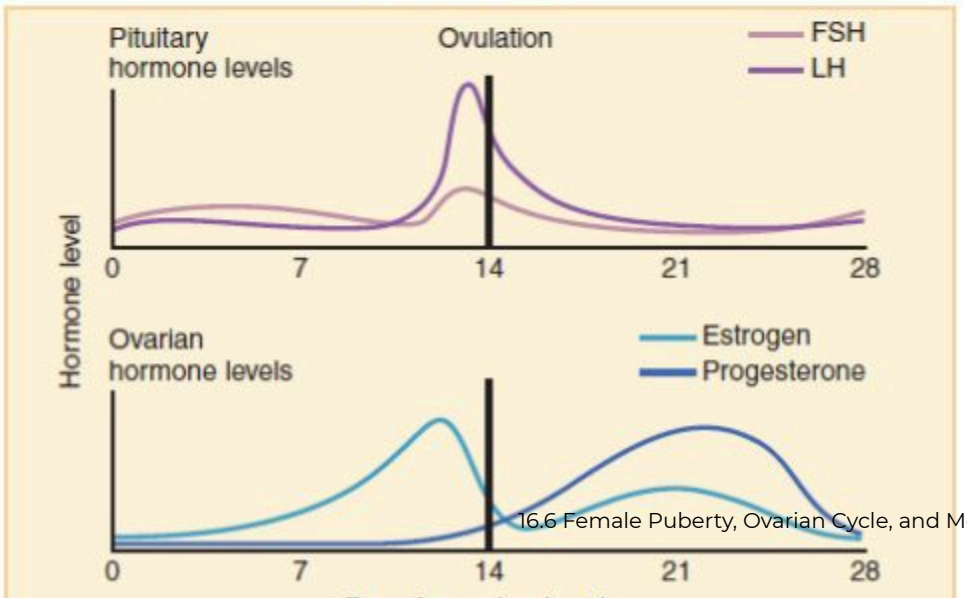

Pituitary hormone levels
Ovulation
FSH
LH
Hormone level
0
7
14
21
28
Ovarian hormone levels
Estrogen
Progesterone
0
7
14
21
28

Figure 16.17 Hormone Levels During the Menstrual Cycle

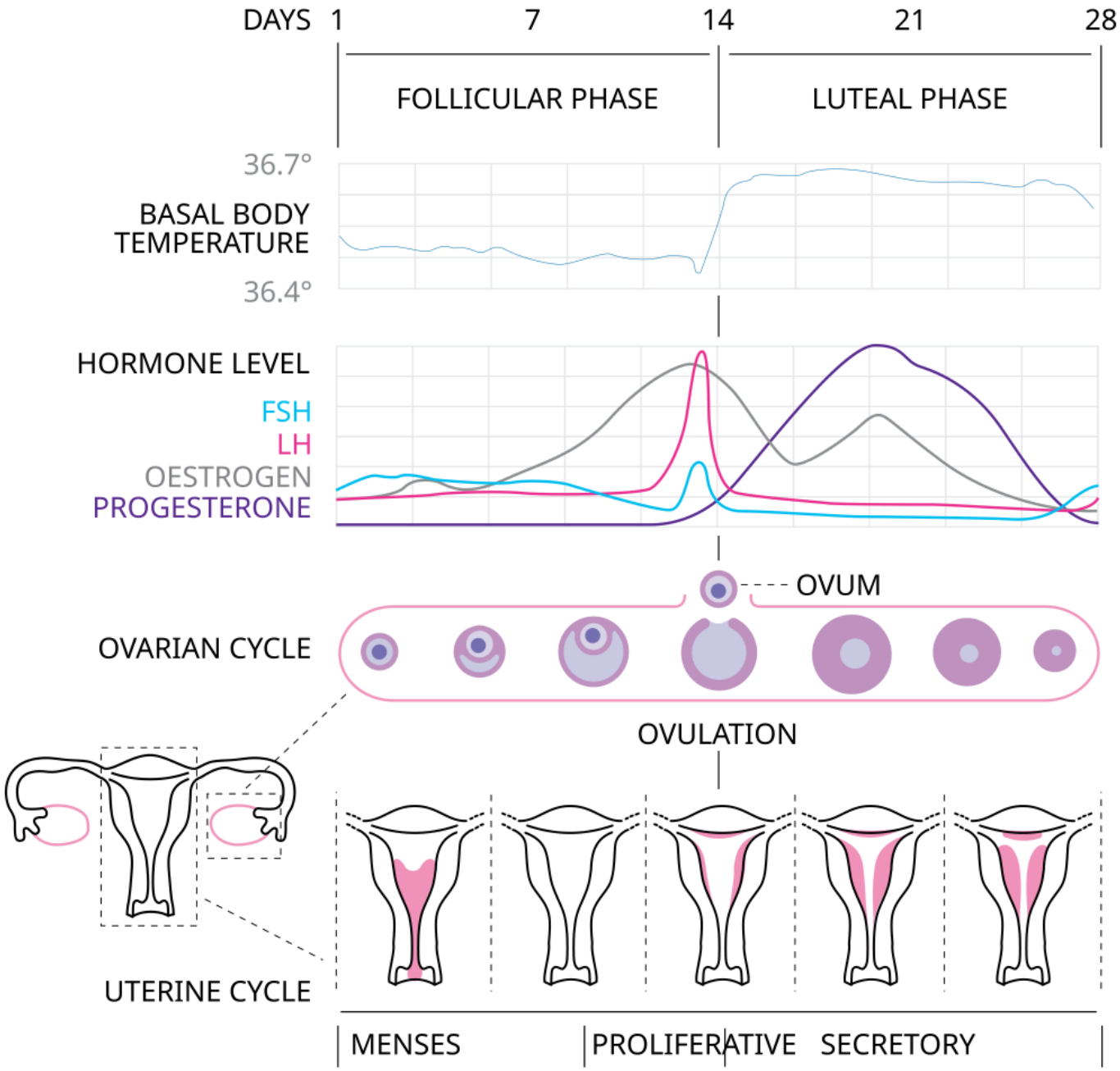


Figure 16.18 Hormone Levels During the Follicular and Luteal Phases of the Menstrual Cycle

Videos

Watch the video "Menstrual Cycle Explained (Ovarian and Uterine Cycles)" below to learn more about the ovarian and uterine cycles involved in reproduction.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

Watch the video "Menstrual Cycle Walkthrough: Phases & Hormonal Regulation" below to learn how hormones regulate the different phases of the menstrual cycle and prepare the body for potential pregnancy.[7]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

7. Amoeba Sisters. (2025, February 27). Menstrual cycle walkthrough: Phases & hormonal regulation [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=h36poEtEbi4

Menopause

Menopause is the cessation of the menstrual cycle as a result of the loss of ovarian follicles and the hormones that they produce. Female fertility (the ability to conceive) peaks when women are in their 20s and slowly declines until 35 years of age. After that time, fertility declines more rapidly until it ends completely at the end of menopause.

Menopause is considered complete if a person has not menstruated for a full year. After that point, they are considered **postmenopausal**. The average age of menopause worldwide is between the ages of 50 and 52, but it can occur any time between 40 and 60. Poor health, including smoking, can lead to earlier loss of fertility and earlier menopause.

As the age of menopause approaches, the decreasing number of follicles in the ovaries affects the hormonal regulation of the menstrual cycle. In the years leading up to menopause, there is a decrease in the hormone inhibin, which leads to an increase in FSH. This increase in FSH stimulates more follicles to grow and secrete estrogen. Because small, secondary follicles also respond to increases in FSH levels, larger numbers of follicles are stimulated to grow, but most undergo atresia and die. Eventually, this process leads to the depletion of all follicles in the ovaries, and the production of estrogen falls dramatically. It is primarily the lack of estrogens that leads to the symptoms of menopause.

The earliest changes occur during the menopausal transition, often referred to as **perimenopause**, when a menstrual cycle becomes irregular but does not stop entirely. As estrogen levels change, other symptoms that occur are hot flashes and night sweats; trouble sleeping; vaginal dryness; mood swings; difficulty focusing; and thinning of hair on the head, along with the growth of more hair on the face. Depending on the individual, these symptoms can be entirely absent, moderate, or severe. Hormone therapy (synthetic estrogen and progesterone) may be prescribed to increase estrogen and progesterone levels and alleviate some of the symptoms of menopause.

After menopause, lower amounts of estrogen can lead to other changes. Cardiovascular disease becomes as prevalent in females as in males, possibly because estrogens reduce the amount of cholesterol in the blood vessels. When estrogen is lacking, many women find they suddenly have high cholesterol and associated cardiovascular issues. Osteoporosis may also occur because bone density decreases rapidly in the first years after menopause. The reduction in bone density leads to a higher incidence of fractures.

16.7 Reproductive System Diseases and Disorders

Andropause (Male Menopause)

Declines in Leydig cell activity can occur in males beginning at 40 to 50 years of age. Because Leydig cells secrete testosterone, the resulting reduction in testosterone can lead to symptoms of **andropause**, also known as male menopause. While the reduction in sex hormones is similar to female menopause, there is no clear sign—such as a lack of a menstrual period—to indicate the beginning of andropause. Instead, people with this condition report feelings of fatigue, reduced muscle mass, depression, anxiety, irritability, loss of libido, and insomnia. A reduction in spermatogenesis resulting in lowered fertility is also reported, and sexual dysfunction can also be associated with andropausal symptoms.

While some researchers believe that certain aspects of andropause are difficult to distinguish from aging in general, testosterone replacement may be prescribed to alleviate some symptoms. Androgen replacement therapy may help prevent new onset of depression in elderly males, but long-term treatment with high doses of testosterone can sharply increase the risk of heart disease and prostate cancer.

Benign Prostatic Hypertrophy

The prostate gland in males normally doubles in size during puberty. At approximately age 25, it gradually begins to enlarge again, but does not cause problems. Abnormal growth of the prostate, or **benign prostatic hypertrophy (BPH)**, can cause constriction of the urethra as it passes through the middle of the prostate gland, leading to a number of lower urinary tract symptoms, such as a frequent and intense urge to urinate, a weak stream, and a sensation that the bladder has not emptied completely.

By age 60, approximately 40% of males have some degree of benign prostatic hypertrophy. By age 80, the number of affected individuals is as high as 80%. Treatments for BPH attempt to relieve the pressure on the urethra so that urine can flow more normally. Mild to moderate symptoms are treated with medication, whereas severe

enlargement of the prostate is treated by surgery in which a portion of the prostate tissue is removed. See Figure 16.19[1] for an illustration comparing a normal prostate to benign prostatic hypertrophy.

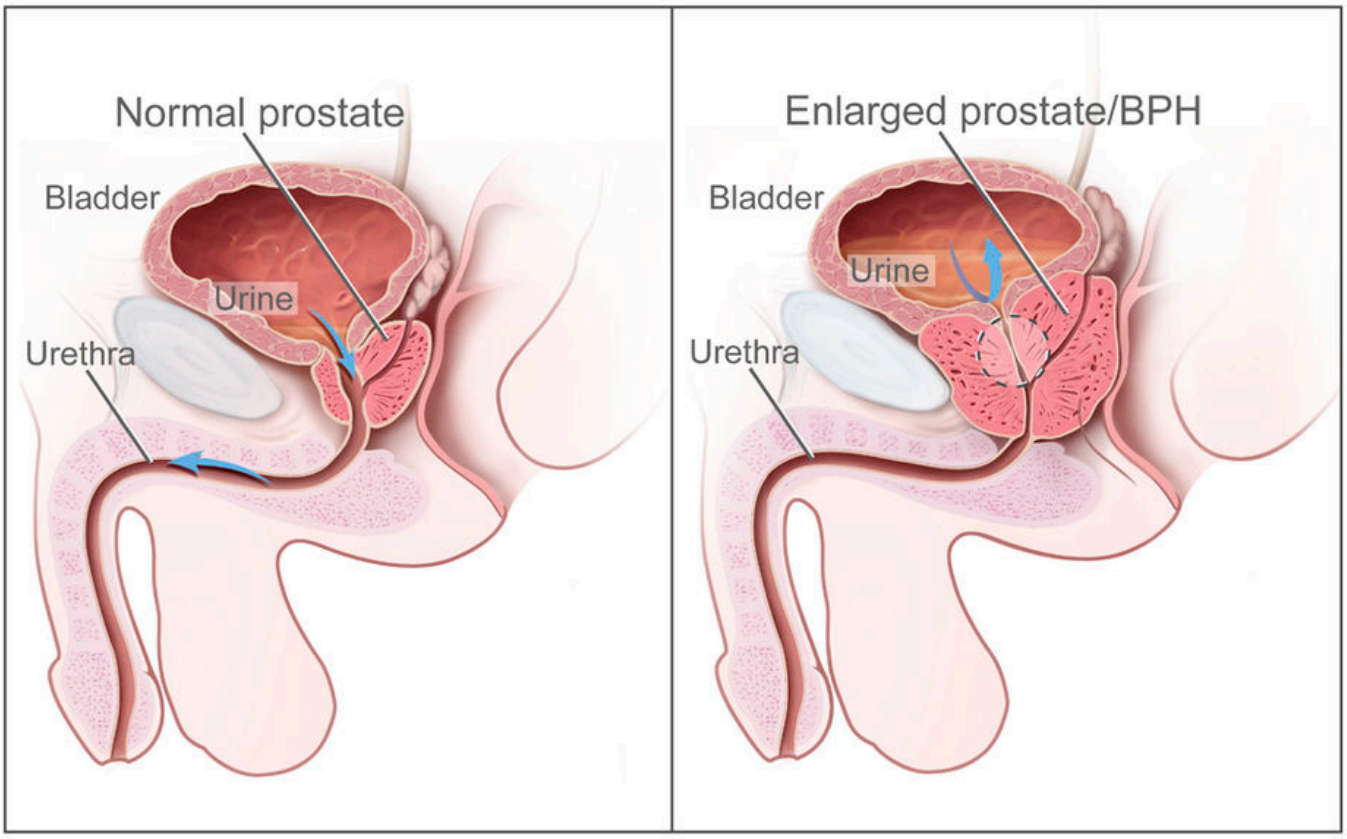


Figure 16.19 Benign Prostatic Hypertrophy

Breast Cancer

Breast cancer occurs when cancerous cells in the breasts multiply and form tumors. About 80% of breast cancer cases are invasive, meaning a tumor may spread from the breast to other areas of the body. Breast cancer typically affects women aged 50 and older, but it can also affect women who are younger than 50. Men may also develop breast cancer. People of both genders who have a strong family history of breast cancer

1. National Cancer Institute. (2008). *Benign Prostatic Hyperplasia* [Diagram]. Wikimedia Commons. Public Domain. https://commons.wikimedia.org/wiki/File:Benign_Prostatic_Hyperplasia_nci-vol-7137-300.jpg

or inherited changes in the BRCA1 and BRCA2 genes have a high risk of getting breast cancer.[2,3]

Types of Breast Cancer

Because there are several types of breast cancer, an accurate diagnosis must be made so that the appropriate treatment is used. Common types of breast cancer include the following:

- **Invasive (infiltrating) ductal carcinoma (IDC)**: This cancer starts in the milk ducts and spreads to nearby breast tissue. It is the most common type of breast cancer in the United States.
- **Lobular breast cancer**: This breast cancer starts in the milk-producing glands (lobules) in the breast and often spreads to nearby breast tissue. It is the second most common breast cancer in the United States.
- **Ductal carcinoma in situ (DCIS)**: Like IDC, this breast cancer starts in the milk ducts. The difference is that DCIS doesn't spread beyond the milk ducts.

Less common breast cancer types are as follows:

- **Inflammatory breast cancer (IBC)**: This rare, fast-growing cancer looks like a rash on the breast.
- **Paget's disease of the breast**: This rare cancer affects the skin of the nipple and may look like a rash. Less than 4% of all breast cancers are Paget's disease of the breast.

Breast Cancer Subtypes

Health care providers classify breast cancer subtypes by receptor cell status. Receptors are protein molecules in or on breast cancer cell membranes that attach to certain proteins or hormones, such as estrogen and progesterone. Estrogen and progesterone promote the growth of cancerous cells. Determining if cancerous cells have estrogen or progesterone receptors helps health care providers plan breast cancer treatment.

2. Cleveland Clinic. (2023). *Breast cancer.* https://my.clevelandclinic.org/health/diseases/3986-breast-cancer
3. American Cancer Society. (2023). *Breast cancer.* https://www.cancer.org/cancer/types/breast-cancer/screening-tests-and-early-detection/american-cancer-society-recommendations-for-the-early-detection-of-breast-cancer.html

Subtypes of breast cancer include the following:

- ER-positive (ER+): Estrogen receptors are present.
- PR-positive (PR+): Progesterone receptors are present.
- HR-positive (HR+): Estrogen and/or progesterone receptors are present.
- HR-negative (HR-): Estrogen or progesterone receptors are not present.
- HER2-positive (HER2+): Higher than normal levels of the HER2 protein are present, leading to accelerated cell growth. About 15% to 20% of all breast cancers are HER2-positive.
- Triple-negative breast cancer (TNBC): Estrogen and progesterone receptors are not present, and HER2 protein is not present. This invasive cancer is aggressive and spreads more quickly than other breast cancers.

Breast cancer may not cause noticeable symptoms, but when it does, symptoms may include a change in the size, shape, or contour of the breast; a mass or lump, which may feel as small as a pea; a lump or thickening in or near the breast or in the underarm that persists throughout the menstrual cycle; a change in the look or feel of the skin on the breast or nipple (dimpled, puckered, scaly, inflamed or red, purple, or darker than other parts of the breast); a marble-like hardened area under the skin; and a blood-stained or clear fluid discharge from the nipple. See Figure 16.20[4] for an illustration of potential symptoms of breast cancer.

4. Rapseck. (2016). *Breast cancer illustration* [Diagram]. Wikimedia Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Breast_cancer_illustration_pt.svg



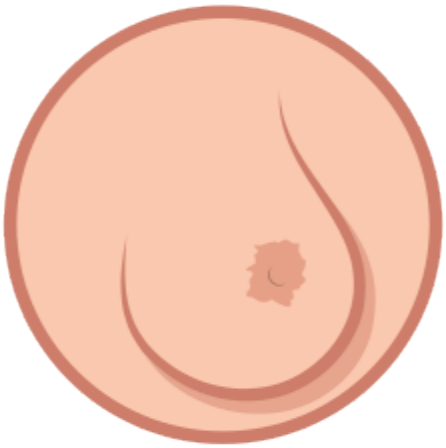
Lump



Skin dimpling



Change in skin color or texture



Change in how the nipple looks, like pulling in of the nipple



Clear or bloody fluid that leaks out of the nipple

Figure 16.20 Potential Symptoms of Breast Cancer

The American Cancer Society recommends a mammogram every year for most women starting at age 45. A mammogram is a radiographic image of breast tissue that can detect signs of cancer, often before a lump is felt. People suspected of having breast cancer or those at high risk may have additional diagnostic tests. Breast cancer may be treated with surgery, such as mastectomy (removal of one or both breasts), lumpectomy (removal of the tumor), and breast reconstruction. Other treatments include chemotherapy, radiation therapy, immunotherapy, or hormone therapy, including selective estrogen receptor modulator (SERM) therapy and other targeted therapy.

Cervical Cancer

Cervical cancer begins when abnormal cells in the cervix become cancerous. This type of cancer tends to grow slowly, but if left untreated, it can spread to other parts of the body. Almost all cervical cancers are caused by infection with a virus called **human papillomavirus (HPV)**. There are many types of HPV, but the types that cause cancer are called "high-risk HPV." High-risk HPV is very common and is transmitted during oral, vaginal, or anal sex. However, HPV typically does not cause symptoms, and most people don't know they have it. When cancer cells begin to grow in the cervix, symptoms may include abnormal vaginal bleeding, such as bleeding after sex or between menstrual periods, or pelvic pain or pain during sex.

Treatment for cervical cancer depends on the type of cancer and whether it has spread. Treatments include surgery to remove the cancer, radiation therapy, chemotherapy, targeted therapy, and immunotherapy.

Almost all cervical cancer can be prevented by the HPV vaccination. Read more about HPV vaccination in the "Human Papillomavirus Infection" subsection. Cervical cancer can also be prevented or diagnosed early by routine cervical cancer screening. Two types of screening tests use a sample of cervical cells that your provider collects with a swab: a Pap smear checks for abnormal cells so they can be treated before they become cancer, and an HPV test checks for high-risk HPV infections that can cause cancer.[5]

5. Medline [Internet]. (n.d.). *Cervical cancer.* https://medlineplus.gov/cervicalcancer.html

Cryptorchidism

A testis that doesn't move down into its proper place in the scrotum before birth is called **cryptorchidism** or an undescended testicle. Most often, just one testicle does not descend into the scrotum, but sometimes both testicles are affected.

An undescended testicle is more common in premature babies than it is in full-term infants. An undescended testicle often moves down into the scrotum on its own within a few months after the baby is born. If a baby has an undescended testicle that doesn't correct itself, surgery is performed to move the testicle into the scrotum. Treatment before age 1 may lower the risk of health problems linked with an undescended testicle, such as infertility and testicular cancer.[6]

Ectopic Pregnancy

An **ectopic pregnancy** occurs when a fertilized egg implants and grows outside of the uterus, most commonly in the Fallopian tube, where the tissue cannot support the growing embryo. If left untreated, rupture of the growing tissue can cause severe internal bleeding and potential death. Symptoms of an ectopic pregnancy are similar to a normal early pregnancy, but additional symptoms, such as abdominal pain and vaginal bleeding, require immediate medical attention. Treatment depends on the stage of the ectopic pregnancy and may include medication to dissolve the ectopic tissue or surgery to remove the ectopic pregnancy (sometimes including the affected Fallopian tube).[7]

Endometriosis

Endometriosis is a common health problem in women, with approximately 11% of women, or more than 6.5 million women in the United States, having endometriosis. Endometriosis can happen in any individual who has menstrual periods, but it is more common in women in their 30s and 40s. It gets its name from the word *endometrium*, the tissue that normally lines the uterus. Endometriosis happens when tissue similar

6. Mayo Clinic. (2023). *Undescended testicle.* https://www.mayoclinic.org/diseases-conditions/undescended-testicle/diagnosis-treatment/drc-20352000

7. Mayo Clinic. (2022). *Ectopic pregnancy.* https://www.mayoclinic.org/diseases-conditions/ectopic-pregnancy/symptoms-causes/syc-20372088

to the lining of the uterus grows outside of the uterus and in other areas in the body where it doesn't belong. Most often, endometriosis is found on the ovaries, Fallopian tubes, tissues that hold the uterus in place, and the outer surface of the uterus. Other sites for growths can include the vagina, cervix, vulva, bowel, bladder, or rectum. Rarely, endometriosis appears in other parts of the body, such as the lungs, brain, and skin.[8]

See Figure 16.21[9] for an illustration of endometriosis.

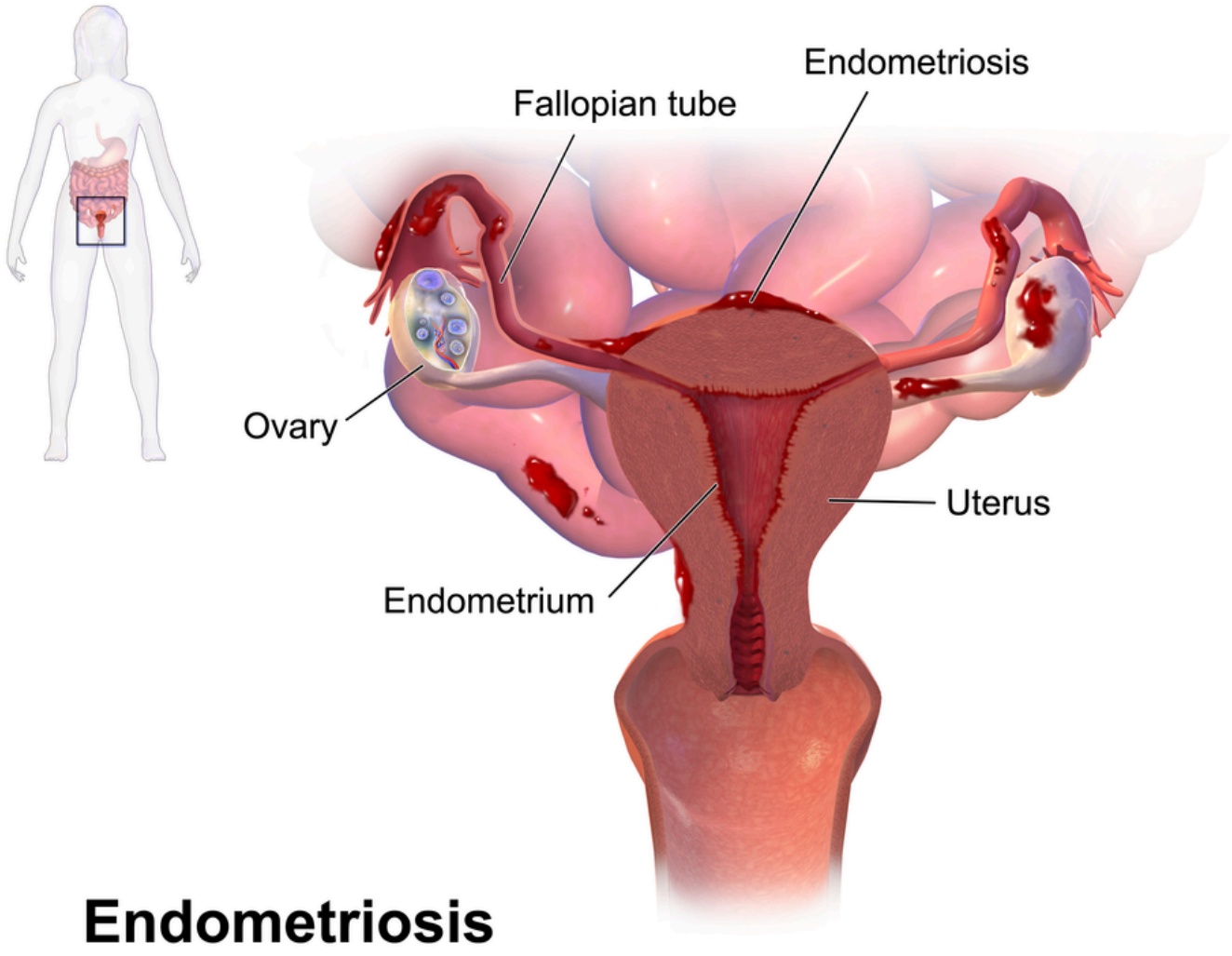


Figure 16.21 Endometriosis

8. Eisenberg, E., & Chahine, E. B. (2021). *Endometriosis.* Office on Women's Health. (https://womenshealth.gov/a-z-topics/endometriosis

9. Blausen.com. (2013). *Blausen 0349 Endometriosis* [Diagram]. Wikimedia Commons. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Blausen_0349_Endometriosis.png

Symptoms of endometriosis are as follows:

- Pain: Women with endometriosis commonly experience different kinds of pain, including the following:
  - Very painful menstrual cramps that may worsen over time
  - Chronic (long-term) pain in the lower back and pelvis
  - Pelvic pain during or after sex, usually described as a “deep” pain
  - Abdominal pain
  - Painful bowel movements or pain when urinating during menstrual periods
- Bleeding or spotting between menstrual periods
- Infertility (not being able to get pregnant)
- Digestive problems such as diarrhea, constipation, bloating, or nausea, especially during menstrual periods

There is no cure for endometriosis. Symptoms may be managed with medications or surgical procedures.

Erectile Dysfunction

Erectile dysfunction (ED) is the difficulty or inability to attain and/or maintain an erection that is sufficient for satisfactory sexual activity. Erectile dysfunction is a relatively common problem, affecting up to 30 million men of all ages in the United States and more than 150 million worldwide. The ability to have an erection requires complex coordination between nerves, blood vessels, muscles, and the brain.

A variety of factors—frequently in combination—can cause erectile dysfunction. These factors include neurological, hormonal, and vascular disorders, as well as the natural aging process and certain chronic diseases. ED is also a common side effect of treatments for prostate cancer. In addition, psychological issues, such as depression, anxiety, or performance concerns, play at least some part in virtually every case of ED.[10]

See Figure 16.22[11] for an illustration of common factors causing erectile dysfunction.

10. Shindel, A. W. (2022). *Erectile dysfunction*. University of California, San Francisco. https://www.ucsfhealth.org/conditions/erectile-dysfunction

11. Click2Pharmacy. (2022). *Common causes of erectile dysfunction* [Infographic]. Flickr. CC BY 4.0. https://commons.wikimedia.org/wiki/File:Common_causes_of_erectile_dysfunction.jpg

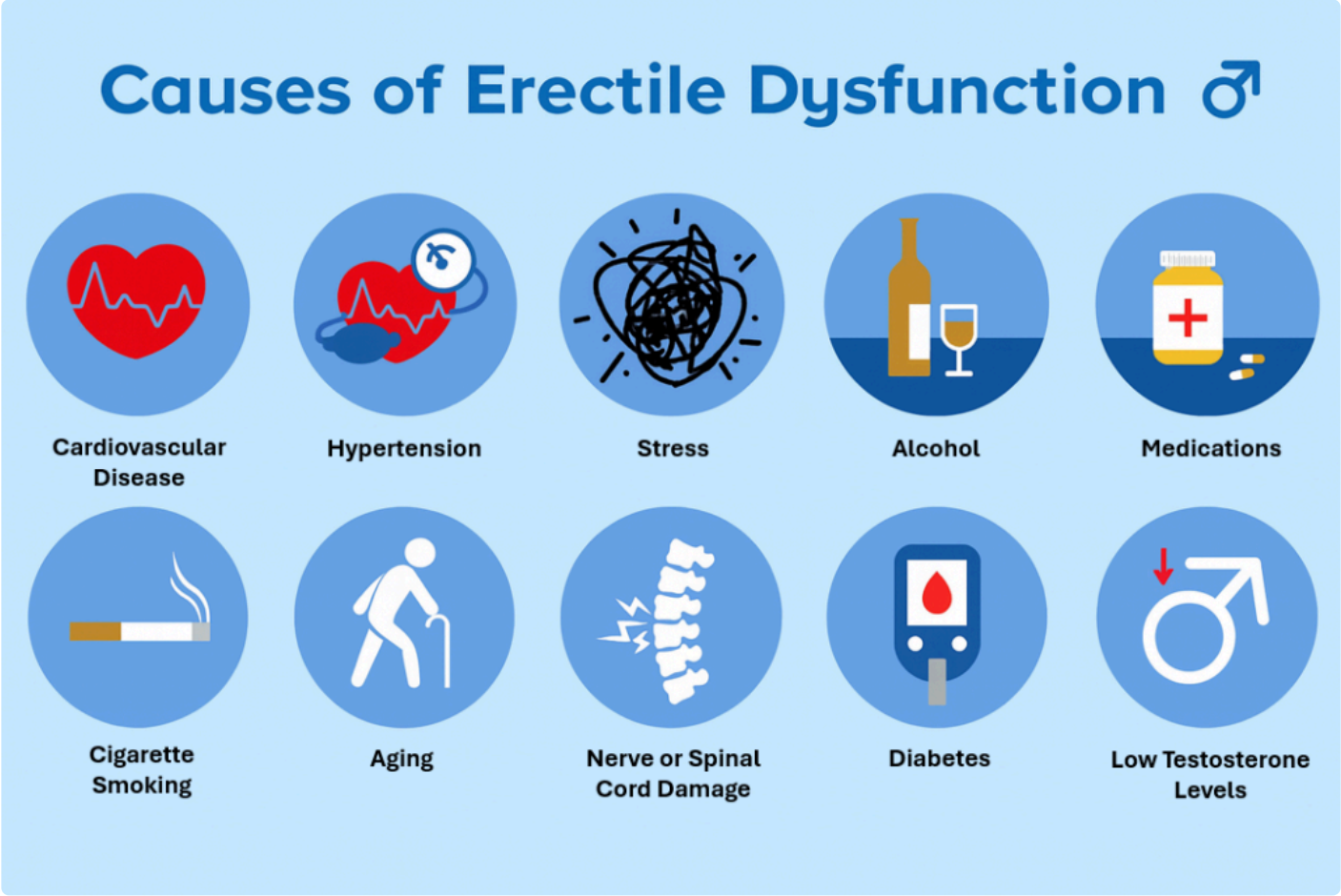


Figure 16.22 Common Factors Causing Erectile Dysfunction

Human Papillomavirus Infection (HPV)

Human papillomavirus (HPV) is a common sexually transmitted infection that can affect males and females. More than half of sexually active men and women will become infected with HPV at some point in their lifetime.

HPV strains are classified as high or low risk according to their potential to cause cancer. Though most HPV infections do not cause disease, the disruption of normal cellular functions in the low-risk forms of HPV can cause genital warts. In most healthy individuals, the immune system is able to clear these strains of HPV infection within two years. However, more serious, high-risk strains of HPV can result in cancer of the

vulva, vagina, penis, anus, or throat. Read more about cancer in the "Cervical Cancer" subsection.[12,13]

The Centers for Disease Control and Prevention recommends routine HPV vaccination for males and females beginning at age 11, before possible exposure when becoming sexually active, and for everyone through age 26 years if not adequately vaccinated when younger.[14]

Infertility

Infertility is the inability to conceive after 12 months of unprotected sexual intercourse or after six months of unprotected intercourse for women over 35 years old. It also refers to the inability of a woman to carry a pregnancy to live birth. Infertility affects millions of people around the world and can also impact their families and communities. Estimates suggest that approximately one in every six people of reproductive age worldwide experiences infertility in their lifetime. In the male reproductive system, infertility is most commonly caused by problems in the ejection of semen, low levels or absence of sperm production, or abnormal morphology (shape) or motility (movement) of sperm. In the female reproductive system, infertility may be caused by a variety of abnormalities of the ovaries, uterus, Fallopian tubes, and the endocrine system. In some cases, a specific cause for a couple's infertility cannot be determined.[15]

Inguinal Hernia

A hernia occurs when tissue from one body cavity bulges through an opening in the muscle wall into another. **Inguinal hernias** are the most common type of hernia, making

12. Betts, J. G., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M., & DeSaix, P. (2022). *Anatomy and physiology 2e.* OpenStax. https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction

13. Johnson, T. C. (2024). *HPV Infection in men.* WebMD. https://www.webmd.com/sexual-conditions/hpv-genital-warts/hpv-virus-men

14. Centers for Disease Control and Prevention. (2021). *HPV vaccination recommendations.* https://www.cdc.gov/vaccines/vpd/hpv/hcp/recommendations.html#:~:text=Dosing%20Schedules%0A%0ATwo%20doses%20of%20HPV%20vaccine%20are,require%20a%20third%20dose%20of%20HPV%20vaccine

15. World Health Organization. (2024). *Infertility.* https://www.who.int/news-room/fact-sheets/detail/infertility

up 75% of all hernias. Around 25% of males will have an inguinal hernia during their lifetime, compared to 2% of females.

Inguinal hernias occur when abdominal tissue bulges through an opening in the lower abdominal wall called the inguinal canal, a passageway that runs down either side of the pelvis into the sex organs. During development in male infants, the testicles descend from the abdomen and pass through the inguinal canal to reach the scrotum, making this preexisting opening a common place for hernias to develop. In females, the inguinal canal is narrower and contains the round ligament that supports the uterus. This tough ligament helps to reinforce the muscle wall. Women with connective tissue disease are more susceptible to hernias. Inguinal hernias are treated with surgery to prevent complications.[16]

Pelvic Inflammatory Disease

Pelvic inflammatory disease (PID) is an infection of the female reproductive organs that typically occurs when a sexually transmitted infection spreads from the vagina to the uterus, Fallopian tubes, or ovaries. Many types of bacteria can cause PID, but gonorrhea and chlamydia are the most common causes. Less commonly, bacteria can enter the reproductive tract during menstruation, childbirth, miscarriage, or abortion.

The signs and symptoms of pelvic inflammatory disease might be mild and difficult to recognize. When signs and symptoms of PID are present, they most often include pain, ranging from mild to severe, in the lower abdomen and pelvis; unusual or heavy vaginal discharge that may have an unpleasant odor; unusual vaginal bleeding during or after sex or between periods; pain during sex; fever; and painful or frequent urination.

PID is treated with medications to treat the underlying infection, but scarring or damage that may have occurred due to the infection cannot be reversed.[17]

*]:pointer-events-auto [content-visibility:auto] supports-[content-visibility:auto]:[contain-intrinsic-size:auto_100lvh] R6Vx5W_threadScrollVars scroll-mb-[calc(var(--scroll-root-safe-area-inset-bottom,0px)+var(--thread-response-height))] scroll-mt-[calc(var(--header-height)+min(200px,max(70px,20svh)))]" dir="auto" data-turn-id="request-WEB:ff92e969-82a0-458a-8989-e28ce1410415-0" data-turn-id-container="request-

16. Cleveland Clinic. (2022). *Inguinal hernia (groin hernia)*. https://my.clevelandclinic.org/health/diseases/16266-inguinal-hernia

17. Mayo Clinic. (2022). *Pelvic inflammatory disease (PID).* https://www.mayoclinic.org/diseases-conditions/pelvic-inflammatory-disease/symptoms-causes/syc-20352594

WEB:ff92e969-82a0-458a-8989-e28ce1410415-0" data-testid="conversation-turn-2" data-scroll-anchor="false" data-turn="assistant">

Polyendocrine Metabolic Ovarian Syndrome (formerly Polycystic Ovary Syndrome)

Polyendocrine Metabolic Ovarian Syndrome (PMOS), formerly referred to as Polycystic Ovary Syndrome (PCOS), is a complex, long-term endocrine and metabolic condition characterized by hormone fluctuations that can affect weight, metabolism, mental health, the skin, and the reproductive system. The name PMOS was introduced to better reflect the condition's hormonal and metabolic features and to move away from the misleading idea that the disorder is primarily caused by abnormal ovarian cysts. According to the Endocrine Society, research has shown that there is no increase in abnormal ovarian cysts in this condition.[18]

PMOS may involve ovulatory dysfunction and changes in ovarian follicles, which are small fluid-filled sacs that contain immature eggs. Instead of releasing an egg during ovulation, follicles may remain in the ovary and appear enlarged on imaging.

PMOS has no single known cause, but it is associated with endocrine and metabolic factors, including insulin resistance and obesity. Common signs and symptoms may include oligomenorrhea, amenorrhea, polymenorrhea, ovulatory dysfunction, and enlarged ovaries due to multiple follicles. High levels of androgen hormones associated with PMOS can cause **hirsutism**, or excess facial and body hair. PMOS can also contribute to infertility.

PMOS is diagnosed using a combination of medical history, physical examination, blood tests to evaluate hormone levels and metabolic factors, and, in some cases, transvaginal ultrasound. Treatments may include birth control pills to help regulate menstrual cycles, diabetes medications to reduce insulin resistance, and medications to promote ovulation.[19]

18. Endocrine Society. (2026, May 12). Polyendocrine Metabolic Ovarian Syndrome: New name to improve diagnosis and care of condition affecting 170 million women worldwide. https://www.endocrine.org/news-and-advocacy/news-room/2026/pcos-name-change

19. Mayo Clinic. (2022). *Polycystic ovary syndrome (PCOS).* https://www.mayoclinic.org/diseases-conditions/pcos/symptoms-causes/syc-20353439

Premenstrual Syndrome (PMS)

Many women feel physical or mood changes during the days before menstruation. When these symptoms happen every month, and they are significant enough to affect a woman's quality of life, they are known as **premenstrual syndrome (PMS)**.

Emotional symptoms include depression, angry outbursts, irritability, crying spells, anxiety, confusion, social withdrawal, poor concentration, insomnia, increased nap taking, and changes in sexual desire. Physical symptoms include thirst and appetite changes (food cravings), breast tenderness, bloating and weight gain, headache, swelling of the hands or feet, aches and pains, fatigue, skin problems, gastrointestinal symptoms, and abdominal pain.

Mild to moderate symptoms may be relieved by changes in lifestyle or diet, but medications may be prescribed if PMS symptoms are severe and interfere with daily life.[20]

Prostate Cancer

Prostate cancer is a common type of cancer in males over age 50. Prostate cancer typically grows slowly. The risk for developing prostate cancer increases in males with a family history of prostate cancer or African American ancestry. Early prostate cancer is often asymptomatic but may cause problems urinating, blood in the urine or semen, or pain in the lower back, hips, or pelvis. However, many men develop problems urinating from an enlarged prostate as they age, making early signs of prostate cancer easy to miss. Aggressive types of prostate cancer can spread to other parts of the body, most commonly the bones and lymph nodes.

Treatment options depend on a person's age, their general health, and the aggressiveness of the cancer. Treatment may include active surveillance, surgical removal of the cancer, radiation therapy, hormone therapy, chemotherapy, targeted therapy, and immunotherapy.[21]

See Figure 16.23[22] for an illustration of prostate cancer.

20. American College of Obstetricians and Gynecologists. (2023). *Premenstrual syndrome (PMS).* https://www.acog.org/womens-health/faqs/premenstrual-syndrome
21. Medline [Internet]. (n.d.). *Prostate cancer.* https://medlineplus.gov/prostatecancer.html
22. Cancer Research UK. (2014). *Diagram showing prostate cancer pressing on the urethra* [Diagram]. Wikimedia

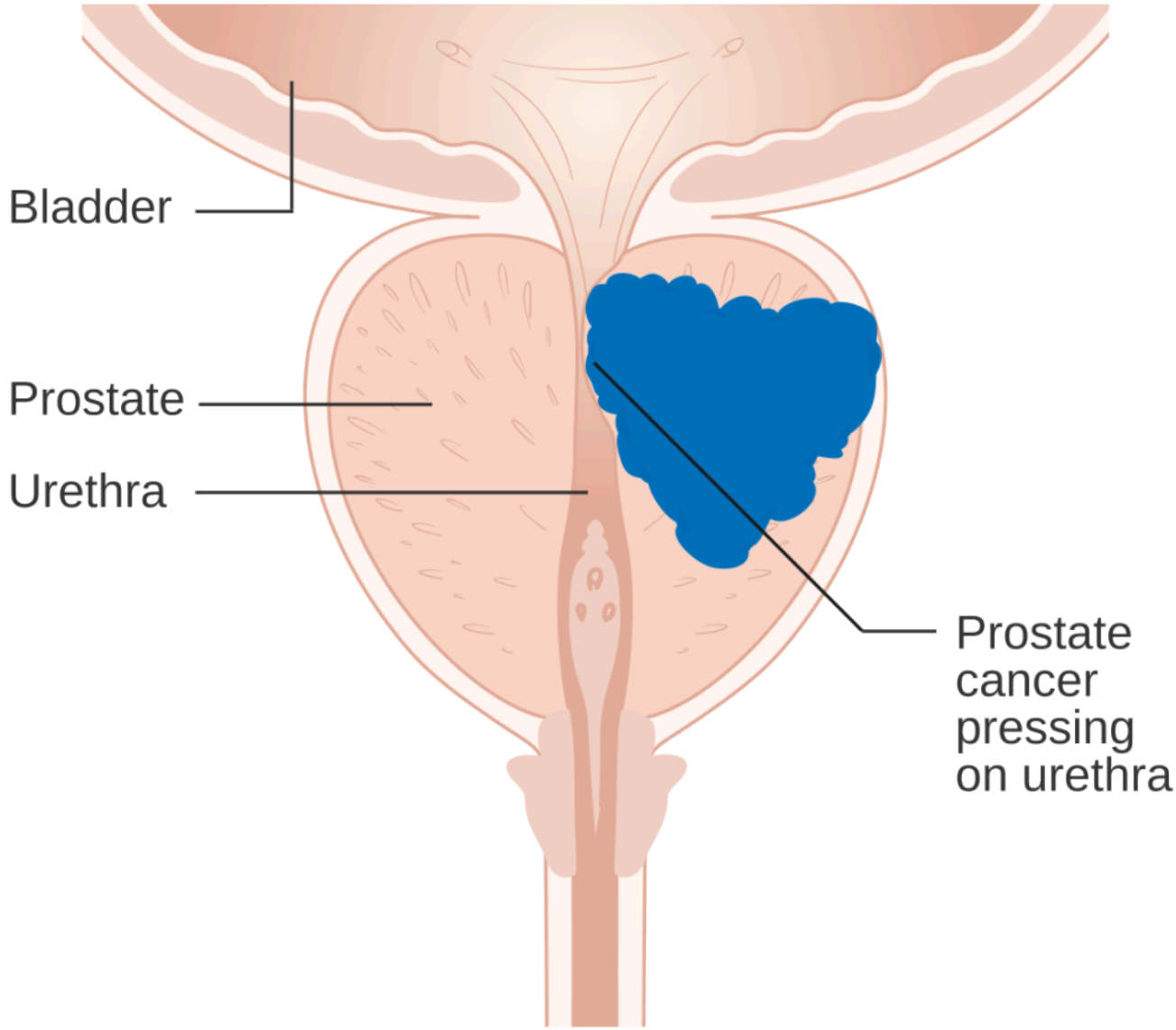


Figure 16.23 Prostate Cancer

Prostatitis

Prostatitis is inflammation of the prostate, a painful condition that occurs in 10-12% of young and middle-aged men. Symptoms of prostatitis include painful urination,

Commons. CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:Diagram_showing_prostate_cancer_pressing_on_the_urethra_CRUK_182.svg

frequent urination, burning in the penis with or without urination, pain in the rectum and scrotal area, lower abdominal or back pain, pain with ejaculation, and fever or chills.[23]

There are four types of prostatitis:

- **Acute bacterial prostatitis** is diagnosed based on bacteria and white blood cells present in the urine and prostate fluid and is typically treated with intravenous antibiotics for up to two to four weeks.
- **Chronic bacterial prostatitis** refers to long-term infection in the prostate that seems to resolve and recur. Treatment includes antibiotics for up to six months to prevent recurrent infection. If a blockage is present that causes incomplete emptying of the bladder, surgery may be performed.
- **Chronic prostatitis/chronic pelvic pain syndrome** is the most common but least understood type of prostatitis and results in inflammation of the prostate for more than three months in men of any age. It may or may not be caused by a bacterial infection, and it may cause chronic pelvic pain. Treatment may include antibiotics if caused by a bacterial infection, medications to relax the muscle tissue in the prostate, and pain relievers. Lifestyle changes, such as avoiding caffeine, alcohol, and spicy foods, as well as stress management techniques, may improve symptoms.
- **Asymptomatic inflammatory prostatitis** is diagnosed when there are white blood cells present in semen, but the patient does not have pain or discomfort. This type of prostatitis is diagnosed when a patient is being evaluated for causes of infertility or tested for prostate cancer, and no treatment is required.

Sexually Transmitted Infection

Sexually transmitted infections (STIs) are caused by bacteria, viruses, or parasites that are passed from person to person during exposure to body fluids during sexual contact, including oral, vaginal, and anal sex. STIs can also spread to infants from their mothers during pregnancy or childbirth. Some STIs, such as hepatitis and HIV, can also be spread through blood by drug users sharing needles.

STIs do not always cause symptoms. A person can get an STI from another person who seems healthy and does not know they have an infection. Common STIs and their symptoms include the following:

23. Department of Urology. (n.d.). *Prostatitis.* University of Washington Medicine. https://urology.uw.edu/patient-care/conditions-and-treatments/prostatitis

- **Chlamydia**: A common bacterial infection that can cause vaginal or penile discharge, painful urination, and pelvic pain.
- **Genital Herpes**: A chronic viral infection that causes sores and blisters on the genitals.
- **Gonorrhea**: A common bacterial infection that can cause painful urination, discharge, and painful intercourse.
- **Hepatitis B or C**: A viral infection that damages the liver.
- **HIV**: A chronic viral infection that weakens the immune system and can lead to AIDS.
- **Human Papillomavirus (HPV)**: A common viral infection that can cause genital warts and cancer.
- **Syphilis**: A bacterial infection that can progress through different stages, causing sores, rash, and serious complications if left untreated.
- **Trichomoniasis**: A parasitic infection that can cause vaginal discharge, itching, and painful urination.

STIs are treated with antibiotics or antivirals based on the cause, but they cannot always be cured. For example, genital herpes cannot be cured. There are many ways to prevent STIs. The best way to prevent STIs is to not have sex or to have sex in a long-term, mutually monogamous relationship, meaning you both agree to be sexually active only with each other after being tested for possible STIs. Vaccinations, such as the HPV or hepatitis vaccines, can also help prevent these STIs. Otherwise, before participating in any sexual contact, it is important to talk to your partner about practicing safer sex and using latex condoms consistently and correctly.[24,25]

Testicular Cancer

Testicular cancer typically occurs in young men between the ages of 15 and 45. The first sign of testicular cancer is often a lump on a testicle. The cancer cells can grow

24. Mayo Clinic. (2023). *Sexually transmitted diseases (STDs).* https://www.mayoclinic.org/diseases-conditions/sexually-transmitted-diseases-stds/symptoms-causes/syc-20351240
25. Medline [Internet]. (n.d.). *Sexually transmitted infections.* https://medlineplus.gov/sexuallytransmittedinfections.html

quickly and spread to other parts of the body. If diagnosed and treated early with surgery and chemotherapy, testicular cancer has a high cure rate.[26]

Testicular Torsion

Testicular torsion occurs when a testicle rotates, twisting the spermatic cord that brings blood to the scrotum. The reduced blood flow causes sudden, severe pain and swelling. Testicular torsion commonly occurs between the ages of 12 and 18 and usually requires emergency surgery. If treated quickly, the testicle can usually be saved. But when blood flow has been cut off for too long, a testicle might become so badly damaged that it has to be removed.[27]

26. Johns Hopkins Medicine. (n.d.). *Testicular cancer.* https://www.hopkinsmedicine.org/health/conditions-and-diseases/testicular-cancer

27. Mayo Clinic. (2022). *Testicular torsion.* https://www.mayoclinic.org/diseases-conditions/testicular-torsion/symptoms-causes/syc-20378270

16.8 Career Connections Related to the Reproductive System

The reproductive system includes the organs and structures involved in reproduction, pregnancy, childbirth, and newborn care. It also plays an important role in hormone production, sexual health, and overall wellness. When patients need reproductive health services, pregnancy care, birth support, newborn care, or help with related health concerns, many professionals may provide education, testing, treatment, patient care, and support. Careers related to the reproductive system can include registered nurses, obstetrics (OB) nurses, neonatal nurses, medical assistants, nursing assistants, and midwives.

Registered Nurse

Registered nurses provide patient care, education, and support in hospitals, clinics, long-term care facilities, home health, and community settings. This career connects to the reproductive system because registered nurses may care for patients during pregnancy, childbirth, postpartum recovery, reproductive health visits, fertility care, gynecologic procedures, or newborn care. They may monitor symptoms, administer medications, provide patient education, support infection prevention, and coordinate care with other health professionals.

OB Nurse

OB nurses are registered nurses who specialize in caring for patients during pregnancy, labor, birth, and the postpartum period. They may monitor the health of the parent and baby, provide comfort measures, assist during labor and delivery, administer medications, support breastfeeding education, and help patients recover after childbirth. OB nurses often work in hospitals, birthing centers, or obstetrics and gynecology clinics.

Neonatal Nurse

Neonatal nurses are registered nurses who care for newborns, including premature infants or newborns with health concerns. They may work in newborn nurseries, neonatal intensive care units, or other hospital settings. Neonatal nurses monitor vital signs, support feeding, administer medications, assist with specialized equipment, educate families, and collaborate with other members of the health care team.

Medical Assistant

Medical assistants work in clinics and other health care settings where they support patient care and office procedures. In obstetrics and gynecology, urology, family practice, or reproductive health settings, medical assistants may help room patients, collect health information, record symptoms, check vital signs, prepare patients for examinations, assist with basic procedures, support documentation, and communicate follow-up instructions.

Nursing Assistant

Nursing assistants provide basic care and help patients with daily activities under the supervision of licensed nursing staff. This career connects to the reproductive system because nursing assistants may help patients during postpartum recovery, after reproductive system procedures, or during hospital stays. They may assist with hygiene, mobility, comfort measures, vital signs, and reporting changes in a patient's condition.

Midwife

Midwives provide care and support during pregnancy, birth, and the postpartum period. Depending on their credentials and scope of practice, midwives may also provide reproductive health education, family planning services, newborn care, and gynecologic care. Midwives use knowledge of pregnancy, childbirth, newborn health, patient education, and safety practices while supporting patients and families.

Take a Closer Look

Explore careers related to the human body's reproductive system on these websites.

- Registered nurse from the American Nurses Association
- OB and neonatal nursing from the Association of Women's Health, Obstetric and Neonatal Nurses
- Nurse midwife from the American College of Nurse-Midwives
- Medical assistant from the American Association of Medical Assistants
- Nursing assistant and orderly careers from the U.S. Bureau of Labor Statistics
- Obstetrics and gynecology from the American College of Obstetricians and Gynecologists

16.9 Learning Activity: Flashcards

Flashcards

Click the Turn button to flip each card and see the answer, then use the arrow to move to the next card. Continue through the set and revisit cards as needed until you can recall the answers on your own.

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.



16.10 Glossary

Acrosome: A cap-like structure on the head of a sperm cell containing enzymes that help the sperm penetrate the egg during fertilization. (**Chapter 16.4**)

Acute bacterial prostatitis: Diagnosed based on bacteria and white blood cells present in the urine and prostate fluid, and is typically treated with intravenous antibiotics for up to 2 to 4 weeks. (**Chapter 16.7**)

Ampulla: The middle region of the Fallopian tube. (**Chapter 16.5**)

Andropause: A condition in males, also called male menopause, marked by a decline in testosterone levels and related symptoms, typically starting around 40 to 50 years of age. (**Chapter 16.7**)

Antrum: A fluid-filled cavity that forms within a developing ovarian follicle. (**Chapter 16.6**)

Areola: The circular pigmented area around the nipple containing glands that secrete lubricating fluid during lactation to protect against chafing. (**Chapter 16.5**)

Asymptomatic inflammatory prostatitis: Diagnosed when there are white blood cells present in semen, but the patient does not have pain or discomfort. (**Chapter 16.7**)

Atresia: The death of ovarian follicles. (**Chapter 16.6**)

Autosomal chromosomes: The 22 pairs of chromosomes in humans that do not determine sex but carry genes for other traits. (**Chapter 16.1**)

Bartholin's (or greater vestibular) glands: Glands that produce mucus that adds lubrication to the vagina. (**Chapter 16.5**)

Benign prostatic hypertrophy (BPH): Noncancerous enlargement of the prostate gland that can constrict the urethra and cause urinary symptoms like frequent urination, weak stream, and incomplete bladder emptying. (**Chapter 16.7**)

Blood–testis barrier: Protects developing sperm from the individual's immune system. (**Chapter 16.3**)

Body (or corpus): The middle section of the uterus. (**Chapter 16.5**)

Breasts: Considered accessory organs of the female reproductive system. (**Chapter 16.5**)

Broad ligament: A primary support for the uterus, extending laterally from both sides of the uterus and attaching it to the pelvic wall. (**Chapter 16.5**)

Bulbourethral glands (Cowper's glands): Small glands that release a thick, salty fluid to lubricate the urethra and vagina and cleanse urine residues from the penile urethra. (**Chapter 16.3**)

Certified nurse-midwife (CNM): A type of advanced practice registered nurse who has completed advanced education and training. (**Chapter 16.8**)

Certified professional midwife (CPM): A skilled maternity care provider who offers education, support, counseling, and expert care for pregnancy, birth, and postpartum. (**Chapter 16.8**)

Cervical cancer: A slow-growing cancer that starts when abnormal cells in the cervix become malignant and can spread to other parts of the body if untreated. (**Chapter 16.7**)

Cervix: The narrow inferior portion of the uterus that projects into the vagina. (**Chapter 16.5**)

Chlamydia: A common bacterial infection that can cause vaginal or penile discharge, painful urination, and pelvic pain. (**Chapter 16.7**)

Chronic bacterial prostatitis: Long-term infection in the prostate that seems to resolve and recur. Treatment includes antibiotics for up to six months to prevent recurrent infection. (**Chapter 16.7**)

Chronic prostatitis/chronic pelvic pain syndrome: The most common but least understood type of prostatitis, which results in inflammation of the prostate for more than three months in men of any age. (**Chapter 16.7**)

Circumcision: A surgical procedure that removes the prepuce (foreskin); often performed for religious or social reasons. (**Chapter 16.3**)

Clitoris: A highly innervated organ derived from the same embryonic tissue as the glans penis and important for sexual sensation and orgasm. (**Chapter 16.5**)

Corpus albicans: A scar-like structure formed when the corpus luteum degenerates if pregnancy does not occur. (**Chapter 16.6**)

Corpus cavernosum: One of two columns of erectile tissue in the penis that fills with blood to produce an erection. (**Chapter 16.3**)

Corpus luteum: A temporary endocrine structure formed from the ruptured follicle after ovulation that secretes progesterone to support pregnancy. (**Chapter 16.6**)

Corpus spongiosum: The single column of erectile tissue surrounding the urethra in the penis that fills with blood during an erection to keep the urethra open. (**Chapter 16.3**)

Cowper's glands: Small glands that release a thick, salty fluid to lubricate the urethra and vagina and cleanse urine residues from the penile urethra; also called bulbourethral glands. (**Chapter 16.3**)

Cremaster muscles: Two muscles that cover each testis like a muscular netting. (**Chapter 16.3**)

Cryptorchidism: A testis that doesn't move down into its proper place in the scrotum before birth. (**Chapter 16.7**)

Dartos muscle: The muscle layer of the scrotum. (**Chapter 16.3**)

Differentiates: Undergoes a process of development to become a more specialized cell type. (**Chapter 16.4**)

Diploid: A cell that contains two full sets of chromosomes (2n), one set from each parent. Somatic cells are diploid. (**Chapter 16.1**)

Ductal carcinoma in situ (DCIS): Breast cancer that starts in the milk ducts but doesn't spread beyond the milk ducts. (**Chapter 16.7**)

Ectopic pregnancy: Occurs when a fertilized egg implants and grows outside of the uterus, most commonly in the Fallopian tube, where the tissue cannot support the growing embryo. (**Chapter 16.7**)

Ejaculatory duct: A short structure formed from the ampulla of the vas deferens and the duct of the seminal vesicle. (**Chapter 16.3**)

Endometriosis: A common health condition where tissue similar to the uterine lining grows outside the uterus, affecting about 11% of women in the U.S., especially those in their 30s and 40s. (**Chapter 16.7**)

Endometrium: Innermost layer of the uterus. (**Chapter 16.5**)

Epididymis: A coiled tube attached to the testis where newly formed sperm continue to mature. (**Chapter 16.3**)

Erectile dysfunction (ED): The difficulty or inability to attain and/or maintain an erection that is sufficient for satisfactory sexual activity. (**Chapter 16.7**)

Estrogens: Hormones produced by the ovaries, including estradiol, estriol, and estrone, that regulate the reproductive system, menstrual cycle, female secondary sex traits, and pregnancy. (**Chapter 16.6**)

External urethral orifice: The external opening at the tip of the penis through which urine and semen exit the body. (**Chapter 16.3**)

Fallopian tubes: Carry the ovulated oocyte to the uterus; also called uterine tubes or oviducts. (**Chapter 16.5**)

Fimbriae: Slender, finger-like projections that sweep the egg into the Fallopian tube. (**Chapter 16.5**)

Flagellum: A long, whip-like tail that enables a sperm cell to swim. (**Chapter 16.4**)

Follicle: A structure that contains one oocyte and its supporting cells. (**Chapter 16.5**)

Follicle-stimulating hormone (FSH): A gonadotropin that promotes the production and development of sex cells (ova in females and sperm in males). (**Chapter 16.6**)

Follicular phase: The phase of the ovarian cycle when the follicles are growing and secreting estrogen. (**Chapter 16.6**)

Folliculogenesis: The process by which ovarian follicles grow and develop, usually resulting in the ovulation of one oocyte and the degeneration of the others. (**Chapter 16.6**)

Foreskin: The fold of skin that covers and protects the glans penis; also known as prepuce. (**Chapter 16.3**)

Fundus: The portion of the uterus superior to the opening of the uterine tubes. (**Chapter 16.5**)

Gamete: A specialized sex cell (sperm or egg) that contains half the number of chromosomes of a typical body cell and is involved in sexual reproduction. (**Chapter 16.1**)

Genital herpes: A chronic viral infection that causes sores and blisters on the genitals. (**Chapter 16.7**)

Glans penis: The rounded, sensitive tip of the penis that is covered by the foreskin unless circumcised. (**Chapter 16.3**)

Gonadotropin-releasing hormone (GnRH): A hormone secreted by the hypothalamus that stimulates the anterior pituitary to secrete follicle-stimulating hormone (FSH) and luteinizing hormone (LH). (**Chapter 16.6**)

Gonorrhea: A common bacterial infection that can cause painful urination, discharge, and painful intercourse. (**Chapter 16.7**)

Granulosa cells: A single flat layer of support cells that surround the oocyte and can stay in this resting state for years—some until right before menopause. (**Chapter 16.6**)

Gynecologist: A physician who specializes in the diagnosis and treatment of diseases and disorders of the female reproductive system. (**Chapter 16.8**)

Haploid: A cell that contains only one complete set of chromosomes (23 in humans), typically seen in gametes like sperm and ova. (**Chapter 16.1**)

Hepatitis B or C: A viral infection that damages the liver. (**Chapter 16.7**)

Heterozygous: Having two different alleles for a particular gene (e.g., Aa). (**Chapter 16.1**)

Hirsutism: The medical term for excessive hair growth in areas where hair is usually minimal or absent. (**Chapter 16.7**)

HIV: A chronic viral infection that weakens the immune system and can lead to AIDS. (**Chapter 16.7**)

Homozygous: Having two identical alleles for a particular gene (e.g., XX for sex chromosomes in females or AA/aa for other traits). (**Chapter 16.1**)

Human papillomavirus (HPV): A virus that causes almost all cases of cervical cancer by infecting cervical cells. (**Chapter 16.7**)

Hymen: A thin membrane that sometimes partially covers the entrance to the vagina. (**Chapter 16.5**)

Infertility: The inability to conceive after 12 months of unprotected sexual intercourse or after six months of unprotected intercourse for women over 35 years old. (**Chapter 16.7**)

Inflammatory breast cancer (IBC): A rare, fast-growing cancer that looks like a rash on the breast. (**Chapter 16.7**)

Infundibulum: The funnel-shaped opening near the ovary that captures and directs the released oocyte into the Fallopian tube. (**Chapter 16.5**)

Inguinal canal: A passage in the lower anterior abdominal wall through which the spermatic cord passes in males (and the round ligament in females). (**Chapter 16.3**)

Inguinal hernias: The most common type of hernia, making up 75% of all hernias. Occurs when abdominal tissues bulge through an opening in the lower abdominal wall. (**Chapter 16.7**)

Interstitial cells: Cells found between the seminiferous tubules in the testes that produce the hormone testosterone. (**Chapter 16.3**)

Invasive (infiltrating) ductal carcinoma (IDC): Cancer that starts in the milk ducts and

spreads to nearby breast tissue. It is the most common type of breast cancer in the United States. (Chapter 16.7)

Isthmus: The narrow medial end of the Fallopian tube that is connected to the uterus. (Chapter 16.5)

Labia majora: Folds of hair-covered skin that begin just posterior to the mons pubis. (Chapter 16.5)

Labia minora: The smaller, hairless inner folds of skin situated medial to the labia majora. (Chapter 16.5)

Lactation: The process by which the breasts produce and supply milk to nourish an infant. (Chapter 16.5)

Leydig cell: Produces the hormone testosterone. (Chapter 16.3)

Lobular breast cancer: Breast cancer that starts in the milk-producing glands (lobules) in the breast and often spreads to nearby breast tissue. It is the second most common breast cancer in the United States. (Chapter 16.7)

Luteinizing hormone (LH): A gonadotropin that triggers ovulation in females and stimulates testosterone production in males. (Chapter 16.6)

Mammary glands: Modified sweat glands that produce breast milk. (Chapter 16.5)

Meiosis: A special type of cell division that occurs only in the sperm and ovum. (Chapter 16.4)

Membranous urethra: The short segment of the male urethra that passes through the pelvic floor muscles between the prostate and the penis. (Chapter 16.3)

Menarche: The start of menstruation. (Chapter 16.6)

Menopause: The ending of a female's reproductive functions. (Chapter 16.6)

Menstrual (uterine) cycle: Starts with the first day of menstruation, referred to as Day 1 of the menstrual cycle. (Chapter 16.6)

Menstrual phase: Phase of the menstrual cycle when the stratum functionalis of the uterus is shed; also known as menstruation. (Chapter 16.6)

Midwife: An individual who assists women during pregnancy and childbirth. (Chapter 16.8)

Mitosis: A process of nuclear division that results in two identical daughter cells with the same number of chromosomes as the parent cell. (Chapter 16.4)

Mons pubis: A pad of fat that is located superficial to the pubic bone. (Chapter 16.5)

Myometrium: The middle smooth muscular layer that makes up most of the uterus and is responsible for uterine contractions. (Chapter 16.5)

Neonatologists: Physicians who specialize in the care of newborns, especially those who require special medical expertise, such as premature and critically ill newborns. (Chapter 16.8)

Obstetrician: A physician who specializes in providing medical care through pregnancy, labor, and delivery of a baby. (Chapter 16.8)

Oogenesis: The production of an ovum (egg). (Chapter 16.6)

Oogonia: Ovarian stem cells formed during fetal development. (Chapter 16.6)

Ovarian ligaments: Fibrous bands that connect each ovary to the uterus, helping to hold the ovary in place. (Chapter 16.5)

Ovaries: A pair of small glands, about the size of an almond, that serve as the female gonads. (Chapter 16.5)

Ovulation: The release of an oocyte from the ovary. (Chapter 16.6)

Ovum: The female gamete, a non-motile cell that carries half the genetic material needed for reproduction and can be fertilized by a spermatozoon. (Chapter 16.1)

Oxytocin: A hormone that triggers the milk ejection reflex (“letdown”), allowing milk to be released from the breast during nursing. (Chapter 16.5)

Paget’s disease of the breast: A rare cancer that affects the skin of the nipple and may look like a rash. Less than 4% of all breast cancers are Paget’s disease of the breast. (Chapter 16.7)

Pediatrician: A doctor who focuses on the health of infants, children, and adolescents, with pediatric care starting at birth. (Chapter 16.8)

Pelvic inflammatory disease (PID): An infection of the female reproductive organs that typically occurs when a sexually transmitted infection spreads from the vagina to the uterus, Fallopian tubes, or ovaries. (Chapter 16.7)

Penis: The male copulatory (sex) organ. (Chapter 16.3)

Perimenopause: The earliest changes occur during the menopausal transition when a menstrual cycle becomes irregular but does not stop entirely. (Chapter 16.6)

Perimetrium: A serous membrane that covers the outside of the uterus. (Chapter 16.5)

Perineum: The area between the genitals and the anus. (**Chapter 16.5**)

Polar body: A small cell produced during oogenesis that contains little cytoplasm and typically disintegrates, ensuring most resources go to the developing oocyte. (**Chapter 16.6**)

Polyendocrine Metabolic Ovarian Syndrome (PMOS): A condition characterized by hormone imbalances, ovulatory dysfunction, and multiple ovarian cysts (i.e., small sacs of fluid). Previously known as polycystic ovary syndrome (PCOS). (**Chapter 16.7**)

Postmenopausal: The stage after menopause, when menstruation has ceased permanently. (**Chapter 16.6**)

Premenstrual syndrome (PMS): Menstrual symptoms that happen every month and are significant enough to affect a woman's quality of life. (**Chapter 16.7**)

Prepuce (foreskin): The fold of skin that covers and protects the glans penis. (**Chapter 16.3**)

Primary follicles: Single layer of granulosa cells, but they become active, increase in size, and proliferate. (**Chapter 16.6**)

Primary oocytes: Immature egg cells that are arrested in Prophase I of meiosis and remain dormant until puberty, when they may resume development during the menstrual cycle. (**Chapter 16.6**)

Primary spermatocyte: A diploid male germ cell that undergoes the first meiotic division to form secondary spermatocytes. (**Chapter 16.4**)

Primordial follicles: The earliest and most immature ovarian follicles, consisting of a primary oocyte surrounded by a single layer of flat supporting cells. (**Chapter 16.6**)

Progesterone: A hormone from the ovaries that helps regulate the menstrual cycle and supports pregnancy preparation and maintenance. (**Chapter 16.6**)

Prolactin (PRL): The hormone that promotes lactation (milk production). (**Chapter 16.5**)

Proliferative phase: A phase of the menstrual cycle that begins when menstrual flow stops and the endometrium begins to grow (proliferate) again; ovulation marks the end of the proliferative phase. (**Chapter 16.6**)

Prostate gland: A walnut-sized gland that surrounds the urethra and secretes a slightly acidic, milky fluid that helps nourish and transport sperm. (**Chapter 16.3**)

Prostate-specific antigen: A protein produced by both cancerous and noncancerous tissue in the prostate. (**Chapter 16.3**)

Prostatic urethra: The portion of the male urethra that passes through the prostate gland. (Chapter 16.3)

Prostatitis: Inflammation of the prostate, a painful condition that occurs in 10-12% of young and middle-aged men. (Chapter 16.7)

PSA test: A blood test used primarily to screen for prostate cancer. (Chapter 16.3)

Puberty: The stage of development when individuals become sexually mature. (Chapter 16.4)

Raphae: A seam or ridge marking the line of fusion between two symmetrical structures in the body. (Chapter 16.3)

Reproduction: The process of forming a new organism. (Chapter 16.1)

Round ligament: Attaches to the uterus near the Fallopian tubes and extends to the labia majora. (Chapter 16.5)

Scrotal septum: A wall that divides the scrotum into two compartments, each housing one testis. (Chapter 16.3)

Scrotum: A muscular sac that contains the testes. (Chapter 16.3)

Secondary follicles: Follicles that have grown larger with dividing granulosa cells and an added outer layer of connective tissue, blood vessels, and theca cells that help produce estrogens. (Chapter 16.6)

Secondary oocyte: A mature egg cell produced after Meiosis I that is released during ovulation and will complete Meiosis II only if fertilization occurs. (Chapter 16.6)

Secondary sex characteristics: Physical characteristics that are influenced by estrogen and are important for reproductive function. (Chapter 16.6)

Secondary spermatocytes: Haploid cells produced from the first meiotic division of primary spermatocytes that quickly undergo the second meiotic division to form spermatids. (Chapter 16.4)

Semen: The thick, milky fluid that is ejaculated. (Chapter 16.3)

Seminal vesicle (or seminal gland): A paired gland that secretes a thick, alkaline fluid rich in fructose and other substances that nourish and promote the motility of sperm. (Chapter 16.3)

Seminiferous tubules: Long, coiled structures within the testes where sperm production occurs. (Chapter 16.3)

Sertoli cells: A type of supporting cell that is typically found in epithelial tissue. (Chapter 16.3)

Sex chromosomes: The pair of chromosomes (X and Y) that determine an individual's biological sex—XX for females and XY for males. (Chapter 16.1)

Spermatic cord: A bundle of nerves, ducts, and blood vessels that supports the testicles and carries sperm to the urethra. (Chapter 16.3)

Spermatid: New haploid cells. (Chapter 16.4)

Spermatogenesis: The process that begins with spermatogonia and ends with mature sperm. (Chapter 16.3, Chapter 16.4)

Spermatogonia: Stem cells located in the seminiferous tubules that divide to produce sperm cells. (Chapter 16.3)

Spermatozoa: Formed sperm. (Chapter 16.4)

Spermatozoon: The male gamete, a motile cell that carries half the genetic material needed for reproduction. (Chapter 16.1)

Spermiogenesis: A process that transforms early spermatids, beginning the formation of the parts of a true sperm. (Chapter 16.4)

Spongy (or penile) urethra: The longest part of the male urethra that runs through the corpus spongiosum of the penis and ends at the external urethral orifice. (Chapter 16.3)

Stratum basalis (or basal layer): The deeper layer of the endometrium that creates the more superficial stratum functionalis. (Chapter 16.5)

Stratum functionalis (or functional layer): Grows and thickens in response to increased levels of estrogen and progesterone in preparation for a potential pregnancy. (Chapter 16.5)

Suspensory ligaments: Connect the breast tissue to the dermis of the overlying skin. (Chapter 16.5)

Syphilis: A bacterial infection that can progress through different stages, causing sores, rash, and serious complications if left untreated. (Chapter 16.7)

Testes: The male reproductive organs or gonads. (Chapter 16.3)

Testicular torsion: Occurs when a testicle rotates, twisting the spermatic cord that brings blood to the scrotum. (Chapter 16.7)

Theca cells: Cells that work with the granulosa cells to produce estrogens. (**Chapter 16.6**)

Trichomoniasis: A parasitic infection that can cause vaginal discharge, itching, and painful urination. (**Chapter 16.7**)

Urologist: A physician who specializes in the diagnosis and treatment of disorders of the urinary and reproductive systems. (**Chapter 16.8**)

Uterosacral ligament: Stabilizes the uterus posteriorly by its connection from the cervix to the pelvic wall. (**Chapter 16.5**)

Uterus: A muscular organ that nourishes and supports a growing embryo and fetus. (**Chapter 16.5**)

Vagina: The female copulatory (sex) organ. (**Chapter 16.5**)

Vas deferens: A long, muscular tube that transports sperm from the epididymis to the ejaculatory duct in preparation for ejaculation. (**Chapter 16.3**)

Vasectomy: A surgical procedure for male sterilization in which the vas deferens is cut or sealed to prevent sperm from entering the semen. (**Chapter 16.3**)

Vasocongestion: Engorgement of the tissues because more arterial blood is flowing into the penis than is leaving. (**Chapter 16.3**)

Vestibule: The area between the labia minora where the external urethral orifice and vaginal orifice are located. (**Chapter 16.5**)

Vulva: The external female reproductive structures. (**Chapter 16.5**)

Zona pellucida: Acellular membrane surrounding the oocyte that protects it and plays a key role in sperm binding during fertilization. (**Chapter 16.6**)

Zygote: A single diploid cell formed by the fusion of a sperm and an ovum during fertilization. (**Chapter 16.1**)

PART XVII

CHAPTER 17 LABORATORY METHODS AND SAFETY PROCEDURES

17.1 Introduction to Laboratory Methods & Safety Precautions

Chapter Competency

Use appropriate laboratory methods and safety precautions.

Learning Objectives

- Identify hazards and safety equipment in the lab.
- Select appropriate personal protective equipment.
- Follow all laboratory practice expectations of the college.

Imagine you are working as a sterile processing technician preparing equipment and supplies used in patient care. Each day, you must follow safety procedures, use appropriate personal protective equipment, handle potentially contaminated materials, and prevent exposure to chemical or biological hazards. To protect yourself, patients, and other members of the care team, you must understand how to identify risks, use safety equipment, and follow established procedures.

The anatomy and physiology laboratory provides hands-on learning opportunities to explore the structure and function of the human body. In the lab, you may work with anatomical models, microscopes, histology slides, chemicals, glassware, biological specimens, and other tools. Because these materials can present physical, chemical, or biological hazards, safe laboratory practices are essential for protecting students, faculty, and staff.

In this chapter, you will explore important laboratory methods and safety precautions used in anatomy and physiology labs. You will learn about appropriate lab attire, general lab rules, personal protective equipment, safety features, and proper use of equipment. You will also examine chemical safety, biohazard safety, sharps disposal, physical safety, and medical considerations related to laboratory participation.

By mastering these concepts, you will gain a deeper understanding of how safe laboratory practices support learning and prevent injury or exposure. This foundation will help you participate responsibly in lab activities, protect yourself and others, and apply safety habits that are also important in health care, laboratory, and clinical settings.

17.2 Anatomy and Physiology Lab Guidelines

Dress Code

The lab enforces a strict dress code for the safety of all lab participants. Students who do not meet the following dress code may not be allowed to participate in lab activities. The dress code during lab, as shown in Figure 17.1,[1] includes the following:

- Closed toe shoes must be worn in the lab at all times. (No sandals, flip flops, heels, or clogs.)
- Long pants are required. (No shorts, skorts, or skirts.)
- Long hair must be tied back.
- Some colleges may require a lab coat.[2]

1. OpenAI. (2026, March 1). *A&P lab dress code* [Large language model]. ChatGPT.
2. Backus, G., Wangerin, H. W., & Rodgers, P. (2022). *Anatomy and Physiology I OER Lab Manual*. Northern Virginia Community College. https://pressbooks.nvcc.edu/ap1labmanual/chapter/chapter-1/

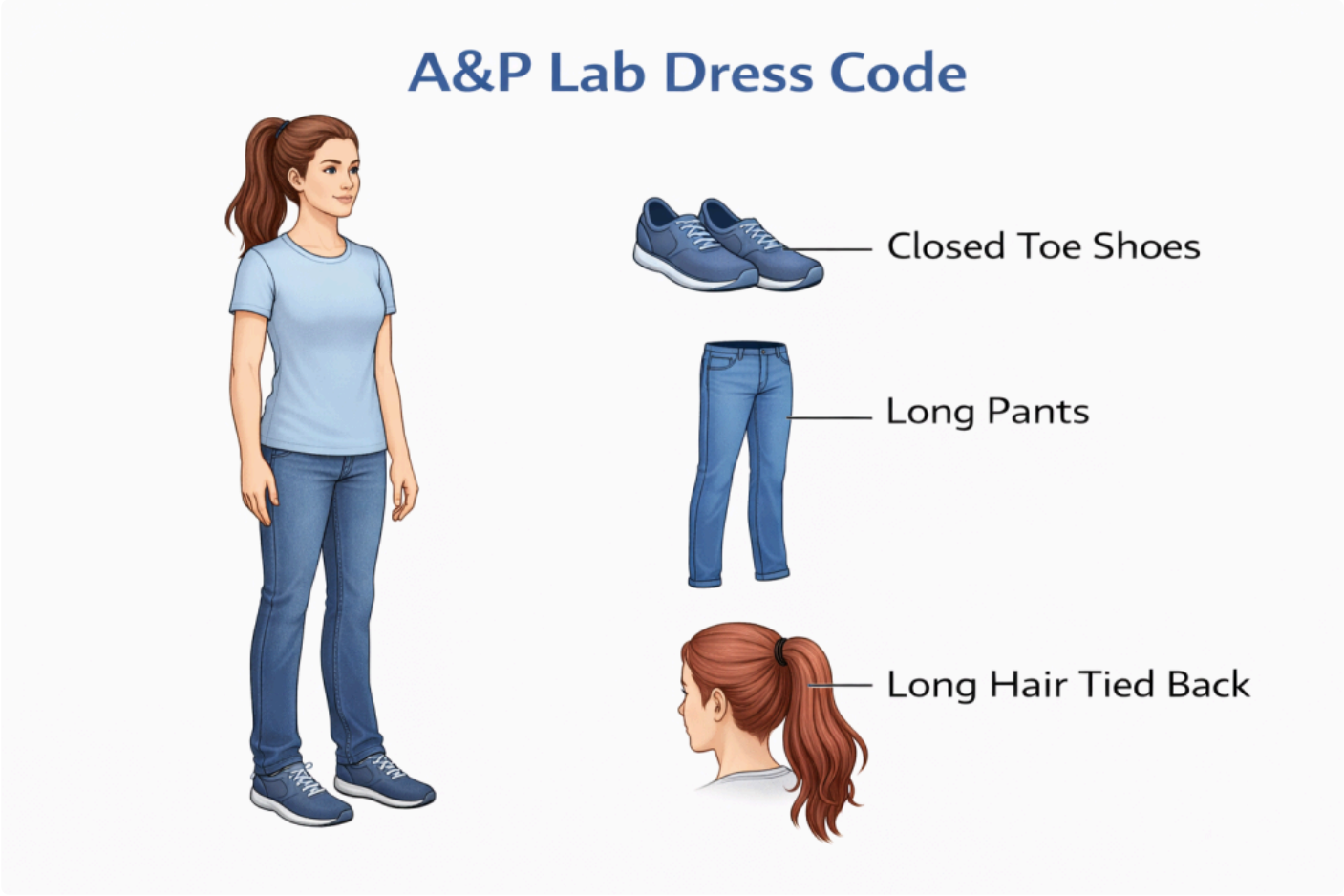


Figure 17.1 A&P lab dress code includes closed-toe shoes, long pants, and long hair tied back.

General Rules

As specimens and chemicals are routinely handled in the anatomy and physiology lab, all individuals who enter the lab must abide by the following rules:[3]

- No eating, drinking, or chewing gum.
- Lab goggles should be worn when handling chemicals, specimens, or biohazards.
- Face shields should be worn when handling specimens.
- Gloves should be worn when handling chemicals, specimens, or biohazards.
- Hands should be washed before exiting the lab.

3. Backus, G., Wangerin, H. W., & Rodgers, P. (2022). *Anatomy and Physiology I OER Lab Manual*. Northern Virginia Community College. https://pressbooks.nvcc.edu/ap1labmanual/chapter/chapter-1/

- Be respectful and courteous to all individuals working in the lab.
- Horseplay and rowdy or disorderly behavior are unsafe and will not be tolerated.
- Report any injury or incident, no matter how minor, to the instructor.
- Keep all work areas clean. Models, microscopes, slides, and any other equipment or supplies must be put away. If using specimens or biohazards, the work area should be cleaned and disinfected before leaving the lab.

Safety Features of the Anatomy and Physiology Lab

The anatomy and physiology lab is equipped with several safety features to keep students and staff safe. Please take a moment at the beginning of the first lab to locate the following:[4]

- Fire extinguisher
- Emergency eye wash station
- Chemical shower
- First aid kit

Equipment Safety

The anatomy and physiology lab has numerous pieces of equipment that enhance the learning experience. Make sure to use equipment exactly as directed and only under the supervision of the instructor. Turn off and unplug all equipment when finished.

If broken glass occurs, clean up the area with a broom and dustpan, not your hands. Dispose of contents in the glass disposal container.

Handle all anatomical models with care. Models are very expensive and used by multiple classes each semester. Models may not be removed from the lab.

4. Backus, G., Wangerin, H. W., & Rodgers, P. (2022). *Anatomy and Physiology I OER Lab Manual*. Northern Virginia Community College. https://pressbooks.nvcc.edu/ap1labmanual/chapter/chapter-1/

Chemical Safety

Treat every chemical as though it were a hazardous substance by using gloves and wearing safety goggles when handling. Only work with chemicals under the direct supervision and instruction by the instructor. Never smell or taste a chemical. Do not mix chemicals. Dispose of chemicals as instructed by your instructor, as it may not be safe to pour them down the sink.

Biohazard Safety

Gloves and safety goggles should be worn when working with biohazards, including saliva, urine, and blood. Biohazardous slides should be disposed of in the red sharps containers. See Figure 17.1[5] for an image of a sharps container.

5. William Rafti. (2003). *Sharps Container* [Photograph]. Wikimedia Commons. CC BY 2.5. https://commons.wikimedia.org/wiki/File:Sharps_Container.jpg



Figure 17.1 Sharps Container

Physical Safety

Please be careful when walking around the lab. Backpacks should be kept out of the way and not left on the floor where they can be a tripping hazard. Use caution when adjusting chairs, and be mindful of the other students working in the lab.

Medical Concerns

Pregnant students should not handle specimens and should only observe. If you are breastfeeding or pregnant or have any other medical concerns about working in a laboratory, please check with your physician. Your instructor can provide Material Safety

Data Sheets (MSDS), if needed, but only your physician can advise you on your medical condition.

Video

Watch the video "General Lab Safety" below to learn about important safety rules and best practices for working in a laboratory environment.[6]

This video, audio, or learning activity has been omitted from this version of the text. You can view this and all other multimedia content by visiting the digital version of the textbook at www.wistechopen.org or scanning the QR code below.

6. Amoeba Sisters. (2017, August 13). General lab safety [Video]. YouTube. All rights reserved. https://www.youtube.com/watch?v=MEIXRLcC6RA

Acknowledgments

The creation of this *General Anatomy and Physiology* textbook has been a journey supported by a dedicated community of educators, mentors, and family members. This book is the result of collective expertise and a shared passion for making high-quality healthcare education accessible to all students.

Project Leadership & Vision

I would like to extend my sincere gratitude to Kim Ernstmeyer and Vince Mussehl for providing me with the incredible opportunity to serve as both author and editor for this work. Your leadership in the OER space and your trust in my vision for this book have been invaluable.

Collegiate Support

A heartfelt thank you goes to my colleagues in the Chippewa Valley Technical College (CVTC) Science Department. I truly believe you are the best A&P instructors in the field. Your commitment to student success and your collaborative spirit provide a constant source of inspiration and professional pride.

Peer Reviewers

This text is significantly stronger thanks to the diligent efforts of our peer reviewers. I am deeply grateful for the time you spent reading the manuscript and for your thoughtful suggestions regarding edits, improvements, additions, and deletions. Your critical eyes helped ensure that this is the best possible resource for our students.

Family & Dedication

Finally, I want to thank my family for their unwavering support. This book was built during many late nights and long weekends, and I could not have finished it without your patience and encouragement.

A very special shout-out to my daughter, Elizabeth. As a medical school student, you humored me by talking about the intricacies of anatomy and physiology until we were both exhausted. Your perspective and passion for medicine reminded me daily of why this work matters.



Julia Brown, Editor

Epilogue

*]:pointer-events-auto [content-visibility:auto] supports-[content-visibility:auto]:[contain-intrinsic-size:auto_100lvh] R6Vx5W_threadScrollVars scroll-mb-[calc(var(--scroll-root-safe-area-inset-bottom,0px)+var(--thread-response-height))] scroll-mt-[calc(var(--header-height)+min(200px,max(70px,20svh)))]" dir="auto" data-turn-id="request-WEB:4e34ffb6-9379-4996-a59f-bcf037beba05-1" data-testid="conversation-turn-2" data-scroll-anchor="false" data-turn="assistant">

Thank You for Reading

Thank you for taking the time to learn with this WisTech Open textbook. We hope this resource has supported your studies, encouraged your growth, and helped you move forward with confidence. We wish you the very best as you continue applying what you have learned in your education, career, and service to others. To support WisTech Open, Wisc-Online, or Open RN and help us continue creating free, high-quality open educational resources, please visit **wistechopen.org**.