

BIOL 40B Lab Manual: Anatomy and Physiology of Neural and Cardiopulmonary Systems

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De Anza College

Biology

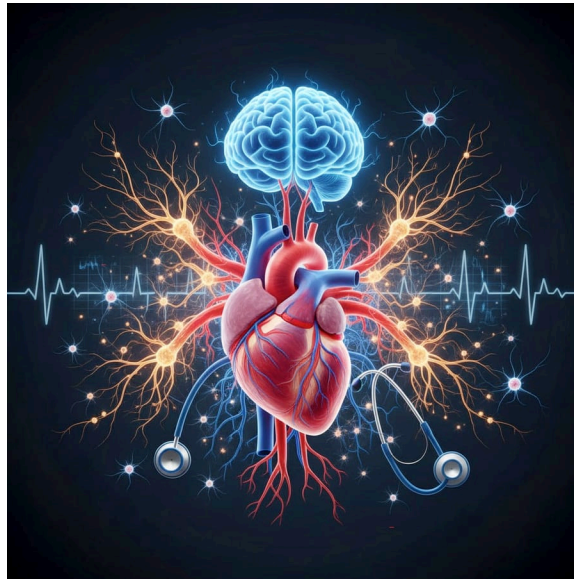
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Integrated Human Anatomy and Physiology Lab Manual II:

Neural and Cardiopulmonary Systems

Nervous, Cardiovascular, Respiratory Systems



Thumbnail: Brain-Heart Connection. (AI-generated image created with Nano Banana).

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Program Page



De Anza College sits in the heart of Silicon Valley, where innovation and opportunity are part of daily life, and also has one of the highest costs of living in the country. For our students, that makes every dollar count, and the price of a textbook can be the difference between staying enrolled or dropping a class. Our Zero Textbook Cost (ZTC) program closes that gap by giving students full access to high-quality, faculty-created course materials at no cost from the first day of class.

De Anza is proud of its diverse student community, and we hold our ZTC materials to the same standard of excellence that defines the college. Faculty across departments write, adapt, and review these resources themselves, keeping them accurate, current, and grounded in the perspectives of the students who use them, with accessibility and inclusive design built in from the start.

This program reflects the time and care our faculty invest in their students. If you have questions, feedback, or come across any issues with a ZTC resource, contact De Anza College's ZTC Grants Coordinator, [Shagun Kaur](#).

Learn more about [De Anza ZTC Program](#) [www.deanza.edu/academic-services/oer/]

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TABLE OF CONTENTS

Program Page

Licensing

Accessibility Statement

About the Lab Manual

About the Contributors

1: Nervous system Organization, Histology and Basic Physiology

1.1: From Nerve Cells to Nerve Signals

1.2: Activity 1

1.3: Activity 2

1.4: Activity 3

1.5: Activity 4

1.6: Activity 5

1.7: Activity 6

1.8: Activity 7

1.9: Activity 8

1.10: Glossary

2: Spinal Cord Anatomy - Physiology, Spinal Nerves and reflexes

2.1: Spinal Cord Anatomy - Key structures

2.2: Background Information

2.3: Activity 1

2.4: Activity 2

2.5: Activity 3

2.6: Activity 4

2.7: Activity 6

2.8: Activity 7

2.9: Activity 8

2.10: Glossary

3: Brain Structure and Function- Exploring with Dissection and Cranial Nerves

3.1: Background Information

3.2: Terminology Checklist

3.3: Activity 1

3.4: Activity 2

3.5: Activity 3

3.6: Activity 4

3.7: Activity 5

3.8: Activity 6

- 3.9: Activity 7
- 3.10: Activity 8
- 3.11: Activity 9
- 3.12: Glossary

4: Exploring General and Special Senses

- 4.1: Background Information
- 4.2: Activity 1
- 4.3: Activity 2
- 4.4: Activity 3
- 4.5: Activity 4
- 4.6: Activity 5
- 4.7: Activity 6
- 4.8: Activity 7
- 4.9: Activity 8
- 4.10: Activity 9
- 4.11: Activity 10
- 4.12: Activity 11
- 4.13: Activity 12
- 4.14: Activity 13
- 4.15: Activity 14
- 4.16: Activity 15
- 4.17: Glossary

5: Blood Anatomy, Blood Grouping, and Hematocrit Analysis

- 5.1: Background Information
- 5.2: Activity 1
- 5.3: Activity 2
- 5.4: Activity 3
- 5.5: Activity 4
- 5.6: Activity 5
- 5.7: Activity 6
- 5.8: Activity 7
- 5.9: Glossary

6: Exploring the Mammalian Heart- A Hands-On Anatomy Lab

- 6.1: Background Information
- 6.2: Activity 1
- 6.3: Activity 2
- 6.4: Activity 3
- 6.5: Activity 4
- 6.6: Activity 5
- 6.7: Activity 6

6.8: Glossary

7: Blood Vessels, Blood Pressure and ECG (Electrocardiogram)

7.1: Background Information

7.2: Activity 1

7.3: Activity 2

7.4: Activity 3

7.5: Activity 4

7.6: Activity 5

7.7: Activity 6

7.8: Activity 7

7.9: Activity 8

7.10: Activity 9

7.11: Activity 10

7.12: Activity 11

7.13: Activity 12

7.14: Glossary

8: Respiratory System Anatomy and Physiology

8.1: Background Information

8.2: Activity 1

8.3: Activity 2

8.4: Activity 3

8.5: Activity 4

8.6: Activity 5

8.7: Activity 6

8.8: Activity 7

8.9: Activity 8

8.10: Glossary

Index

Glossary

Detailed Licensing

Licensing

A detailed breakdown of this resource's licensing can be found in **Back Matter/Detailed Licensing**.

Accessibility Statement

Accessibility

De Anza College is dedicated to creating learning materials that are accessible and benefit all students. Our materials follow the Web Content Accessibility Guidelines (WCAG) 2.1 Level AA. Our authors and contracted accessibility specialists checked all resources using this ASCCC OERI checklist, the accessibility tool in LibreTexts, WAVE, JAWS, and other more detailed checks for complex materials such as interactive components.

We selected LibreTexts as our preferred platform because of its [commitment to accessibility](#). In addition to the platform's inherent accessibility, we collaborated with the LibreTexts team to fix any accessibility issues we found.

Our Accessibility Review Process

Accessibility was built into the resource as it was written. This resource went through the following stages of review:

1. **Template check.** The project coordinator and instructional designers checked the first chapter for accessibility as a model to ensure later chapters meet accessibility standards.
2. **Progress checks.** The manuscript was checked at approximately 40%, 60%, and 80% completion to catch and correct accessibility issues in production.
3. **Specialist review.** Once the manuscript was complete, an accessibility expert conducted an accessibility check.
4. **Remediation.** The author and the project manager who conducted the earlier progress checks worked together to remediate the issues identified by the accessibility expert.
5. **Final check.** The resource underwent another full check by the accessibility expert before the book was deemed ready for publication.

This process combines ongoing checks during writing with a final specialist review, so issues are caught early and confirmed fixed before publication.

Report an Accessibility Problem

We are always looking for ways to make our resources more accessible. If you run into a barrier while using this resource, please let us know so we can look into it. When you [contact us](#), it helps to include:

- The name of the resource
- The location of the problem (a web address or page/chapter description)
- A description of the problem you encountered
- The device, browser, and any assistive technology you were using (e.g., Windows 11, Google Chrome, JAWS screen reader)

Contact us: [De Anza ZTC team](#)

This statement was last updated August 2026

This resource was project-managed by **Jyothsna Viswanadha**, overseeing scope, and schedule; stakeholder coordination via monthly meetings; training and platform support (LibreTexts, troubleshooting, technical support); QA/accessibility check scheduling; and licensing and copyright governance.

A Note on Known Limitations

No accessibility check is perfect. We've made a genuine, sustained effort to catch and fix issues throughout the writing and review process described above, but some barriers may remain, especially in complex or interactive content. We'd rather be upfront about that than claim a standard of perfection we can't guarantee.

About the Lab Manual

Philosophy and Approach

Designed for the Human Anatomy and Physiology II laboratory in a CSU- and UC-transferable sequence, this second volume in a three-part series introduces the nervous, circulatory, and respiratory systems for aspiring health professionals and transfer students. The manual aligns with lower-division expectations at four-year institutions and is grounded in a student-centered, inclusive approach to learning.

The manual is designed with a diverse student population in mind, including first-generation students, returning students, multilingual students, working students, and veterans. Activities, instructions, and pacing are intentionally structured to support varied levels of preparation while still maintaining high expectations for critical thinking, independence, and academic rigor.

This lab manual serves as the central through line of the course so that weekly activities feel coherent, connected, and cumulative rather than isolated. Each lab is organized around a small set of clearly stated, measurable objectives that align with program outcomes and transfer expectations.

Activities are scaffolded to move from guided observation to deeper analysis and synthesis. Students are asked to:

- identify structures
- describe relationships and pathways
- explain function
- apply knowledge to clinical or real-world scenarios

Throughout the manual, anatomy and physiology concepts related to the nervous, circulatory, and respiratory systems are consistently connected to common clinical examples, such as stroke, myocardial infarction, arrhythmias, asthma, chronic obstructive pulmonary disease, and shock.

This volume assumes that students already have foundational knowledge from earlier parts of the sequence, including cells, tissues, and the integumentary, skeletal, and muscular systems. The manual intentionally activates that prior knowledge through integrative prompts that help students connect systems rather than study them in isolation. For example, students may be asked to consider how skeletal muscle function depends on both nervous system signaling and circulatory system support in a given scenario.

The manual also prepares students for later topics, such as the endocrine and renal systems, by emphasizing recurring physiological themes including feedback regulation, gradients, and transport. These recurring ideas help students build a more unified understanding of the human body and strengthen transfer of knowledge across systems.

Framework

Students were placed at the center of the design of this lab manual. The primary goal was to support student success by making clear what students are expected to do, why the work matters, and how they can demonstrate mastery. To support these goals, the manual is organized with accessible steps, purpose-driven activities, and transparent criteria for success. This structure is intended to reduce barriers, build confidence, and guide practice toward meaningful, transferable skills.

Each lab begins with an introduction and clearly defined learning objectives. Background information helps bridge theory and practice by preparing students before they begin working with laboratory models, microscopes, and other equipment. This structure helps reduce cognitive load during lab procedures and makes the purpose of each step explicit by clarifying what students are doing, where they should focus, and why the task matters.

This zero-cost, accessible manual is designed to honor students' time, budgets, and diverse ways of learning. It makes essential course elements—including procedures, safety expectations, and scientific thinking—available in a clear and consistent format. Professional habits such as safety, careful data practices, teamwork, clarity in communication, and academic integrity are embedded throughout the labs and assignments.

Each lab also includes a glossary. Anatomy and physiology rely on a large number of specialized terms, many of which are derived from Latin or Greek. Including a glossary in every lab gives students a consistent and reliable reference for unfamiliar vocabulary. This helps support comprehension and ensures that students and instructors can use a shared language when discussing body structures and functions.

Images and Accessibility

Images—including models, diagrams, micrographs, and clinical photographs—are central to learning in anatomy and physiology laboratories. Because visual materials play an essential role in student understanding, this manual is intentionally designed to be usable by all learners.

The manual follows accessibility best practices so content is more perceivable, operable, understandable, and robust across print and digital formats. Whenever images and figures are instructionally important, they include meaningful text alternatives that communicate the purpose of the visual content. Decorative visuals are identified appropriately so they do not create unnecessary distraction for screen-reader users.

To support accessibility and usability, this manual includes:

- structured headings that clearly describe topics and sections
- readable typography and consistent page organization
- strong color contrast for text and instructional visuals
- meaningful alternative text for images and figures
- descriptive hyperlink text
- simple, clearly structured tables when tables are needed
- captions and transcripts for media
- plain-language instructions that clarify expectations and support comprehension

Whenever possible, the manual uses Creative Commons–licensed visuals and references. This supports local adaptation, revision, and accessibility customization by instructors and institutions.

This manual reflects an equity-focused design philosophy. By providing zero-cost course materials, accessible formats from the outset, and inclusive learning supports, the manual is intended to promote equitable access, strengthen student persistence and success, and support program and accreditation expectations related to accessibility and inclusion.

Acknowledgements

The authors gratefully acknowledge funding from the California Community Colleges Chancellor's Office (CCCCO) through Zero Textbook Cost (ZTC) grants awarded to De Anza College.

This manual owes a special debt of gratitude to [Shagun Kaur](#), Communications Studies faculty member and ZTC Grants Coordinator at De Anza College. Her weekly coaching guided this project from outline to publication. Her mentorship, organized process, and unwavering encouragement were essential to bringing this manual to completion.

We also gratefully acknowledge the leadership and support of Sam Bliss, Associate Vice President at De Anza College, for championing zero-cost, accessible learning and for providing steady support throughout the development of this manual.

We thank James Perla-Adams, Librarian and Open Educational Resources (OER) Coordinator at De Anza College, for his guidance and support in the development of this zero-cost, accessible lab manual. This project also benefited from De Anza's accessibility expertise, including support for meaningful alternative text for figures, high-contrast visual design, tagged PDF and HTML formats for screen-reader access, and a cleaner, keyboard-friendly layout aligned with Universal Design for Learning (UDL) principles.

Our sincere thanks also go to Jyothsna Viswanadha, Mathematics faculty member at De Anza College, for helping build equity and accessibility into every page. Her contributions included adding alternative text, improving visual contrast, supporting tagged PDF and HTML formatting, and streamlining the layout so that students can access and navigate the manual more easily.

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About the Contributors

Team	Team Bios
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Team	Team Bios
	Author: Lakshmikanta Sengupta, Ph.D. is a biology educator with 39 years of experience teaching and mentoring across postsecondary fields, including genetics, biotechnology, and human anatomy & physiology. He envisions educational institutions as vibrant communities, much like a living village, where learning and collaboration thrive. With rigorous academic training and experience, he translates complex biology into clear, engaging explanations. Dr. Sengupta actively encourages collaboration among educators and students to share best practices and improve the quality of educational materials available to all learners. He collaborated with the Community College Biology Faculty Enhancement through Scientific Teaching (CCB FEST), a program funded by the National Science Foundation (NSF), to coauthor research publications, including those in Proceedings of the National Academy of Sciences (PNAS), USA, and CBE—Life Sciences Education (Published by the American Society for Cell Biology). With a keen eye for detail, he uses photography to capture intricate aspects of life, including natural phenomena and anatomical structures. Cooking is another important passion that allows him to explore the science of nutrition and health. Gardening reflects his commitment to sustainability and the natural world.
	Accessibility and Editor: Jyothsna Viswanadha is a Mathematics Instructor at De Anza College with experience teaching community college-level mathematics courses. Passionate about student-centered and equity-minded pedagogies, she has taught courses ranging from developmental mathematics to calculus and business calculus. Jyothsna has taught in several programs designed to bridge equity gaps in mathematics education, including the Math Performance Success (MPS) program. She is committed to adopting Open Educational Resources (OER) for her classes and has been actively involved in the development of OER workbooks for Calculus III. As part of this work, Jyothsna helped transfer course content from existing files to LibreTexts, formatted and standardized all images, formatted instructional labs, and performed accessibility checks to ensure compliance with accessibility standards. She is also committed to community service, volunteering with organizations such as Vision Literacy and Assistance League, where she supports underserved populations in achieving their educational goals.

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1: NERVOUS SYSTEM ORGANIZATION, HISTOLOGY AND BASIC PHYSIOLOGY

Introduction

In this lab, we will explore “How does the structure of the nervous system relate to its function?”. The nervous system is extraordinarily complex and is critical for sensing internal and external environments, integrating and processing them to make decisions, and regulating body functions and movements. The exercises here will review cellular function and structure, and explore several basic neural networks within the larger body. We will use a combination of laboratory models and microscopic analysis, and physiological exercises to study nervous systems.

Learning Objectives

- Describe the functions of the nervous system.
- Identify the anatomical features of a neuron cell and relate the form to the function (include histology), cell body (soma), Nissl bodies, nucleus with nucleolus, dendrites, axon, axolemma, neurolemma, axon hillock, axon terminals, myelin sheath, nodes of Ranvier, axon collaterals.
- Compare and contrast the types of neurons based on structural organization (unipolar, bipolar or multipolar) or functions (sensory neuron, motor neuron, interneuron/association neuron).
- Demonstrate structure-function-location relationships of the glial cells in the Central Nervous System (CNS) and Peripheral Nervous System (PNS).
- Explain the terminology associated with alterations in membrane potential during the formation of graded and action potentials, including resting membrane potential, depolarization, repolarization, and hyperpolarization, and describe the role of ions in these processes.

1.1: From Nerve Cells to Nerve Signals

1.2: Activity 1

1.3: Activity 2

1.4: Activity 3

1.5: Activity 4

1.6: Activity 5

1.7: Activity 6

1.8: Activity 7

1.9: Activity 8

1.10: Glossary

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1.1: From Nerve Cells to Nerve Signals

Background Information

When we are hungry, we eat, when we are cold, we are motivated to put on a jacket. This ability to “sense or read” the environment and respond is obviously essential for survival. Information gathering structures in the body called receptors respond to a variety of stimuli; receptors in the eye react to light, those in skin sense touch, pressure, and temperature. Other receptors respond to pain or visceral stretch. The nervous system integrates, analyzes, makes a decision either to store the information for future use or send a message to the effector (muscle or glands) to act. An understanding of the nervous system begins with basic morphological and functional unit, the neuron. Neurons are nerve cells that form the conducting system that carries information throughout the central nervous system (CNS) and the peripheral nervous system (PNS).

- Central nervous system (CNS) consists of the brain and spinal cord, which occupy the dorsal body cavity and act as the integrating and command centers of the nervous system.
- Peripheral nervous system (PNS), the part of the nervous system outside the CNS, consists mainly of the nerves, ganglion, sensory receptors and effectors. Receptor is a term used for the part of a sensory organ that detects the signal.

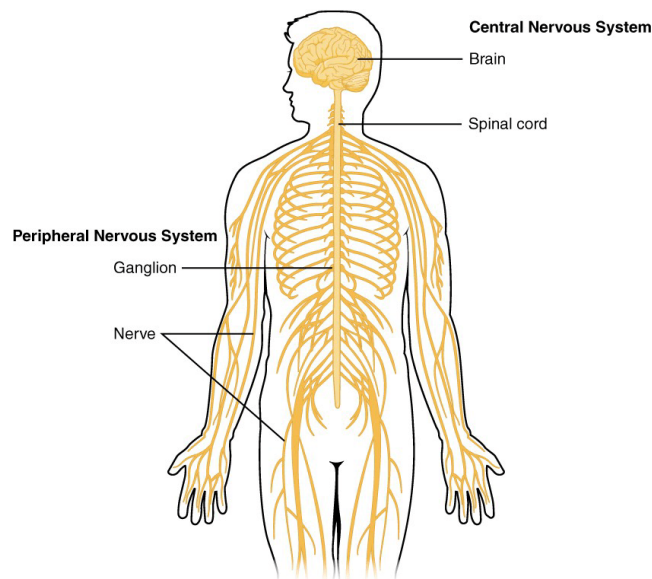


Figure 1.1.1: Central Nervous System (CNS) consists of the brain and spinal cord and Peripheral Nervous System (PNS) consists mainly of the nerves, ganglion, sensory receptors and effectors. (CC-BY 4.0; Aylin Marz; Ganesan Kamatchi; Joseph D'Silva; Krishnan Prabhakaran; Rajeev Chandra; and Solomon Isekeije via [OpenStax](#) and [Anatomy and Physiology Laboratory Manual for Nursing and Allied Health](#)).

Figure 1.1.1 compares the central nervous system (CNS) and peripheral nervous system (PNS) by showing the types of neurons and glial (support) cells found in each.

The CNS panel shows a multipolar neuron surrounded by several CNS glial cells:

- Astrocyte and microglial cell are shown near the neuron to represent support and maintenance cells in CNS tissue.
- Ependymal cell is shown as a lining-type cell, representing cells associated with CNS internal spaces.
- Oligodendrocyte is shown wrapping segments of nerve fibers, emphasizing that oligodendrocytes form insulating coverings on CNS axons (often supporting multiple segments).

The PNS panel shows a pseudounipolar neuron and the glial cells that support neurons in peripheral structures:

- Satellite cells are shown clustered around the neuron's cell body, indicating support cells that surround neuron cell bodies in peripheral ganglia.
- Schwann cells are shown wrapped around an axon in segments, emphasizing that Schwann cells provide insulation and

support along PNS axons.

Both the CNS and PNS contain neurons plus glial support cells, but the support cell types differ. The image highlights that oligodendrocytes are the insulating glial cells in the CNS, while Schwann cells provide insulation in the PNS, and that satellite cells support neuron cell bodies in the PNS.

Components of the Nervous Tissue

Parts of a Neuron

The basic unit of the nervous system is a nerve cell or neuron. They are responsible for the computation and communication that the nervous system provides. They are electrically active and release chemical signals to target cells. The human brain contains about 100 billion neurons and is made up of many networks of communicating neurons and glia. These networks allow different parts of the brain to “talk” to each other and work together to control body functions, emotions, thinking, behavior, and other activities.

The main part of a neuron is the cell body (soma known as “body”). The cell body contains the nucleus and most of the major organelles. What makes neurons special is that they have many extensions of their cell membranes, which are generally referred to as processes. The two types of processes are axons and dendrites. Neurons are usually described as having one, and only one, axon which is a fiber that emerges from the cell body and projects to target cells. That single axon can branch repeatedly to communicate with many target cells. It is the axon that propagates the nerve impulse, carrying the electrical signal away from the cell body and to one or more cells, where the axon emerges from the cell body, there is a special region referred to as the axon hillock. This is a tapering of the cell body toward the axon fiber and it is the location where the outgoing electrical signal is generated. The other processes of the neuron are dendrites, which receive information from other neurons at specialized areas of contact called synapses.

The dendrites are usually highly branched processes, providing locations for other neurons to communicate with the cell. Information flows through a neuron from the dendrites, across the cell body, and down the axon. Many axons are wrapped by an insulating substance called myelin, which is actually made of glial cells. 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 of an axon. Each gap is called a node of Ranvier. These gaps are exchange points for ions that allow electrical signals travel down the axon. At the end of the axon is the axon (synaptic) terminal, where there are usually several branches extending toward the target cell, each of which ends in an enlargement called a synaptic knob. These knobs are what make the connection with the target cell at the synapse. Neurons are highly specialized and amitotic. This means that if a neuron is destroyed, it cannot be replaced because neurons do not go through mitosis.

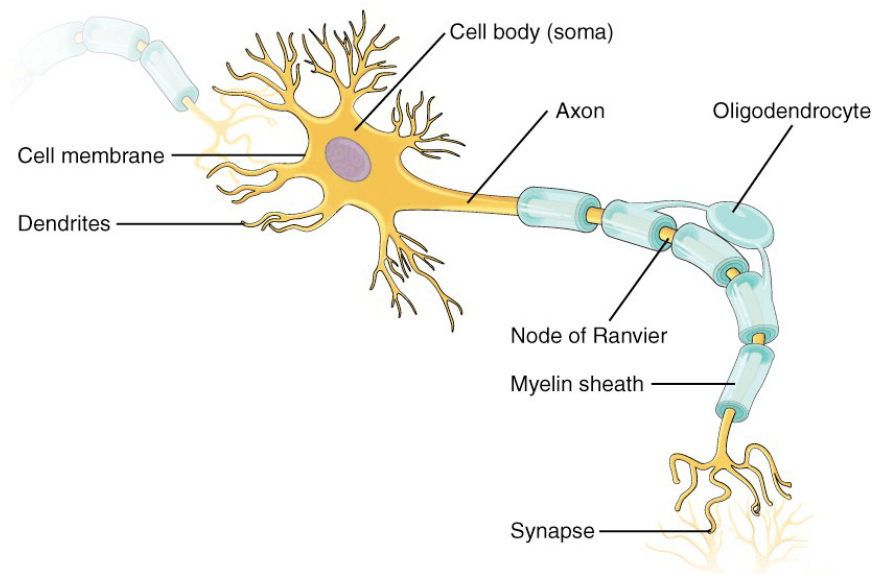


Figure 1.1.2: Parts of a Neuron. The major parts of the neuron, cell membrane, cell body (soma), dendrites, axon and associated structures such as myelin sheath, node of Ranvier and oligodendrocyte are labeled. (CC BY-SA 4.0; Lindsay M. Biga, Staci Bronson, Sierra Dawson, AmyHarwell, Robin Hopkins, Joel Kaufmann, Mike LeMaster, Philip Matern , Katie Morrison-Graham, Kristen Oja, Devon Quick, Jon Runyeon, OSU OERU, and OpenStax via [Anatomy & Physiology](#)).

Figure 1.1.2 labels major parts of a neuron and explains each part's role in signal transmission.

- Dendrites: branched extensions that receive incoming signals from other cells.
- Cell body (soma): contains the nucleus and integrates incoming information.
- Axon: a long extension that carries signals away from the soma.
- Myelin sheath: an insulating covering around the axon that helps signals travel faster.
- Nodes of Ranvier: small gaps between myelin segments where the signal is regenerated, enabling faster “jumping” conduction (saltatory conduction).
- Oligodendrocytes: support cells in the central nervous system (CNS) that produce myelin around axons.
- Synapse: the communication site where the neuron passes a signal to another neuron or target cell.

When a neuron sends a message to another neuron, it sends an electrical signal down the length of its axon. At the end of the axon, the electrical signal changes to a chemical signal. The axon then releases the chemical signal with chemical messengers called neurotransmitters into the synapse which is the space between the end of an axon and the tip of a dendrite from another neuron. The neurotransmitters move the signal through the synapse to the neighboring dendrite, which converts the chemical signal back into an electrical signal. The electrical signal then travels through the neuron and goes through the same conversion processes as it moves to neighboring neurons.

Types of Neurons

There are different types of neurons, and the functional role of a given neuron is intimately dependent on its structure. There is an amazing diversity of neuron shapes and sizes found in different parts of the nervous system, as illustrated by the neurons shown in Figure 1.1.3.

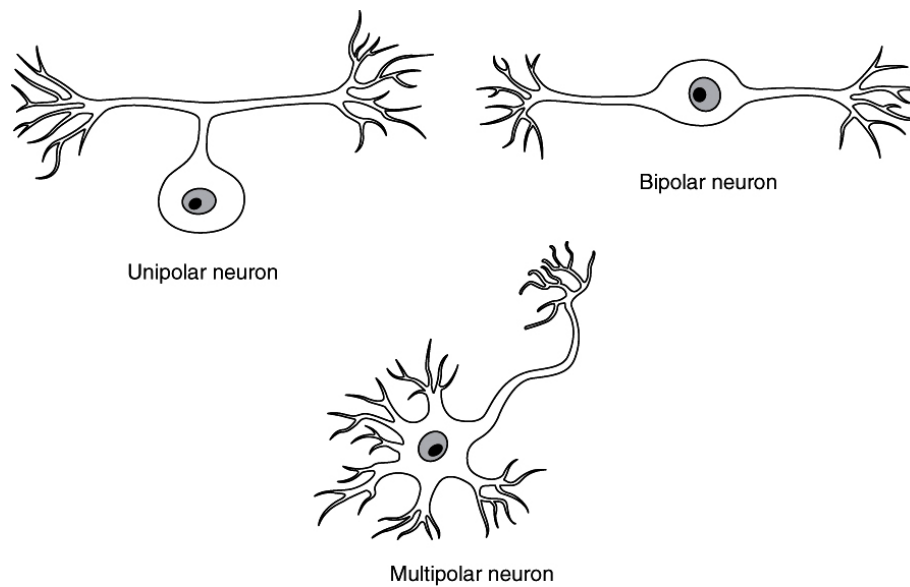


Figure 1.1.3: Structural diversity of neurons. Neurons are broadly divided into three main types based on the number and placement of axons unipolar, bipolar, multipolar. (CC BY 4.0; via [Wikimedia Commons](#)).

Figure 1.1.3 compares three neuron types—unipolar, bipolar, and multipolar—by showing how many processes extend from the cell body (soma) and how those processes branch.

- Unipolar neuron: A single process extends from the cell body and then splits into two branches. The diagram emphasizes the “one main extension” pattern.
- Bipolar neuron: Two processes extend from opposite ends of the cell body: one dendrite (signal input) and one axon (signal output). The diagram emphasizes the “two-ended” pattern.
- Multipolar neuron: Multiple dendrites extend from the cell body, and a single axon extends away. The diagram emphasizes the “many inputs, one output” pattern.

It's intriguing to consider how these structural types correlate with functional classifications, such as excitatory, inhibitory, or modulatory neurons, providing a broader view of neuronal diversity.

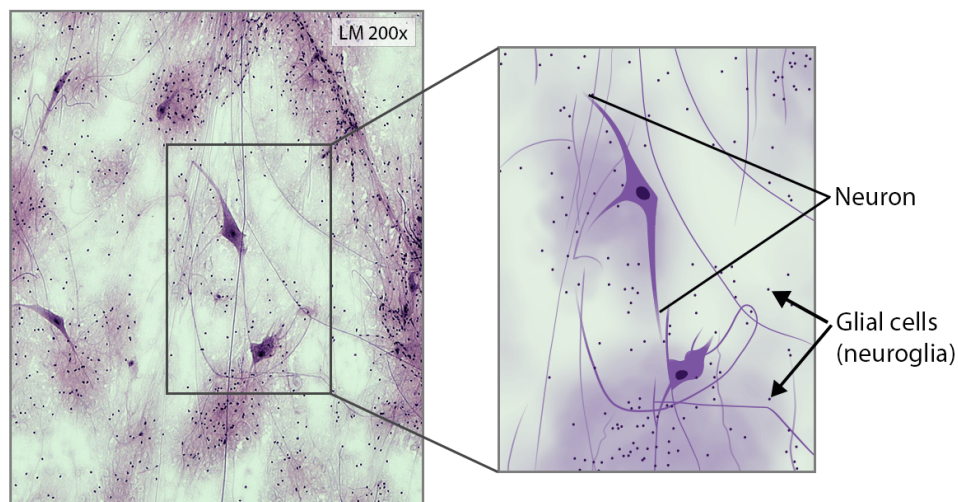


Figure 1.1.4: Nervous Tissue. A small chunk of tissue from the spinal cord was spread on a microscope slide to show neurons and glial cells. Glial cells are smaller and in larger quantities than neurons. The neuron shown is large and has multiple processes coming out of the soma. (CC-BY-NC-SA 4.0; Claire McGuire via [Anatomy of Nervous Tissue](#)).

Figure 1.1.4 is a light microscope image at 200 times magnification (labeled “LM 200 times”) showing nervous tissue. It is presented in two parts: a larger micrograph on the left and a magnified inset on the right.

Left panel: full field of view

The left image shows a pale background with many fine, thread-like structures and scattered dark dots. A rectangular box outlines one region of interest. Lines connect this boxed region to the zoomed inset on the right, indicating that the inset is a closer view of the highlighted area.

Right panel: zoomed inset with labels

The inset enlarges the boxed region and labels two main features:

- **Neuron:** A large, dark-stained cell with a prominent cell body and long, branching extensions. The neuron stands out because it is much larger and more distinctly shaped than the surrounding cells.
- **Glial cells (neuroglia):** Numerous much smaller, dark-stained dots surrounding the neuron. These represent support cells that are more abundant and smaller than neurons in nervous tissue.

Glial Cells

The nervous system also includes non-neuron cells, called glia. Glial cells are supporting cells in the nervous system that maintain the environment around neurons:

- Oligodendrocytes create the myelin sheath that insulates axons, allowing electrical messages to travel faster.
- Astrocytes provide nutrients to neurons, maintain their extracellular environment, and provide structural support.
- Microglia scavenge pathogens and dead cells.
- Ependymal cells line the spinal cord and brain ventricles, and create cerebrospinal fluid.
- Schwann cells myelinate neurons in the peripheral nervous system.
- Satellite cells surround neurons in the sensory, sympathetic, and parasympathetic ganglia.

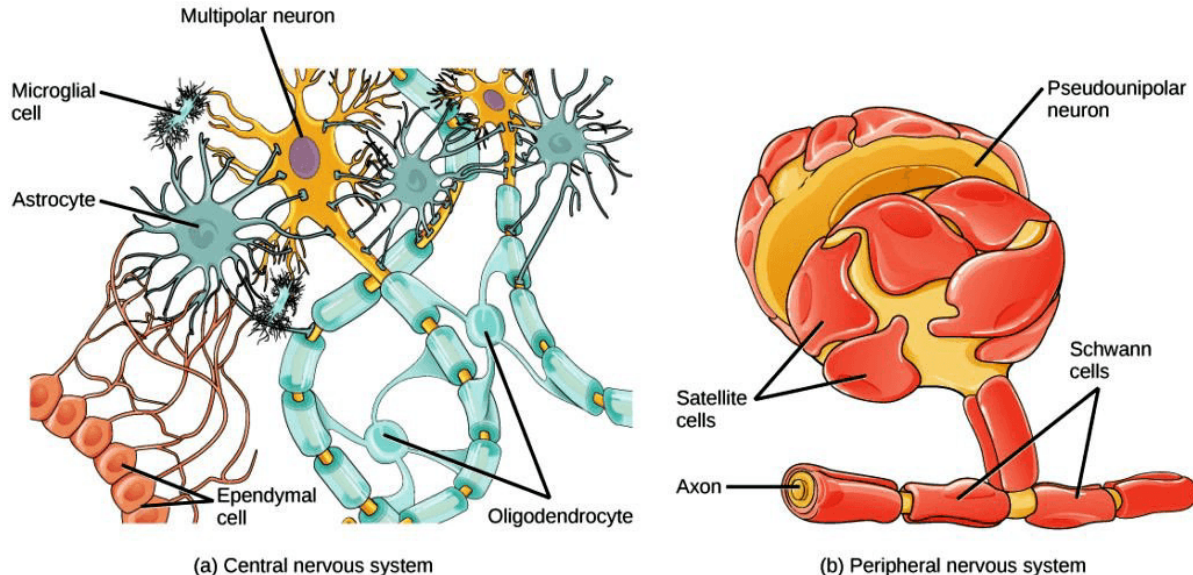


Figure 1.1.5: Glial cells support neurons and maintain their environment. Glial cells of the (a) central nervous system include oligodendrocytes, astrocytes, ependymal cells, and microglial cells. Oligodendrocytes form the myelin sheath around axons. Astrocytes provide nutrients to neurons, maintain their extracellular environment, and provide structural support. Microglia scavenge pathogens and dead cells. Ependymal cells produce cerebrospinal fluid that cushions the neurons. Glial cells of the (b) peripheral nervous system include Schwann cells, which form the myelin sheath, and satellite cells, which provide nutrients and structural support to neurons. (CC-BY-NC-SA 4.0; OpenStaxCollege via [Anatomy of Nervous Tissue](#)).

Figure 1.1.5 compares the central nervous system (CNS) and peripheral nervous system (PNS) by labeling the neuron types and glial (support) cells shown in each system.

Panel A: Central nervous system. The image shows multipolar neurons with branching dendrites and long axons. Labeled glial cells include microglial cells, astrocytes, ependymal cells, and oligodendrocytes. Oligodendrocytes are shown forming myelin around axons. Microglial cells appear near the dendrites. Astrocytes are positioned around neurons and near other support cells. Ependymal cells are arranged in a row at one edge of the panel.

Panel B: Peripheral nervous system. The image shows a pseudounipolar neuron with a single process that branches in a T shape. Satellite cells surround the neuron cell body. Schwann cells wrap around the axon.

Main idea: The diagram contrasts glial cells in the CNS and PNS, showing that oligodendrocytes myelinate axons in the CNS, while Schwann cells myelinate axons in the PNS, and satellite cells surround neuron cell bodies in the PNS.

Myelin Sheath

The axons of many neurons are encased in a fatty sheath (~ 80% lipid and 20% protein) called the myelin sheath. Myelin is a concentrically laminated membrane structure surrounding an axon around which lamellae (or cellular protrusions) repeat radially at a period of about 12 nm. The myelin lamella is formed by fusion of the apposed inner leaflets of the plasma membrane in glial cells, with no intervening cytoplasm. Are all axons covered with myelin? No; they can be either myelinated or unmyelinated. Myelin is essential for overall brain function and cognitive processes.

Myelin allows for rapid and efficient transmission of electrical impulses through a process called saltatory conduction, where the impulse "jumps" between gaps in the sheath called nodes of Ranvier. Produced by oligodendrocytes in the central nervous system and Schwann cells in the peripheral nervous system, it is primarily made of protein and fatty substances.

The degeneration or loss of myelin, known as demyelination, can lead to significant neurological problems, including vision loss, muscle weakness, and loss of coordination, as seen in diseases like multiple sclerosis.

Gray Matter and White Matter

Gray Matter

The neurons within the CNS are distributed so that there are separate regions of gray and white matter. Gray matter is a major component of the CNS, it refers to un-myelinated neurons and other cells of the central nervous system such as glial cells and dendrites. It is present in the brain, brainstem and cerebellum, and present throughout the spinal cord. Gray matter contains most of the brain's neuronal cell bodies. The grey matter includes regions of the brain involved in muscle control, and sensory perception such as seeing and hearing, memory, emotions, speech, decision making, and self-control.

White Matter

A second major component of the CNS is white matter. It is composed mainly of bundles of myelinated axons, with very few neuronal bodies. White matter connects the various grey matter regions of the nervous system to each other and carries nerve impulses between neurons.

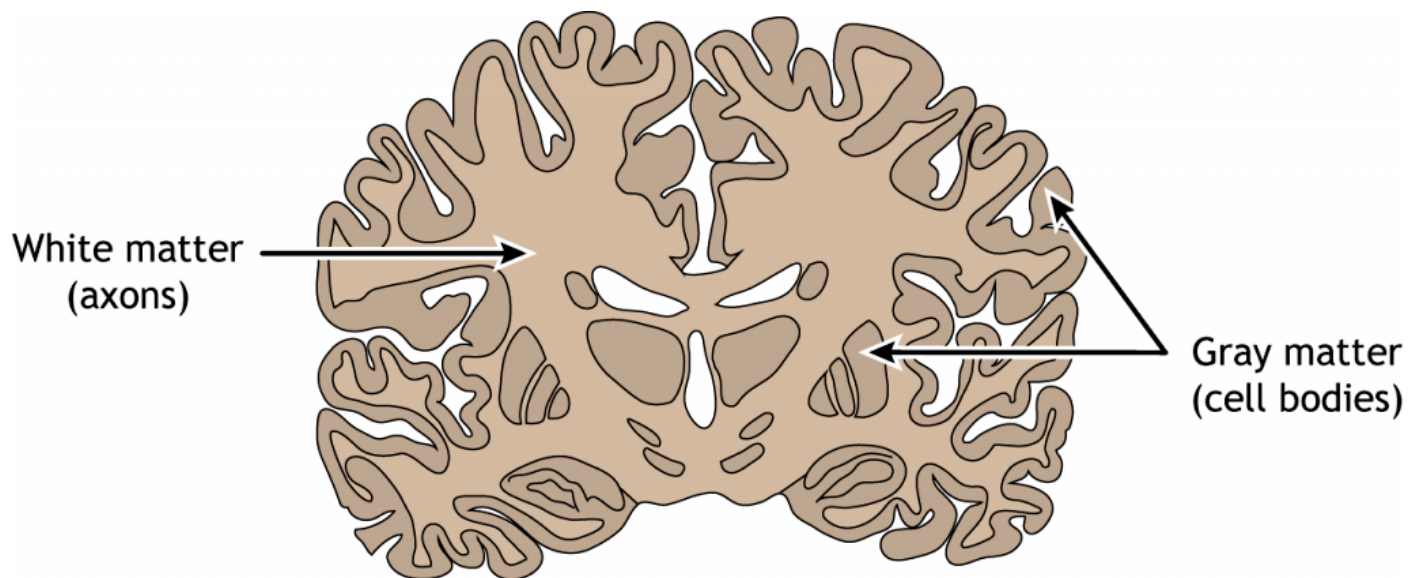


Figure 1.1.6: The central nervous system tissue can be divided into white and gray matter. White matter is primarily myelinated axons. Gray matter is primarily neuronal cell bodies and dendrites. In the brain, the surface of the cerebral cortex is a layer of gray matter. White matter can be found below the gray matter layer and is the location of the axons traveling to and from the cortical cell layer. Gray matter can also be found deep in the brain in subcortical regions that play critical roles in behavior. (CC-BY-NC-SA 4.0; Casey Henley via [Anatomical Terminology](#)).

Figure 1.1.6 displays a coronal-section view of the brain. Arrows label the white matter, which consists of axons, and the gray matter, which contains cell bodies. The image highlights the structural organization of brain tissue and helps distinguish between these two key components of the nervous system.

The PNS consists of all the neural structures lying outside the CNS, and includes the cranial and spinal nerves as well as the autonomic and somatic nervous systems. It is important not to confuse nerves with neurons. Nerves are made up of many nerve fibers (axons or dendrites or both) bound together with connective tissue, and occur in the PNS. Bundles of fibers found within the CNS are called tracts.

Table 1.1.1: Tissue and Organ Components of the Nervous System

CNS (Central Nervous System)	PNS (Peripheral Nervous System)
Structures and Systems	Functions
White matter – myelinated axons in the CNS. Sometimes referred to as tracts, or fasciculi (or may have older, unique names).	Connections between CNS regions to coordinate functions. Allows integration of information.
Gray matter – neuron cell bodies in the CNS, includes cortical tissue (e.g. cerebral cortex) and nuclei (e.g. caudate nucleus assists with motor coordination).	Sites of information integration and decision making, e.g. temporal cortex in the brain processes auditory signals and interprets speech.
Nerve – bundle of axons in the PNS	Can be classified as sensory (or afferent) for signals coming into the CNS from PNS, or motor (or efferent) for signals from CNS to PNS. Most nerves are mixed and carry both sensory and motor information.
Ganglia – clusters of neuron cell bodies in PNS	Various functions controlling and monitoring body functions, e.g. dorsal root ganglia are sensory neurons clustered lateral to the spinal cord.
Somatic Nervous System (or voluntary)	Nervous tissues related to conscious perception and voluntary body control.
Autonomic Nervous System (or visceral) – subdivided into the Sympathetic and Parasympathetic subdivisions. Nervous tissues related to unconscious perception and involuntary body control.	Sympathetic – regulates ‘fight-or-flight’, short term stress responses (e.g., increase heart rate, pupil dilation); Parasympathetic – regulates ‘rest and digest’ functions (e.g., decrease in skeletal muscle activity, increase in digestive function – liver, pancreas function).

Mechanisms of Neuron Action Potential

The functions of the nervous system are sensation, integration, and response—depend on the functions of the neurons underlying these pathways. To understand how neurons are able to communicate, it is necessary to describe the role of an excitable membrane in generating these signals. The basis of this communication is the action potential, which demonstrates how changes in the membrane can constitute a signal.

Excitable cells are those that can be stimulated to create a tiny electric current. Neurons communicate with one another via action potentials. An action potential (AP) is a sudden brief change in the distribution of charge on the intracellular fluid (ICF) and extracellular fluid (ECF) of a nerve cell membrane (i.e., between the inside of the nerve cell versus the outside of the cell). This is caused by the flow of electrically charged particles (ions, such as Na^+ , K^+ , Cl^- , Ca^{++}) through special structures in the membrane, called ion channels or ion pumps.

When at rest, the cell membrane of the neuron allows certain ions to pass through while preventing or restricting other ions from moving. In this state, sodium and potassium ions cannot easily pass through the membrane. Chloride ions, however, are able to freely cross the membrane. The negative ions inside the cell are unable to cross the barrier.

1. The resting membrane potential (RMP) of the neuron refers to the difference between the voltage inside and outside the neuron and may be called polarized state. The resting potential of the average neuron is around -70 millivolts, indicating that the inside of the cell is 70 millivolts less than the outside of the cell. The resting potential arises from two activities:
 - The sodium/potassium ATPase: This pump pushes only two potassium ions (K^+) into the cell for every three sodium ions (Na^+) it pumps out of the cell so its activity results in a net loss of positive charges within the cell.
 - Some potassium channels in the plasma membrane are "leaky" allowing a slow facilitated diffusion of K^+ out of the cell.

Thus, in brief, an AP (action potential) is simply a change in the resting membrane potential (polarized state), which is used to transmit information along the length of a neuron. Depolarization, repolarization and hyperpolarization are processes that describe changes in the electrical charge of a cell or tissue:

2. Depolarization also called also called the rising phase. Certain stimuli reduce the charge across the plasma membrane. Mechanical stimuli (e.g., stretching, sound waves) activate mechanically-gated sodium channels. Certain neurotransmitters (e.g., acetylcholine) open ligand-gated sodium channels. In each case, the facilitated diffusion of sodium into the cell reduces the resting potential at that spot on the cell creating an excitatory postsynaptic potential or EPSP. If the potential is reduced to the threshold voltage (about -50 mv in mammalian neurons), an action potential is generated in the cell. Action potential is a brief reversal of membrane potential in which the membrane potential changes from -70mV to $+30\text{mV}$.
3. Repolarization or falling phase is caused by the slow closing of sodium channels and the opening of voltage-gated potassium channels. As a result, the membrane permeability to sodium declines to resting levels. As the sodium ion entry declines, the slow voltage-gated potassium channels open and potassium ions rush out of the cell. This leads to restore the localized negative membrane potential of the cell.
4. Hyperpolarization is a phase where some potassium channels remain open and sodium channels reset. A period of increased potassium permeability results in excessive potassium efflux before the potassium channels close. This results in hyperpolarization as seen in a slight dip following the spike.

These events happen over just a few milliseconds.

- All or None concept: An action potential is considered "all or none," meaning that once a neuron reaches its threshold, it will always fire an action potential of the same magnitude, regardless of the strength of the stimulus above the threshold; if the stimulus is below the threshold, no action potential will occur.
- Refractory Period: A "refractory period" in the nervous system refers to a brief time period following an action potential where a neuron cannot fire another action potential, essentially acting as a "recovery phase" where the neuron is temporarily unresponsive to stimuli, ensuring the signal travels in one direction only along the axon; this is primarily due to the inactivation of sodium channels involved in generating the action potential.
- Figure 1.1.7 represents potential results by summation of excitatory and inhibitory signals. A single neuron can receive both excitatory and inhibitory inputs from multiple neurons, resulting in local membrane depolarization (EPSP input) and hyperpolarization (IPSP input). All these inputs are added together at the axon hillock. If the EPSPs are strong enough to overcome the IPSPs and reach the threshold of excitation, the neuron will fire.

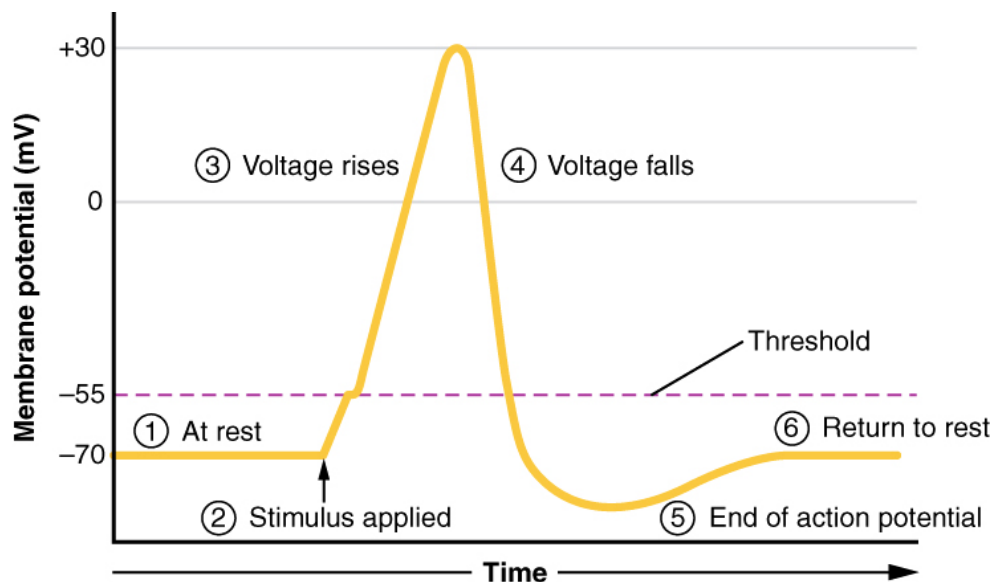


Figure 1.1.7: Plotting voltage measured across the cell membrane against time, the events of the action potential can be related to specific changes in the membrane voltage. (1) At rest, the membrane voltage is -70 mV. (2) The membrane begins to depolarize when an external stimulus is applied. (3) The membrane voltage begins a rapid rise toward $+30$ mV. (4) The membrane voltage starts to return to a negative value. (5) Repolarization continues past the resting membrane voltage, resulting in hyperpolarization. (6) The membrane voltage returns to the resting value shortly after hyperpolarization. (CC-BY-NC-SA 4.0; OpenStax College via [The Action Potential](#)).

Figure 1.1.7 is a line graph of an action potential showing how membrane potential (mV) changes over time. The vertical axis is labeled Membrane potential (mV) with reference values near $+30$ mV, 0 mV, -55 mV, and -70 mV. The horizontal axis is labeled Time. A dashed horizontal line labeled Threshold is shown at approximately -55 mV. The action potential curve is labeled with six numbered stages:

1. At rest: The membrane potential is stable at about -70 mV (resting potential).
2. Stimulus applied: A stimulus causes the membrane potential to begin moving upward from the resting level toward threshold.
3. Voltage rises: The membrane potential rises steeply, crossing the threshold line and continuing upward (depolarization) toward a peak near $+30$ mV.
4. Voltage falls: After the peak, the membrane potential drops rapidly back downward (repolarization).
5. End of action potential: The membrane potential briefly falls below the resting level (an undershoot or after-hyperpolarization) before starting to recover.
6. Return to rest: The membrane potential gradually returns to the resting level near -70 mV.

Signal Summation

Sometimes a single EPSP is strong enough to induce an action potential in the postsynaptic neuron, but often multiple presynaptic inputs must create EPSPs around the same time for the postsynaptic neuron to be sufficiently depolarized to fire an action potential. This process is called summation and occurs at the axon hillock. Additionally, one neuron often has inputs from many presynaptic neurons—some excitatory and some inhibitory—so IPSPs can cancel out EPSPs and vice versa. It is the net change in postsynaptic membrane voltage that determines whether the postsynaptic cell has reached its threshold of excitation needed to fire an action potential. Together, synaptic summation and the threshold for excitation act as a filter so that random “noise” in the system is not transmitted as important information.

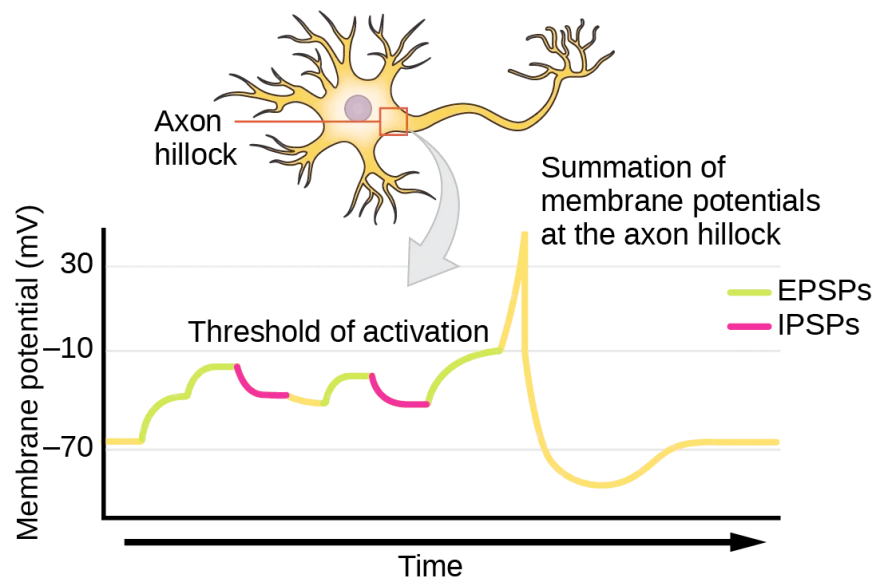


Figure 1.1.8: Summation. A single neuron can receive both excitatory and inhibitory inputs from multiple neurons, resulting in local membrane depolarization (EPSP input) and hyperpolarization (IPSP input). All these inputs are added together at the axon hillock. If the EPSPs are strong enough to overcome the IPSPs and reach the threshold of excitation, the neuron will fire. (CC-BY-NC-SA 4.0; Janet Wang-Lee via [Human Biology](#)).

Figure 1.1.8 is a graph that plots membrane potential, or mV (x axis) over time (y axis). It explains the summation of membrane potentials at the axon hillock and how a neuron reaches the threshold of activation to fire an action potential. The axon hillock is located at the base of the axon on the neuron.

Background information provided on this graph:

- The membrane potential axis is labeled -70, -10, and 30.
- The threshold of activation, or the voltage level that must be reached to trigger an action potential is -10 on the Membrane Potential axis.
- The summation of membrane potentials at the axon hillock indicates that multiple inputs add together at this site.
- EPSPs, or excitatory postsynaptic potentials, are upward changes in membrane potential.
- IPSPs, or inhibitory postsynaptic potentials, are downward changes in membrane potential.
- Axes: the vertical axis is membrane potential (mV) and the horizontal axis is time.

Summary:

The membrane potential begins near a resting level around -70 mV. Several EPSPs raise the membrane potential closer to the threshold of activation. IPSPs briefly lower the membrane potential, moving it farther from threshold. As additional EPSPs occur, their combined effect (summation) brings the membrane potential up to the threshold. When the threshold is reached, the graph shows a rapid spike upward to a positive voltage value, representing an action potential. After the spike, the membrane potential drops below the resting level briefly (after hyperpolarization) and then returns toward resting potential.

Myelin and the Propagation of the Action Potential

The nodes of Ranvier are gaps in the myelin sheath along the axon. These unmyelinated spaces are about one micrometer long and contain voltage gated Na⁺ and K⁺ channels. Flow of ions through these channels, particularly the Na⁺ channels, regenerates the action potential over and over again along the axon. This 'jumping' of the action potential from one node to the next is called saltatory conduction. If nodes of Ranvier were not present along an axon, the action potential would propagate very slowly since Na⁺ and K⁺ channels would have to continuously regenerate action potentials at every point along the axon instead of at specific points. Nodes of Ranvier also save energy for the neuron since the channels only need to be present at the nodes and not along the entire axon.

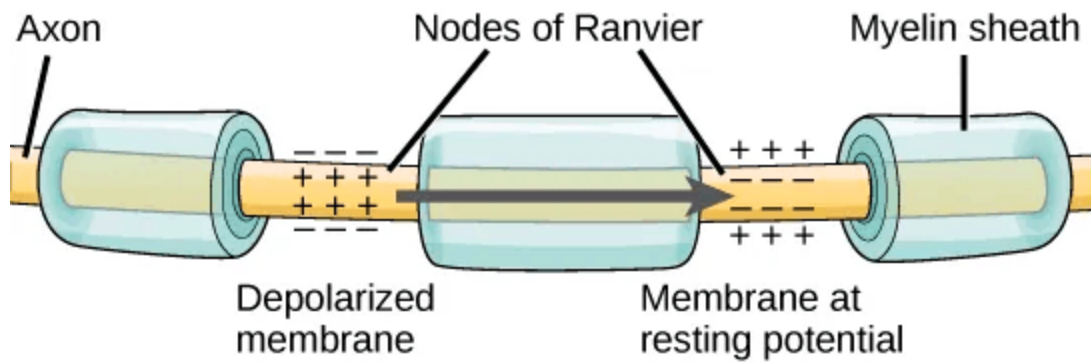


Figure 1.1.9: Nodes of Ranvier are gaps in myelin coverage along axons. Nodes contain voltage-gated K^+ and Na^+ channels. Action potentials travel down the axon by jumping from one node to the next. (CC-BY-NC-SA 4.0; Janet Wang-Lee via Human Biology)

Figure 1.1.9 illustrates saltatory conduction along a myelinated axon by labeling where the membrane is depolarized versus where it remains at resting potential.

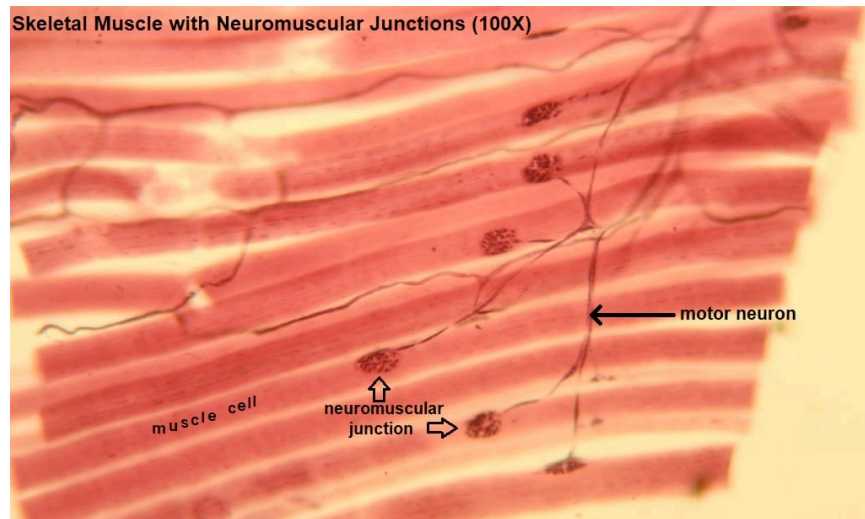
- Axon: the long nerve fiber running through the center of the diagram.
- Myelin sheath: insulating segments wrapped around the axon.
- Nodes of Ranvier: the gaps between myelin sheath segments where the axon membrane is exposed.
- Depolarized membrane: labeled at a node, indicating the area where the membrane potential changes and the signal is actively regenerated.
- Membrane at resting potential: labeled under the myelin sheath, indicating that these insulated regions do not depolarize in the same way as the nodes.

In a myelinated axon, action potentials are regenerated mainly at the nodes of Ranvier, while the myelin sheath helps the signal travel faster between nodes by insulating the axon.

Synaptic Transmission

The synapse or is the place where information is transmitted from one neuron to another. Synapses usually form between axon terminals and dendritic spines, but this is not universally true. There are also axon-to-axon, dendrite-to- dendrite, and axon-to-cell body synapses. The neuron transmitting the signal is called the presynaptic neuron, and the neuron receiving the signal is called the postsynaptic neuron. Note that these designations are relative to a particular synapse most neurons are both presynaptic and postsynaptic. There are two types of synapses: chemical and electrical.

A skeletal muscle cell (fiber) contracts when stimulated by a motor neuron at a special synapse known as a neuromuscular junction. Although the axon of a single motor neuron can branch and stimulate the contraction of a group of many skeletal muscle cells simultaneously (known as a motor unit), each skeletal muscle cell has only one neuromuscular junction. A neuromuscular junction consists of the end of a motor neuron known as the synaptic terminal or axon terminal, a region of the muscle cell membrane (sarcolemma) known as the motor end plate, and a narrow space that separates the synaptic terminal from the motor end plate known as the synaptic cleft.



A skeletal muscle cell (fiber) contracts when stimulated by a motor neuron at a special synapse known as a neuromuscular junction.

Figure 1.1.10: Neuromuscular junction (NMJ) under the microscope shows the striking interface where a motor neuron communicates with a skeletal muscle fiber. (CC-BY-NC-SA 4.0; Brian Bich via [Histology Atlas for Anatomy and Physiology](#)).

Figure 1.1.10 represents a skeletal muscle cell (fiber) contracts when stimulated by a motor neuron at a special synapse known as a neuromuscular junction (NMJ). Figure 1.1.10 highlights neuromuscular junctions where motor neurons synapse with muscle cells (myofibers).

This microscopic image of skeletal muscle tissue at 100 times magnification shows regular bands of muscle cells, with dark threads of motor neurons winding through the bands. At the ends of some threads, ovoid clusters of dots appear. These are neuromuscular junctions, specialized synapses where a motor neuron communicates with a skeletal muscle fiber, enabling voluntary muscle contraction.

1.2: Activity 1

Think - Pair - Share

Think-Pair-Share activity encourages critical thinking, collaboration, and communication, providing an opportunity to deepen your understanding of the lab material.

Step 1: Think

- Take a few minutes to think about the question/problem/prompt individually and formulate your own response. Write down your thoughts, ideas, or solutions. Consider any relevant lab observations or data.

Step 2: Pair

- Pair up with a partner or partners, to share your individual thoughts and discuss your ideas; listen actively and consider alternative perspectives. Aim to clarify any misunderstandings and build on each other's ideas.

Step 3: Share

- As a pair or group, share your collective insights with the rest of the class when prompted by the instructor.
- Be ready to explain your reasoning and any conclusions you've reached, and engage in further discussion if needed.

Prompt: 'How do we recognize and distinguish odors?

1. Think (Individual Reflection): Reflect individually on how we recognize and distinguish odors. Consider the following questions/prompts to guide your thinking:
 - i. Where in the body and brain is odor processing primarily occurring?
 - ii. Why is the ability to distinguish odors important for survival and daily life?

Response space (record individual ideas) -

2. Pair (Partner Discussion): Compare your answers and explore any differences in your understanding or perspective.

Response space (record shared ideas)

- **My Partner's Ideas -**
- **Our Consensus -**

3. Share (Whole-Class Report Out):

Response

Our Main Idea to Share -

- **Other Ideas from the Class**

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1.3: Activity 2

Instructions

Objective: Use the laboratory model to observe a typical neuron, identify key parts and structures, write short anatomical descriptions, and relate each part to its function.

1. Use offline resources such as textbooks or lab manuals available in the lab or library to supplement your understanding.
2. Record your descriptions and functional relationships in Table 1.3.1.
3. Be prepared to discuss your findings and the role of each neuron part during the lab session.

Table 1.3.1: Comparison of CNS and PNS structures and their functions.

Structure	Brief Anatomical Description	Physiological Role
Neuron cell body (Soma)		
Nissl bodies		
Dendrites	Short, branched projections/extensions of a neuron cell body, covers large surface area, 97% of the surface area of a motor neuron is dendritic.	
Axon hillock		Both inhibitory postsynaptic potentials (IPSPs) and excitatory postsynaptic potentials (EPSPs) are summed in the axon hillock and once a triggering threshold is exceeded, an action potential propagates through the rest of the axon.
Axon		
Myelin sheath		
Nodes of Ranvier		
Axon terminals		
Axolemma		
Neurolemma		

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1.4: Activity 3

Microscopic Exploration of a Multipolar Motor Neuron

Objective: The objective of this lab activity is to observe and identify the structural features of a multipolar motor neuron under a microscope.

Materials

Microscope, Multipolar Motor Neuron Prepared Slide

Instructions

1. Start with a lower magnification objective 4 times (scanning lens), focus, change to 10 times, to appreciate the most important tissue features.
 2. Use a higher-power objective lens (40 times) only to confirm details.
 3. Inspect the slide with a good light source to determine the shape of the prepared section.
- Label the following structures: axon, cell body, dendrite, nucleus, Nucleolus, Nissl bodies, neurofibrils, and glial cells. **Note:** sometimes it is difficult to differentiate axons and dendrites.
 - Summarize your observations and findings in this space.

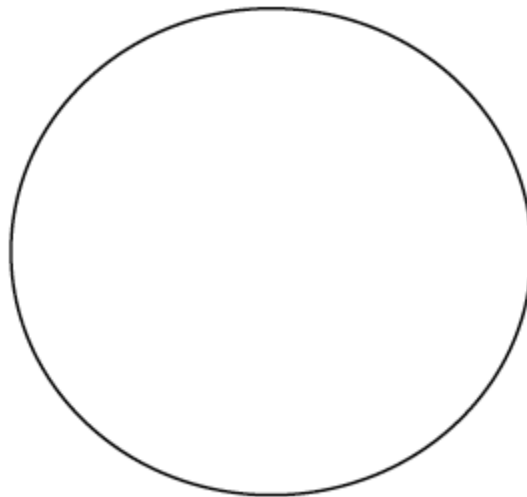


Figure 1.4.1: Circle to note the observations. ([CC BY-NC-SA 4.0](#); LakshmiKanta Sengupta).

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1.5: Activity 4

Microscopic Examination of a Teased Medullated Nerve

Objective: The objective of this lab activity is to examine the structure of a teased medullated (myelinated) nerve under a microscope. Students will identify key components such as myelin sheaths and nodes of Ranvier, and understand their importance in the rapid conduction of nerve impulses.

Materials

Microscope, prepared slides of teased medullated nerve fibers

Instructions

1. Start with a lower magnification objective 4 times (scanning lens), focus, change to 10 times, to appreciate the most important tissue features.
2. Use a higher-power objective lens (40 times) only to confirm details.
3. Draw (total magnification 400 times), and label axon, Schwann cells, and node of Ranvier.

Alternately you can take microphotograph of your observation and label parts.

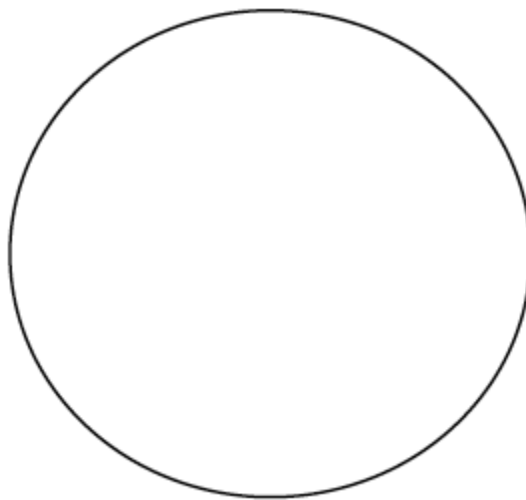


Figure 1.5.1: Circle to note the observations. ([CC BY-NC-SA 4.0](#); LakshmiKanta Sengupta).

1.6: Activity 5

Microscopic Observation of a Motor End Plate

Objective: The objective of this lab activity is to observe the structure of a motor end plate at the neuromuscular junction under a microscope. Students will identify key features such as the synaptic cleft and the arrangement of muscle fibers, and understand the role of the motor end plate in muscle contraction.

Materials

Microscope, prepared slide labeled motor end plate

Instructions

1. Start with a lower magnification objective 4 times (scanning lens), focus, change to 10 times, to appreciate the most important tissue features.
2. Use a higher-power objective lens (40 times) only to confirm details.
3. View carefully and draw (total magnification 400 times), label muscle fibers, axon fibers, axon end bulbs.

Alternately you can take microphotograph of your observation and label parts.

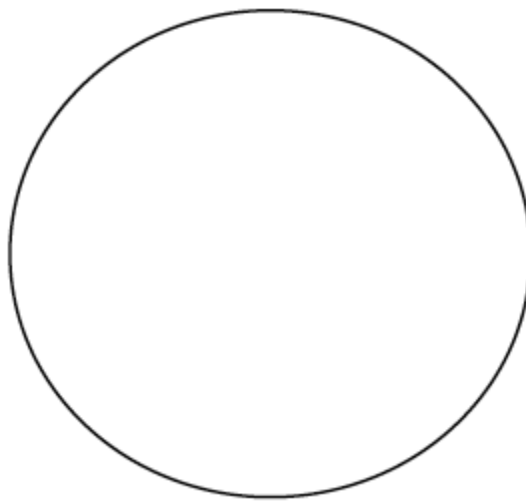


Figure 1.6.1: Circle to note the observations. ([CC BY-NC-SA 4.0](#); LakshmiKanta Sengupta).

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1.7: Activity 6

Understanding Demyelinating Diseases

Objective: The objective of this activity is to enhance students' comprehension of demyelinating diseases through the reading of a scientific paragraph, answering objective questions, and developing skills in interpreting scientific literature. This will facilitate a deeper understanding of how these diseases impact the nervous system and the critical role myelin plays in neural function.

Instructions

1. Reading the Paragraph
 - Carefully read the provided paragraph on "Understanding Demyelinating Diseases." Pay attention to how the information is structured and presented, which will help improve your ability to read and interpret scientific literature effectively.
2. Key Concepts to Note
 - **Myelin Function:** Understand how myelin insulates nerve fibers and facilitates the rapid transmission of signals across the nervous system.
 - **Demyelinating Diseases:** Familiarize yourself with diseases like Multiple Sclerosis (MS) and Guillain-Barre Syndrome, noting their causes, symptoms, and the scientific terminology used to describe them.
 - **Impact on Nervous System:** Recognize how demyelination affects communication within the nervous system and can lead to various neurological deficits.
3. Answering Objective Questions
 - After reading, answer the set of objective questions provided. These questions are designed to test your understanding of the material and your ability to extract and recall specific details from scientific text.

Paragraphs for Reading

Neurodegenerative disorders are diseases that occur when nerve cells in the brain or peripheral nervous system malfunction and/or die over time. Several diseases can result from the demyelination of axons. The causes of these diseases are not the same; some have genetic causes, some are caused by pathogens, and others are the result of autoimmune disorders. Though the causes are varied, the results are largely similar. The myelin insulation of axons is compromised, making electrical signaling slower.

Multiple sclerosis (MS) is one such disease. It is an example of an autoimmune disease. The antibodies produced by lymphocytes (a type of white blood cell) mark myelin as something that should not be in the body. This causes inflammation and the destruction of the myelin in the central nervous system. As the insulation around the axons is destroyed by the disease, scarring becomes obvious. This is where the name of the disease comes from; sclerosis means hardening of tissue, which is what a scar is. Multiple scars are found in the white matter of the brain and spinal cord. The symptoms of MS include both somatic and autonomic deficits. Control of the musculature is compromised, as is control of organs such as the bladder. Guillain-Barré (pronounced gee-YAN bah-RAY) syndrome is an example of a demyelinating disease of the peripheral nervous system. It is also the result of an autoimmune reaction, but the inflammation is in peripheral nerves. Sensory symptoms or motor deficits are common, and autonomic failures can lead to changes in the heart rhythm or a drop in blood pressure, especially when standing, which causes dizziness.

Objective Type Questions

Select the best answer based on your understanding of the material.

1. A 45-year-old man develops sudden weakness in his legs, leading to difficulty walking. He reports experiencing a recent

- upper respiratory infection. What is the most likely diagnosis?
- A. Multiple Sclerosis
 - B. Guillain-Barré Syndrome
2. A patient with Guillain-Barré Syndrome is experiencing autonomic dysfunction. Which of the following symptoms might they exhibit?
- A. Hyperactivity
 - B. Bradycardia
 - C. Increased appetite
3. Which of the following best describes the mechanism of action in Multiple Sclerosis?
- A. Direct attack on neurons by pathogens
 - B. Inflammation and destruction of myelin by the immune system
4. A patient with MS is experiencing muscle weakness and bladder dysfunction. What is the most effective approach to manage these symptoms?
- A. Surgical intervention
 - B. Medications to reduce inflammation
 - C. Physical therapy and lifestyle modifications
 - D. Complete rest and isolation

1.8: Activity 7

Instructions

Fill in the Table with pertinent information to Demonstrate structure - function - location relationships about the structural and functional classes of neuron.

Table 1.8.1: Functional and structural classification of neurons with location details.

Functional Class	Structural Class Select to relate	Function	Location of Cell body CNS or PNS?	Location of Axon terminal CNS or PNS?
Sensory Neuron	A. Unipolar			
	B. Bipolar			
	C. Multipolar			
Interneuron	A. Unipolar			
	B. Bipolar			
	C. Multipolar			
Motor Neuron	A. Unipolar			
	B. Bipolar			
	C. Multipolar			

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1.9: Activity 8

Physiological Role of Glial Cells

Objective: The objective of this lab activity is to understand the diverse physiological roles of glial cells in the nervous system. Students will identify different types of glial cells, explore their functions, and appreciate their importance in maintaining neural health and function.

Instructions

- Begin by reviewing background information on the types of glial cells, including astrocytes, oligodendrocytes, microglia, and Schwann cells.
- Familiarize yourself with the basic , location (CNS or PNS) and general functions of each type of glial cell in both the central and peripheral nervous systems.
- Circle CNS or PNS to indicate location of each. Of the six types of neuroglia cells, four are in the CNS and two in the PNS.
- Use textbooks, scientific articles, and online resources to supplement your understanding of glial cell physiology. Demonstrate knowledge by filling in the column.

Table 1.9.1: Glial cell types, their CNS or PNS location, and brief physiological roles.

Glial Cells	Location	Briefly describe Physiological Role
Astrocytes	CNS or PNS	
Microglia	CNS or PNS	
Schwann Cells	CNS or PNS	
Oligodendrocytes	CNS or PNS	
Ependymal Cells	CNS or PNS	
Satellite Cells	CNS or PNS	

Key Terms and Definitions

- **Action potential:** change in voltage of a cell membrane in response to a stimulus that results in transmission of an electrical signal; unique to neurons and muscle fibers.
- **Astrocyte:** glial cell type of the CNS that provides support for neurons and maintains the blood-brain barrier.
- **Autonomic nervous system (ANS):** functional division of the nervous system that is responsible for homeostatic reflexes that coordinate control of cardiac and smooth muscle, as well as glandular tissue
- **Axon hillock:** tapering of the neuron cell body that gives rise to the axon.
- **Axon segment:** single stretch of the axon insulated by myelin and bounded by nodes of Ranvier at either end (except for the first, which is after the initial segment, and the last, which is followed by the axon terminal)
- **Axon terminal:** end of the axon, where there are usually several branches extending toward the target cell.
- **Axon:** single process of the neuron that carries an electrical signal (action potential) away from the cell body toward a target cell.
- **Axoplasm:** cytoplasm of an axon, which is different in composition than the cytoplasm of the neuronal cell body.
- **Bipolar:** shape of a neuron with two processes extending from the neuron cell body—the axon and one dendrite.
- **Blood-brain barrier (BBB):** physiological barrier between the circulatory system and the central nervous system that establishes a privileged blood supply, restricting the flow of substances into the CNS.
- **Brain:** the large organ of the central nervous system composed of white and gray matter, contained within the cranium and continuous with the spinal cord.
- **Central nervous system (CNS):** anatomical division of the nervous system located within the cranial and vertebral cavities, namely the brain and spinal cord.
- **Continuous conduction:** slow propagation of an action potential along an unmyelinated axon owing to voltage-gated Na⁺ channels located along the entire length of the cell membrane.
- **Dendrite:** one of many branchlike processes that extends from the neuron cell body and functions as a contact for incoming signals (synapses) from other neurons or sensory cells.
- **Depolarization:** change in a cell membrane potential from rest toward zero.
- **Enteric nervous system (ENS):** neural tissue associated with the digestive system that is responsible for nervous control through autonomic connections.
- **Ependymal cell:** glial cell type in the CNS responsible for producing cerebrospinal fluid
- **Ganglion:** localized collection of neuron cell bodies in the peripheral nervous system.
- **Gated:** property of a channel that determines how it opens under specific conditions, such as voltage change or physical deformation.
- **Glial cell:** one of the various types of neural tissue cells responsible for maintenance of the tissue, and largely responsible for supporting neurons.
- **Graded potential:** change in the membrane potential that varies in size, depending on the size of the stimulus that elicits it.
- **Gray matter:** regions of the nervous system containing cell bodies of neurons with few or no myelinated axons; actually may be more pink or tan in color, but called gray in contrast to white matter.
- **Initial segment:** first part of the axon as it emerges from the axon hillock, where the electrical signals known as action potentials are generated.
- **Integration:** nervous system function that combines sensory perceptions and higher cognitive functions (memories, learning, emotion, etc.) to produce a response.
- **Leakage channel:** ion channel that opens randomly and is not gated to a specific event, also known as a non-gated channel.
- **Ligand-gated channels:** another name for an ionotropic receptor for which a neurotransmitter is the ligand.
- **Mechanically gated channel:** ion channel that opens when a physical event directly affects the structure of the protein.
- **Membrane potential:** distribution of charge across the cell membrane, based on the charges of ions.
- **Microglia:** glial cell type in the CNS that serves as the resident component of the immune system.
- **Multipolar:** shape of a neuron that has multiple processes—the axon and two or more dendrites.
- **Myelin sheath:** lipid-rich layer of insulation that surrounds an axon, formed by oligodendrocytes in the CNS and Schwann cells in the PNS; allowing for faster transmission of electrical signals.
- **Nerve:** cord-like bundle of axons located in the peripheral nervous system that transmits sensory input and response output to and from the central nervous system.
- **Neuron:** neural tissue cell that is primarily responsible for generating and propagating electrical signals into, within, and out of the nervous system.
- **Neurotransmitter:** chemical signal that is released from the synaptic end bulb of a neuron to cause a change in the target cell.

- **Node of Ranvier:** gap between two myelinated regions of an axon, allowing for strengthening of the electrical signal as it propagates down the axon.
- **Nucleus:** in the nervous system, a localized collection of neuron cell bodies that are functionally related; a “center” of neural function.
- **Oligodendrocyte:** glial cell type in the CNS that provides the myelin insulation for axons in tracts.
- **Peripheral nervous system (PNS):** anatomical division of the nervous system that is largely outside the cranial and vertebral cavities, namely all parts except the brain and spinal cord.
- **Process:** in cells, an extension of a cell body; in the case of neurons, this includes the axon and dendrites.
- **Propagation:** movement of an action potential along the length of an axon.
- **Repolarization:** return of the membrane potential to its normally negative voltage at the end of the action potential.
- **Response:** nervous system function that causes a target tissue (muscle or gland) to produce an event as a consequence to stimuli.
- **Resting membrane potential:** the difference in voltage measured across a cell membrane under steady- state conditions, typically -70 mV.
- **Schwann cell:** glial cell type in the PNS that provides the myelin insulation for axons in nerves.
- **Saltatory conduction:** quick propagation of the action potential along a myelinated axon owing to voltage-gated Na⁺ channels being present only at the nodes of Ranvier.
- **Satellite cell:** glial cell type in the PNS that provides support for neurons in the ganglia.
- **Sensation:** nervous system function that receives information from the environment and translates it into the electrical signals of nervous tissue.
- **Soma:** in neurons, that portion of the cell that contains the nucleus; the cell body, as opposed to the cell processes (axons and dendrites).
- **Somatic nervous system (SNS):** functional division of the nervous system that is concerned with conscious perception, voluntary movement, and skeletal muscle reflexes.
- **Spinal cord:** organ of the central nervous system found within the vertebral cavity and connected with the periphery through spinal nerves; mediates reflex behaviors.
- **Stimulus:** an event in the external or internal environment that registers as activity in a sensory neuron.
- **Synapse:** narrow junction across which a chemical signal passes from neuron to the next, initiating a new electrical signal in the target cell.
- **Synaptic cleft:** small gap between cells in a chemical synapse where neurotransmitter diffuses from the presynaptic element to the postsynaptic element.
- **Synaptic end bulb:** swelling at the end of an axon where neurotransmitter molecules are released onto a target cell across a synapse.
- **Threshold:** membrane voltage at which an action potential is initiated.
- **Tract:** bundle of axons in the central nervous system having the same function and point of origin.
- **Unipolar:** shape of a neuron which has only one process that includes both the axon and dendrite.
- **Voltage-gated channel:** ion channel that opens because of a change in the charge distributed across the membrane where it is located.
- **White matter:** regions of the nervous system containing mostly myelinated axons, making the tissue appear white because of the high lipid content of myelin

2: SPINAL CORD ANATOMY - PHYSIOLOGY, SPINAL NERVES AND REFLEXES

Introduction

In this lab, we will explore the anatomy and physiology of the spinal cord, the organization and function of spinal nerves, and the mechanisms behind the reflex arc and spinal reflexes. This hands-on investigation will help you understand the role of the spinal cord as a vital part of the central nervous system (CNS) and its connection to the peripheral nervous system (PNS) through spinal nerves. Additionally, we will examine how reflexes are mediated through the spinal cord to enable rapid, automatic responses to stimuli.

The spinal cord serves as the primary communication highway between the brain and the body, coordinating sensory input and motor output. Reflex arcs, which bypass conscious brain activity, are essential for maintaining homeostasis and protective responses. By the end of this lab, you will gain a deeper understanding of the spinal cord's anatomy and its functional significance.

Learning Objectives

- Define the boundaries of the spinal cord and explain the rationale for performing lumbar punctures below the L3 level.
- Identify key structures of the spinal cord and nerves using anatomical models and images.
- Describe the processing of sensory and motor signals by the spinal cord.
- Explain reflex arcs and differentiate between normal and abnormal reflex responses. Understand how abnormal reflexes can indicate nerve or spinal damage.
- Observe and interpret reflexes, such as the patellar reflex, in laboratory settings.
- Relate the structure of the spinal cord to its function in both healthy and diseased states.

2.1: Spinal Cord Anatomy - Key structures

2.2: Background Information

2.3: Activity 1

2.4: Activity 2

2.5: Activity 3

2.6: Activity 4

2.7: Activity 6

2.8: Activity 7

2.9: Activity 8

2.10: Glossary

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2.1: Spinal Cord Anatomy - Key structures

Spinal Cord Gross Anatomy

Students are responsible for identification and establishing the structure - function - location relationships of the following anatomical features.

- Spinal cord levels vs. vertebral levels
- Dural sac and safe lumbar puncture zone (L3 to L4/L4 to L5)
- Cervical enlargement
- Lumbar enlargement
- Conus medullaris
- Filum terminale
- Cauda equina
- Nerve roots (dorsal roots and ventral roots)
- Spinal nerve
- Dorsal root ganglia
- Anterior ramus (Plural is Rami)
- Posterior ramus (Plural is Rami)

Meninges and spaces

- Dura mater
- Arachnoid mater
- Pia mater
- Epidural space
- Subarachnoid space (contains Cerebrospinal Fluid)
- Denticulate ligaments

Nerve plexus and Spinal Nerves

- Cervical plexus (C1 to C4) and Brachial plexus (C5 to T1): Phrenic nerve (C3 to C5), Musculocutaneous, Median, Ulnar, Radial, Axillary.
- Lumbar plexus (L1 to L4) and Sacral plexus (L4 to S4): Femoral, Obturator, Sciatic (tibial + common fibular).

Spinal Cord Cross Section

- Anterior median fissure
- Posterior median sulcus
- Anterior/ventral/gray horn
- Posterior funiculus
- Central canal
- Gray commissure
- Anterior white matter
- Lateral gray horn
- Posterior/dorsal gray horn
- Anterior/ventral root (motor)
- Posterior/dorsal root (sensory)

Components of a Reflex Arc

- Receptor
- Sensory neuron (know specific nerve)
- Integration center (interneuron - know general location in CNS)
- Motor neuron (know specific nerve)
- Effector (know specific muscle)

Reflexes

- Ipsilateral reflexes
- Contralateral reflexes
- Simple stretch reflex
 - Patellar reflex

2.2: Background Information

Spinal Cord Gross Anatomy

Think of the spinal cord as a superhighway for information traffic (action potentials) that are incoming and outgoing from the CNS. In an adult, the spinal cord is about eighteen inches long and extends from the foramen magnum of the skull to approximately the first lumbar vertebra and is divided into regions Figure 2.2.1 that correspond to cervical (neck), thoracic (upper back), lumbar (lower back), sacral (pelvis), and coccygeal (tailbone). The spinal cord connects to these regions via spinal nerves, transmitting sensory information to the brain and motor commands from the brain to the body.

The spinal cord begins at the terminal end of the brain stem and extends to approximately the L1 vertebra adults and L2 vertebrae in children; it is located within the vertebral foramen and is divided into 4 distinct regions. The cervical segment extends from C1 to the C7 vertebrae. The thoracic segment extends from T1 to the T8 vertebrae. The lumbar segment corresponds with T9 to T11 vertebrae. Finally, the sacral segment extends from T12 to L2. The conus medullaris, the tapered, cone-shaped terminal end of the spinal cord is located at approximately the L1 to L2 vertebral level in adults (higher in children, around L2 to L3). The spinal cord does not extend the full length of the vertebral column; instead, it terminates at the conus medullaris, where it transitions into the cauda equina. The conus medullaris contains sacral and coccygeal spinal cord segments responsible for lower limb motor control, sensory innervation to the perineal region and autonomic function related to bladder, bowel, and sexual function.

The filum terminale is a thin, fibrous extension of the pia mater that extends from the conus medullaris to attach to the coccyx. The cauda equina (Latin for "horse's tail") is a bundle of spinal nerves and nerve roots that extends from the conus medullaris (the tapered end of the spinal cord) at approximately L1 to L2 down through the lumbar and sacral regions Figure 2.2.1. These nerves continue within the lumbar cistern (a cerebrospinal fluid-filled space) until they exit through their respective intervertebral foramina.

The spinal cord has two enlargements, the cervical enlargement and the lumbar enlargement, which correspond to the nerve plexuses innervating the upper and lower limbs, respectively. The cervical enlargement is located at the C5 to T1 levels and is associated with the brachial plexus, which innervates the upper limbs. The lumbar enlargement is situated at the T11 to L1 levels and corresponds to the lumbar and sacral plexuses, which innervate the lower limbs. The enlargements are clinically relevant because they are the target areas for certain neurological procedures, such as lumbar punctures, which involve collecting cerebrospinal fluid from the area surrounding the cauda equina.

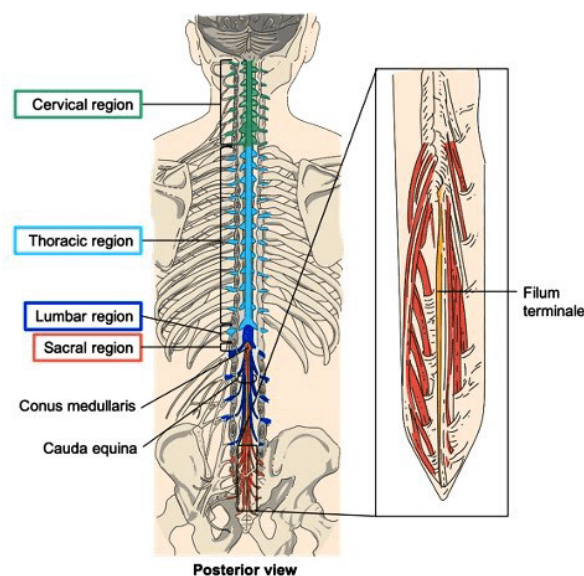


Figure 2.2.1: Gross Anatomy of the Spinal Cord. The spinal cord is divided into four regions: cervical, thoracic, lumbar and sacral. The sacral region has a tapered end called the conus medullaris. The bundle of axons inferior to the conus medullaris is the cauda equina. The cauda equina is anchored to the coccyx by the filum terminale, a thin strand of pia mater. (CC BY 4.0; Chiara Mazzasette via [Spinal Cord and Spinal Nerve](#)).

Figure 2.2.1 illustrates the gross structure of the spinal cord, including its major regions and terminal structures.

Spinal cord regions, superior to inferior:

- Cervical (neck) region
- Thoracic region, which runs from the shoulders to the bottom of the ribcage
- Lumbar region (the lower back), the five vertebrae just below the ribcage
- Sacral region, from the lumbar region to the sacrum (tailbone)

Terminal structures:

- Conus medullaris: the tapered, inferior end of the spinal cord
- Cauda equina: a bundle of spinal nerve roots that continues inferiorly from the conus medullaris
- Filum terminale: a slender strand of pia mater that helps anchor the cauda equina and spinal cord to the coccyx

Protective Coverings of the Spinal Cord

The spinal cord, as the brain, is protected by meninges, which are continuous with the cranial meninges. From outermost to innermost, the spinal meninges are: dura mater, arachnoid mater and pia mater Figure 2.2.2.

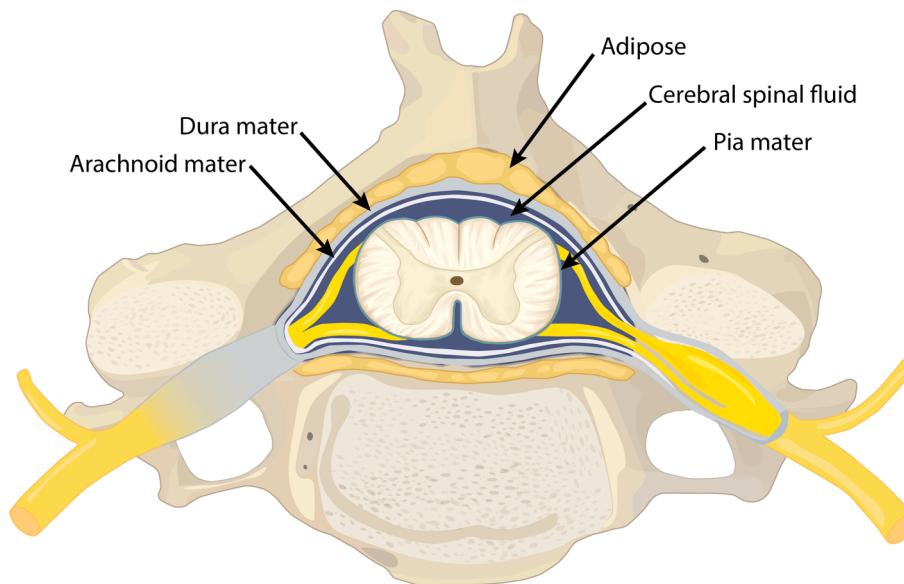


Figure 2.2.2: Spinal Cord Protection. The spinal cord is protected by a bony case, an adipose cushion, and three meningeal layers with cerebrospinal fluid. They protect the spinal cord from outside impacts and from movement within the vertebral column. (CC BY-NC-SA 4.0; "Spinal Cord Protection" by Sofia Elizondo via [Spinal Cord](#)).

Figure 2.2.2 is illustrating the protective structures of the spinal cord. The spinal cord is encased in a bony vertebral column, cushioned by adipose tissue, and surrounded by three layers of meninges: the dura mater, arachnoid mater, and pia mater. Cerebrospinal fluid fills the space between the arachnoid mater and pia mater, providing additional protection. This layered system safeguards the spinal cord from external impacts and mitigates movement within the vertebral column, ensuring its stability and safety.

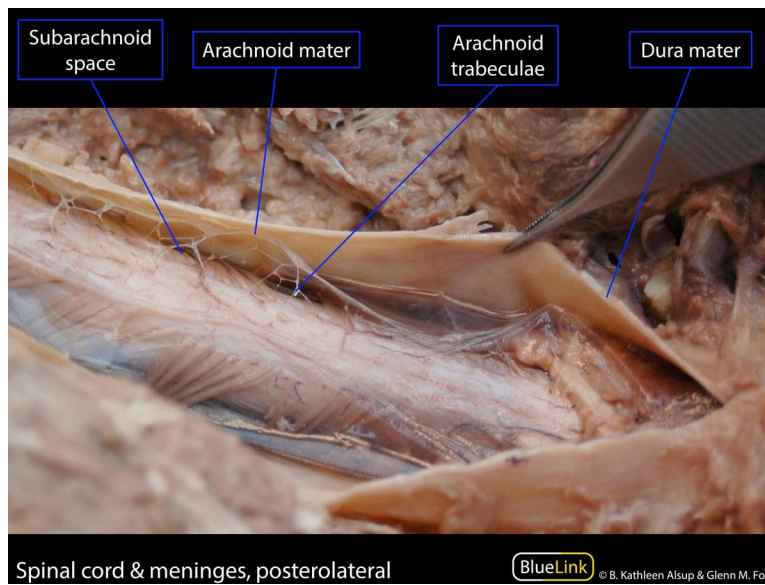


Figure 2.2.3: Spinal Cord Meninges. In this cadaver dissection, the retracting the thick dura mater reveals the thinner arachnoid mater attached to it as well as the trabeculae crossing the subarachnoid space to the pia (not visible but tightly adhered to the cord). (CC BY 4.0; Spinal Meninges by BlueLink via Spinal Cord).

Figure 2.2.3 presents a posterolateral dissection of the spinal cord and its surrounding meninges. It includes labeled structures such as the subarachnoid space, arachnoid mater, arachnoid trabeculae, and dura mater. The thick dura mater is retracted, revealing the thinner arachnoid mater directly attached to it. Visible trabeculae span the subarachnoid space, connecting to the pia mater, which is not visible in this view but is tightly adhered to the spinal cord. This illustration highlights the protective layers surrounding the spinal cord and their structural relationships.

One space between the spinal meninges also differs slightly from the ones present around the brain. The epidural space between the periosteum and dura mater is a real space around the spinal cord and houses areolar and adipose connective tissues Figure 2.2.3.

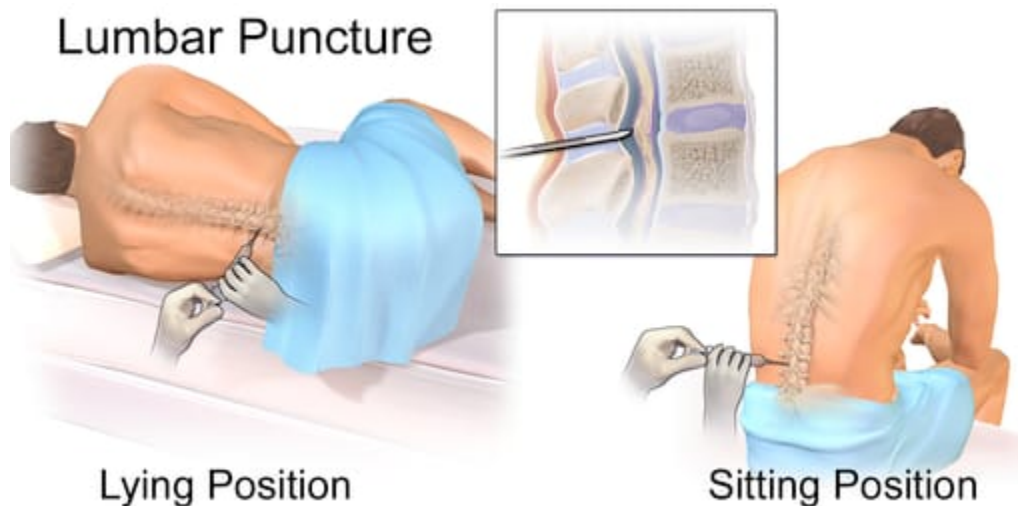


Figure 2.2.4: Epidural Space and Subarachnoid Space. The epidural space is located between the bone and the dura mater while the subarachnoid space is between the arachnoid mater and the pia mater. (CC BY-SA 4.0; Jennifer Lange via Spinal Cord).

Figure 2.2.4 This image displays two illustrations of a lumbar puncture procedure. On the left, a patient lies on their side with knees pulled to the chest while a healthcare provider inserts a needle into the lower back, this is labeled "Lying Position." On the right, another patient is seated and leaning forward as the same procedure is performed, labeled "Sitting Position." A central inset provides a close-up view of the spinal needle entering the space between vertebrae.

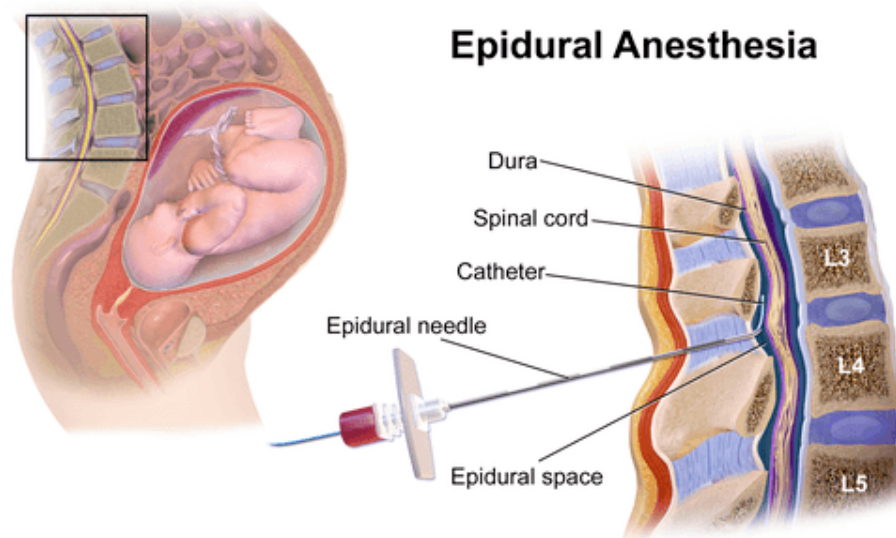


Figure 2.2.5: Administration of epidural anesthesia during childbirth, showing lumbar vertebrae and labeled structures including dura, spinal cord, epidural space, needle, and catheter. (CC BY-SA 4.0; Jennifer Lange via [Spinal Cord](#)).

Figure 2.2.5 shows a pregnant woman receiving an epidural. The image highlights the lumbar spine with vertebrae L3, L4, and L5. An epidural needle is inserted into the lower back in the space between L3 and L4, and a catheter is placed in the epidural space. Labels identify the dura mater, spinal cord, epidural space, needle, and catheter.

The subarachnoid space is filled with circulating CSF, which also provides a liquid cushion to the brain and spinal cord Figure 2.2.3. Similar to clinical blood work, a sample of CSF can be withdrawn to find chemical evidence of neuropathology or metabolic traces of the biochemical functions of nervous tissue. 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 CSF. This procedure is called a lumbar puncture and avoids the risk of damaging the central tissue of the spinal cord.

Spinal Cord Cross Sectional Anatomy

Whereas the brain develops out of expansions of the neural tube into primary and then secondary vesicles, the spinal cord maintains the tube structure and is only specialized into certain regions. As the spinal cord continues to develop in the newborn, anatomical features mark its surface. Viewed in cross section, the anterior midline is marked by the anterior median fissure, and the posterior midline is marked by the posterior median sulcus Figure 2.2.6. In the central region of the spinal cord, a central canal is the continuation of the fourth ventricle of the brain and contains cerebrospinal fluid (CSF). Surrounding the central canal, a horizontal line of gray matter called the gray commissure (Figure 2.2.6) connects the left and right sides of the spinal cord.

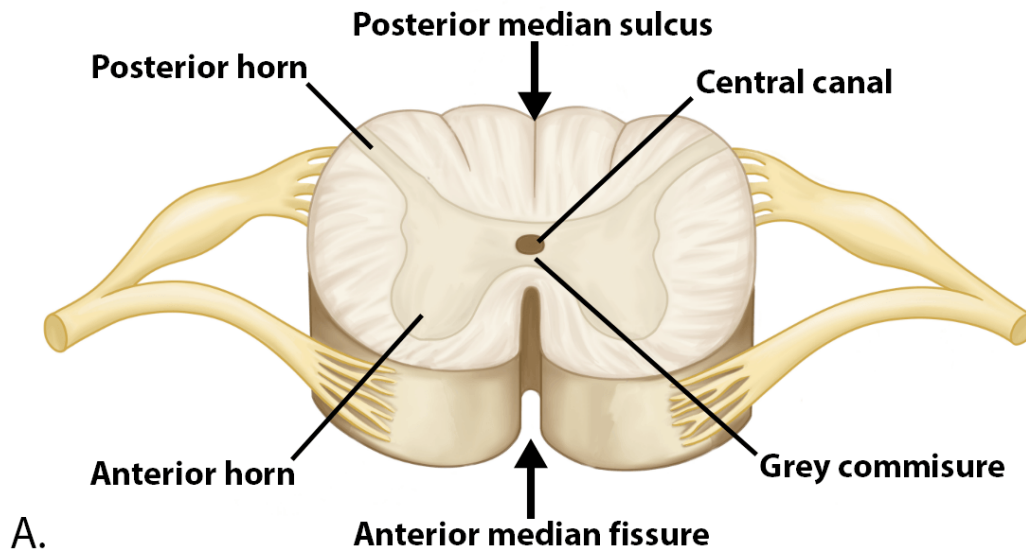


Figure 2.2.6: Cross-sectional view of the spinal cord highlighting major internal structures and anatomical landmarks. (CC BY-NC-SA 4.0; "Spinal Cord CrossSection " by Sofia Elizondo via [Spinal Cord](#)).

Figure 2.2.6 shows a cross-sectional view of the spinal cord and labels key landmarks used to orient the section and identify major gray matter structures.

Orientation landmarks

- Posterior median sulcus: a shallow groove on the posterior (back) midline of the spinal cord section.
- Anterior median fissure: a deeper groove on the anterior (front) midline of the spinal cord section.

These two midline features help distinguish the posterior side from the anterior side.

Labeled internal structures

- Posterior horn: a posterior projection of gray matter on each side of the spinal cord section.
- Anterior horn: an anterior projection of gray matter on each side of the spinal cord section.
- Central canal: a small channel near the center of the spinal cord section.
- Gray commissure: the bridge of gray matter that connects the left and right sides and surrounds the central canal.

The image emphasizes how to orient a spinal cord cross-section using the posterior median sulcus and anterior median fissure, and it identifies the major gray matter regions—posterior horns, anterior horns, and the gray commissure around the central canal.

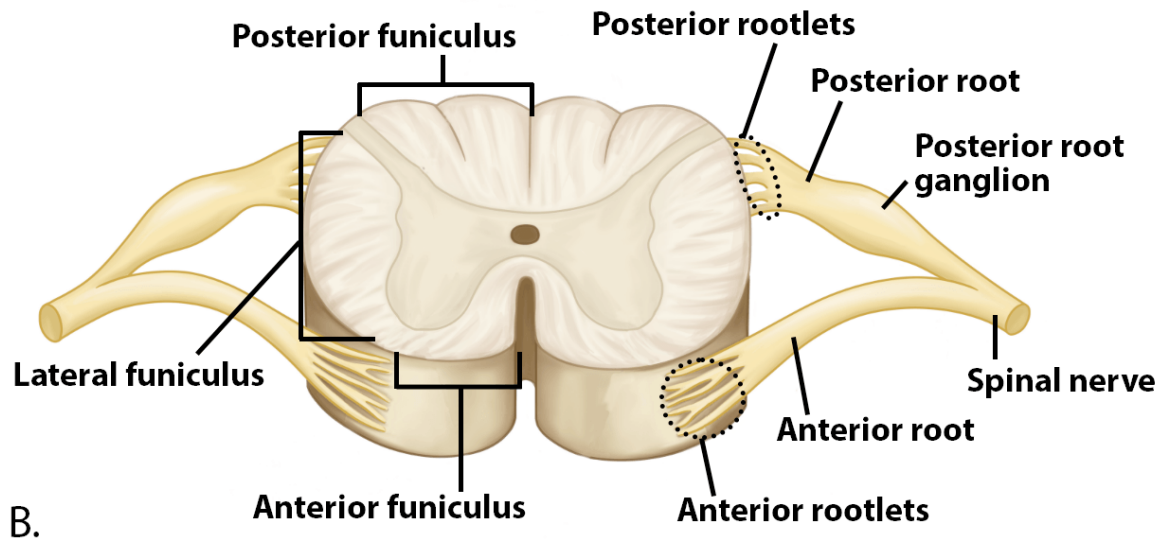


Figure 2.2.7: Cross-sectional diagram of the spinal cord showing labeled funiculi, rootlets, roots, ganglion, and spinal nerve. (CC BY-NC-SA 4.0; "Spinal Cord CrossSection " by Sofia Elizondo via [Spinal Cord](#)).

Figure 2.2.7 is a labeled anatomical diagram showing a cross-section of the spinal cord. It highlights key structures including the posterior funiculus, posterior rootlets, posterior root, posterior root ganglion, spinal nerve, anterior rootlets, anterior root, anterior funiculus, and lateral funiculus. The diagram illustrates the organization of nerve roots and funiculi, essential for understanding spinal cord anatomy.

In cross - section, the gray matter of the spinal cord is subdivided into regions that are referred to as horns:

- Posterior (dorsal) horn: primarily involved in sensory processing. It contains axons of sensory neurons and cell bodies of interneurons. Sensory neuron cell bodies are located in the posterior (dorsal) root ganglion, and their central processes enter the spinal cord via the posterior root.
- Anterior (ventral) horn: contains the cell bodies of somatic motor neurons that control skeletal muscle. These motor neurons are typically multipolar, and their axons exit the spinal cord via the anterior (ventral) root.
- Lateral horn: present in specific spinal cord levels (commonly described in the thoracic and upper lumbar spinal cord). It is associated with the autonomic nervous system and contains cell bodies of autonomic motor neurons that innervate cardiac muscle, smooth muscle, and glands.

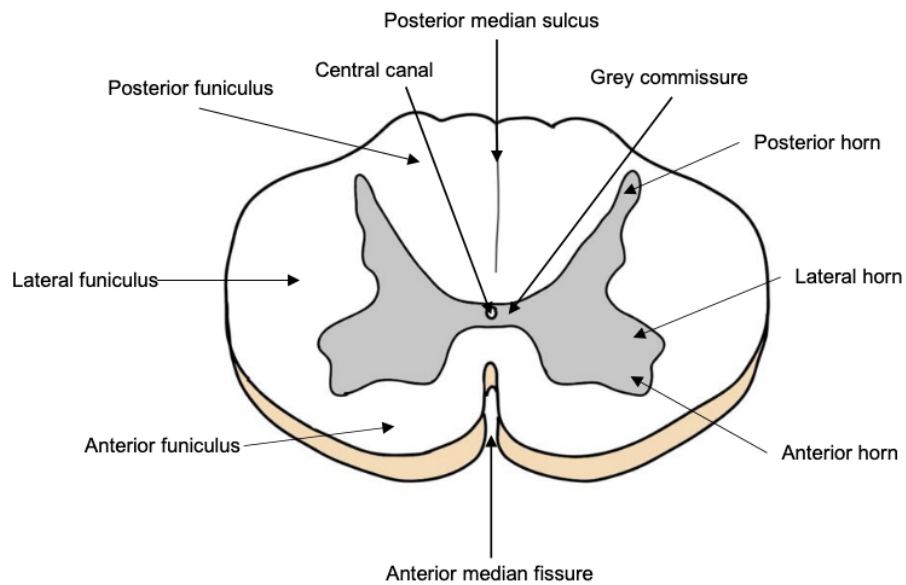


Figure 2.2.8: Cross Sectional Anatomy of the Spinal Cord showing the posterior and anterior median sulcus, posterior , anterior and lateral funiculus; posterior, anterior and lateral horn. The lateral horn is present in the thoracic, inferior lumbar, and sacral regions of the cord. (CC BY-NC-SA 4.0; Spinal Cord and Spinal Nerve Lab).

Figure 2.2.8 shows a cross-section of the spinal cord and labels key landmarks that organize gray matter and white matter.

Midline orientation landmarks

- Posterior median sulcus: a shallow groove on the posterior midline.
- Anterior median fissure: a deeper groove on the anterior midline.

Gray matter (horns and commissure) - Gray matter forms a central region with projections called horns:

- Posterior horn
- Lateral horn (noted as present at specific spinal cord levels, commonly described in thoracic and upper lumbar regions)
- Anterior horn The gray commissure connects the left and right sides of gray matter and surrounds the central canal.

White matter (funiculi) - White matter surrounds the gray matter and is divided into three columns called funiculi:

- Posterior funiculus
- Lateral funiculus
- Anterior funiculus

Functional organization of tracts - White matter tracts within the funiculi include:

- Ascending tracts that carry sensory information toward the brain.
- Descending tracts that carry motor commands from the brain.

The posterior funiculus contains axons primarily associated with ascending pathways. The anterior and lateral funiculi contain multiple groups of axons that may include both ascending and descending tracts.

Spinal Nerves

The term spinal nerve refers to a mixed spinal nerve that carries motor, sensory, and autonomic signals between the spinal cord and the body. The sensory axons enter the spinal cord as the dorsal nerve root. The motor fibers, both somatic and autonomic, emerge as the ventral nerve root.

Thirty-one pairs of spinal nerves extend from the spinal cord and each pair is named for the level of the spinal cord from which each pair emerges: C1 to C8, T1 to T12, L1 to L5, S1 to S5, Co1.

- Eight pairs of cervical nerves designated C1 to C8,

The first nerve, C1, emerges between the first cervical vertebra and the occipital bone. The second nerve, C2, emerges between the first and second cervical vertebrae. The same occurs for C3 to C7, but C8 emerges between the seventh cervical vertebra and the first thoracic vertebra.

- Twelve pairs of 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 designated Co1.

For the thoracic and lumbar nerves, each one emerges between the vertebra that has the same designation and the next vertebra in the column. The sacral nerves emerge from the sacral foramina along the length of that unique vertebra.

Spinal nerves extend outward from the vertebral column to enervate the periphery. The nerves in the periphery are not straight continuations of the spinal nerves, but rather the reorganization of the axons in those nerves to follow different courses. Axons from different spinal nerves will come together into a systemic nerve. This occurs at four places along the length of the vertebral column, each identified as a nerve plexus, whereas the other spinal nerves directly correspond to nerves at their respective levels. In this instance, the word plexus is used to describe networks of nerve fibers with no associated cell bodies.

After exiting the intervertebral foramen, each spinal nerve splits into two branches called rami (ramus for singular) (Figure 2.2.9). On the posterior side, the dorsal ramus is a short nerve that innervates the deep muscle and skin of the back. On the anterior side, the ventral ramus splits into multiple branches that eventually can form nerve plexuses.

The ventral ramus innervates the anterior and lateral portions of the trunk, the upper and the lower limbs. Spinal nerves are also associated with other branches called rami

communicantes which are formed by the gray and white rami and connect the spinal nerve to the autonomic ganglia.

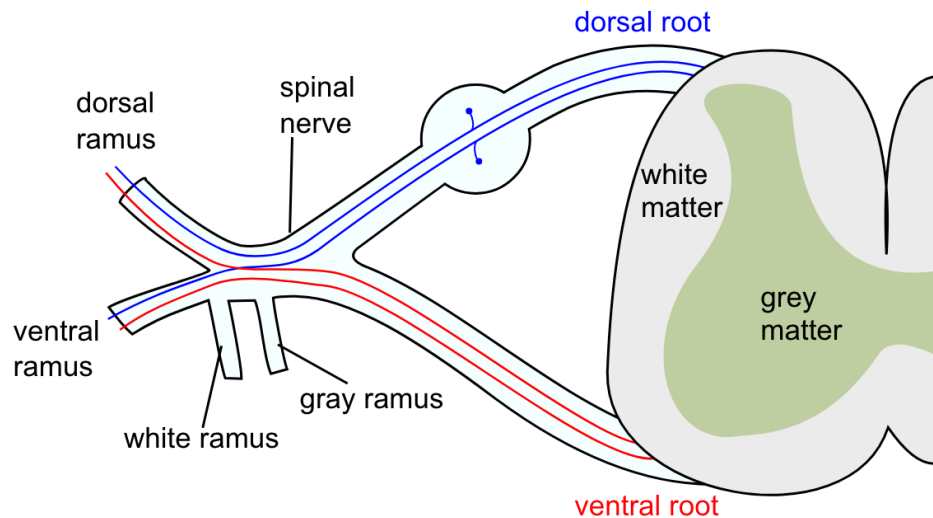


Figure 2.2.9: Spinal Nerve: The ventral and dorsal nerve roots exiting a cross section of spinal cord fuse together to form a spinal nerve, which then splits into the dorsal and ventral rami. The white and gray ramus form the rami communicantes that connect spinal nerves to autonomic ganglia. (CC BY-NC-SA 4.0; Jennifer Kong, Zoe Soon, and Helen Dyck via Pathology).

Figure 2.2.9 is a diagram of a spinal nerve illustrating the anatomy of its components. The ventral (anterior) and dorsal (posterior) nerve roots are shown exiting a cross-section of the spinal cord, where they fuse to form the spinal nerve. This spinal nerve then bifurcates into the dorsal and ventral rami. Additionally, the diagram depicts the white and gray rami that form the rami communicantes, which connect the spinal nerves to the autonomic ganglia, highlighting their role in the nervous system's communication pathways.

Spinal 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 Figure 2.2.9. 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 arms, 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 axons of the ventral rami of spinal nerves T12 through L4 and gives rise to nerves enervating the pelvic region and the anterior leg. 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 leg. The sacral plexus comes from the lower lumbar nerves L4 and L5 and the sacral nerves S1 to S4. The most significant systemic 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.

These plexuses are described as arising from spinal nerves and giving rise to certain systemic nerves, but they contain fibers that serve sensory functions or fibers that serve motor functions. This means that some fibers extend from cutaneous or other peripheral sensory surfaces and send action potentials into the CNS. Those are axons of sensory neurons in the dorsal root ganglia that enter the spinal cord through the dorsal nerve root. Other fibers are the axons of motor neurons of the anterior horn of the spinal cord, which emerge in the ventral nerve root and send action potentials to cause skeletal muscles to contract in their target regions. For example, the radial nerve contains fibers of cutaneous sensation in the arm, as well as motor fibers that move muscles in the arm.

Spinal nerves of the thoracic region, T2 through T11, are not part of the plexuses but rather emerge and give rise to the intercostal nerves found between the ribs, which articulate with the vertebrae surrounding the spinal nerve.

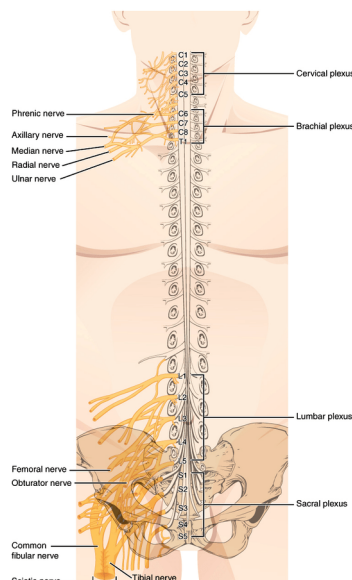


Figure 2.2.10: Nerve Plexuses of the Body: There are four main nerve plexuses in the human body. The cervical plexus supplies nerves to the posterior head and neck, as well as to the diaphragm. The brachial plexus supplies nerves to the arm. The lumbar plexus supplies nerves to the anterior leg. The sacral plexus supplies nerves to the posterior leg. (CC BY-SA 4.0; Lindsay M. Biga, Staci Bronson, Sierra Dawson, Amy Harwell, Robin Hopkins, Joel Kaufmann, Mike LeMaster, Philip Matern, Katie Morrison-Graham, Kristen Oja, Devon Quick, Jon Runyeon, OSU OERU, and OpenStax via [Spinal and Cranial Nerves](#)).

Figure 2.2.10 is a diagram illustrating the four main nerve plexuses of the human body. The cervical plexus is shown supplying nerves to the posterior head, neck, and diaphragm. The brachial plexus is depicted providing nerves to the arm. The lumbar plexus is highlighted as supplying nerves to the anterior leg, while the sacral plexus is illustrated supplying nerves to the posterior leg. This visual representation emphasizes the distribution and function of each plexus in the nervous system.

Reflex Arc and Reflexes

A spinal reflex is a rapid activation of muscle produced by the stimulation of sensory receptors. Spinal reflexes are mediated by nerve cells in the peripheral nervous system (sensory neurons) and the spinal cord (spinal interneurons, cells confined to the spinal cord and motor neurons, the cells that innervate skeletal muscle). Unlike planned, intentional movements, reflexes are involuntary and can be evoked without the involvement of the brain.

The simplest spinal reflex is called the tendon jerk or knee jerk and it is widely used in neurological examinations to examine the integrity of sensory and motor functions of the spinal cord. This spinal reflex is mediated by actions of just two populations of neurons: the primary sensory receptors of a sense organ called the muscle spindle and motor neurons, the cells that activate skeletal muscle fibers.

Reflexes may be spinal or cranial, depending on the nerves and central components that are involved. An innate reflex is an involuntary and nearly instantaneous movement in response to a stimulus; they are designed to help us function properly or protect us from potential injuries. A reflex arc is the neural pathway that mediates a reflex. It consists of the following five components:

- **Receptor:** A nervous system structure that intakes the stimulus (sensory information from the internal or external environment) and “translates” it to electrical language understood by neurons.
- **Sensory (afferent) neuron:** These are typically classified as the neurons responsible for converting various external stimuli that come from the environment into corresponding internal stimuli. They carry the sensory information to the brain or spinal cord.
- **Integration center:** The brain or spinal cord where sensory information is sorted, “understood”, and a decision about responding to the sensory information is made.
- **Motor (efferent) neuron:** A neuron located in the central nervous system that projects its axon outside the CNS and directly or indirectly controls effectors. The motor neuron carries the “do something” information to the effector.
- **Effector:** The muscle or gland that responds (e.g., quadriceps muscle contraction in the patellar reflex) to the motor neuron’s signal.

Reflexes require a minimum of two neurons, a sensory neuron (input) and a motor neuron (output). The sensory neuron detects stimuli and sends a signal towards the CNS. The sensory neuron synapses with a motor neuron, which innervates an effector tissue, such as skeletal muscle in order to pull away from painful stimuli. This type of reflex is a “withdrawal” reflex and is monosynaptic, meaning only one synapse has to be crossed between the sensory neuron and the motor neuron.

This is the simplest reflex arc, and the integrating center is in the spinal cord. Polysynaptic reflexes are more complex, but also more common. They involve interneurons, found in the CNS, which further process stimulus and output information. Beyond simple reflexes with integrating centers in the spinal cord, more complex reflexes have integration centers in the brainstem or even in the cerebrum.

Deep Tendon Reflexes

A deep tendon reflex, or stretch reflex, is elicited by a strong tap to a tendon, such as in the patellar reflex. The muscle associated with the tendon is quickly stretched, resulting in activation of the muscle spindle. The muscle spindle then sends a signal to the spinal cord through the dorsal root. The fiber synapses directly on the motor neuron of the ventral horn. The motor signal travels from the ventral horn to the ventral root of the spinal nerve, activating the muscle, causing contraction.

Characteristics of Deep Tendon Reflexes

- **Monosynaptic:** Only involves one synapse between the sensory and motor neuron.
- **Ipsilateral:** The response occurs on the same side as the stimulus.
- **Fast and Involuntary:** Helps maintain muscle tone and posture.
- **Protective Mechanism:** Prevents muscle overextension or injury.

Common Deep Tendon Reflexes

- **Patellar Reflex (Knee-Jerk Reflex)** – Tests the L2 to L4 spinal segments.
- **Achilles Reflex (Ankle-Jerk Reflex)** – Tests the S1 to S2 spinal segments.

- Biceps Reflex – Tests the C5 to C6 spinal segments.
- Triceps Reflex – Tests the C6 to C7 spinal segments.
- Brachioradialis Reflex – Tests the C5 to C6 spinal segments.

Patellar Reflex (Knee-Jerk Reflex)

Mechanism

- Stimulus: A tap on the patellar tendon (just below the kneecap) with a reflex hammer.
- Receptor: Muscle spindles in the quadriceps femoris detect the stretch.
- Afferent Pathway: The sensory neuron sends a signal to the spinal cord (L2 to L4 segments).
- Integration Center: The signal synapses directly with a motor neuron in the spinal cord (monosynaptic).
- Efferent Pathway: The motor neuron sends an impulse to the quadriceps muscle.
- Response: The quadriceps contracts, extending the leg at the knee.

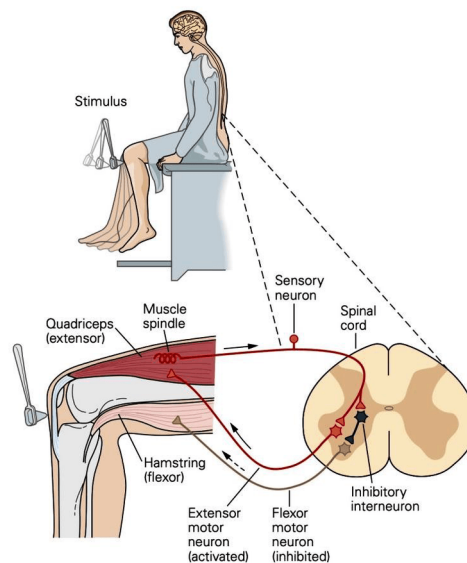


Figure 2.2.11: The knee-jerk reflex is controlled by a simple circuit of sensory and motor neurons. Tapping the kneecap with a reflex hammer pulls on the tendon of the quadriceps femoris, a muscle that extends the lower leg. When the muscle stretches in response to the pull of the tendon, information regarding this change in the muscle is conveyed to the central nervous system by sensory neurons. In the spinal cord the sensory neurons form excitatory synapses with extensor motor neurons that contract the quadriceps, the muscle that was stretched. The sensory neurons act indirectly, through interneurons, to inhibit flexor motor neurons that would otherwise contract the opposing muscle, the hamstring. These actions combine to produce the reflex behavior. In the drawing each extensor and flexor motor neuron represents a population of many cells. (CC BY-SA 4.0; Charles Asbury; Fred Rieke; Bertil Hille; Mark Bothwell; John Tuthill; and Oscar Vivas via [Physiology](#)).

Figure 2.2.11 depicts the knee-jerk reflex pathway, highlighting the simple circuit involving sensory and motor neurons. The diagram shows the process initiated by tapping the kneecap with a reflex hammer, which pulls on the tendon of the quadriceps femoris muscle, causing it to stretch. This stretch triggers sensory neurons to convey information about the muscle's change to the central nervous system. Within the spinal cord, the sensory neurons form excitatory synapses with extensor motor neurons that stimulate the contraction of the quadriceps. Additionally, sensory neurons interact with interneurons to inhibit flexor motor neurons, preventing contraction of the hamstring muscle. The illustration emphasizes the coordinated actions that result in the reflex behavior, with each motor neuron symbolizing a population of many cells involved in the reflex arc.

Clinical Significance

- Normal Response: A quick contraction of the quadriceps, causing leg extension.
- Exaggerated Response (Hyperreflexia): May indicate upper motor neuron lesions (example spinal cord injury, stroke).
- Diminished or Absent Response (Hyporeflexia): May indicate lower motor neuron lesions (example peripheral nerve damage, diabetes-related neuropathy, spinal cord injury at L2 to L4).

Why Is It Important?

- Assesses spinal cord integrity at L2 to L4.
- Helps diagnose neurological disorders affecting sensory or motor function.
- Evaluates muscle tone and nervous system health in routine exams.

2.3: Activity 1

Key Structures of the Spinal Cord (Thoracic and Lumbar Region)

The objective of this lab activity is to identify and understand the key anatomical structures (Conus medullaris, Filum terminale, Spinal nerve, Cauda equina) of the spinal cord in the thoracic and lumbar regions using both detailed image Figure 2.3.1 and a three-dimensional laboratory model. This exercise will enhance students' ability to recognize and describe the anatomy and functions of these spinal cord regions.

Instructions

- Familiarize yourself with the basic anatomy of the spinal cord, focusing on the thoracic and lumbar regions.
- Examine the three-dimensional model of the spinal cord to reinforce your understanding of the spatial relationships between structures.
- Match the labeled parts indicated by letters (A, B, C, D) to the key anatomical features and fill the Table 2.3.1.

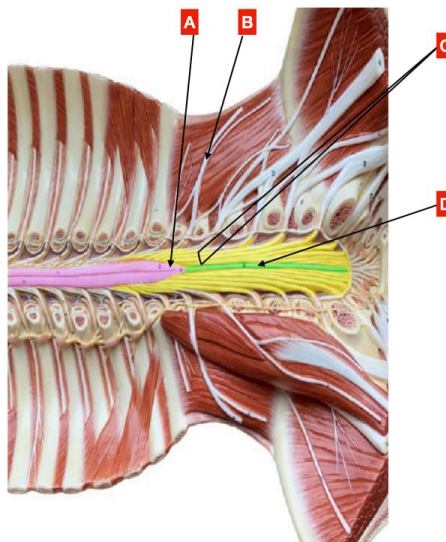


Figure 2.3.1: Anatomical model depicting the human spinal cord with surrounding muscles and nerves. (CC BY-NC-SA 4.0; via [Spinal Cord and Spinal Nerve Lab](#)).

Figure 2.3.1 shows a detailed anatomical model of the spinal column. It includes vertebrae, spinal nerves, and surrounding muscles. This diagram is intended for educational use to illustrate the structure and spatial relationships of spinal components. Model depicts:

- A central, elongated structure representing the spinal cord within the vertebral canal.
- Multiple nerve root fibers emerging from the spinal cord and traveling laterally to form a spinal nerve.
- Surrounding tissues representing the bony canal and nearby soft tissues.

Table 2.3.1: Identify spinal cord anatomy features: conus medullaris, filum terminale, spinal nerve, cauda equina.

Anatomy Features	Identifying Letters
Cauda equina	
Filum terminale	
Spinal nerve	
Conus medullaris	

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2.4: Activity 2

Identification of Key Spinal Cord Structures

The objective of this lab activity is to identify and understand key anatomical structures related to the spinal cord and associated nerves, including the phrenic nerve, cervical enlargement, sympathetic trunk (chain), thoracic nerve, brachial plexus, cervical plexus, sympathetic trunk ganglion, femoral nerve, conus medullaris, sacral plexus, lumbar enlargement, lumbar plexus, and sciatic nerve. Students will use a labeled images Figure 2.4.1, Figure 2.4.2 and a 3D laboratory model to enhance their anatomical understanding. Some of the key structures are shared in the images.

Instructions

- Review the basic anatomy of the cervical and thoracic regions to familiarize yourself with the context of these structures.
- Carefully analyze the colored image provided, noting the numbered structures (1 to 7).
- Observe the 3D model to gain a spatial understanding of each structure's location and orientation.
- Compare the model with the image to visualize how these structures appear in three dimensions.
- Describe Functional Roles of each structure identified.

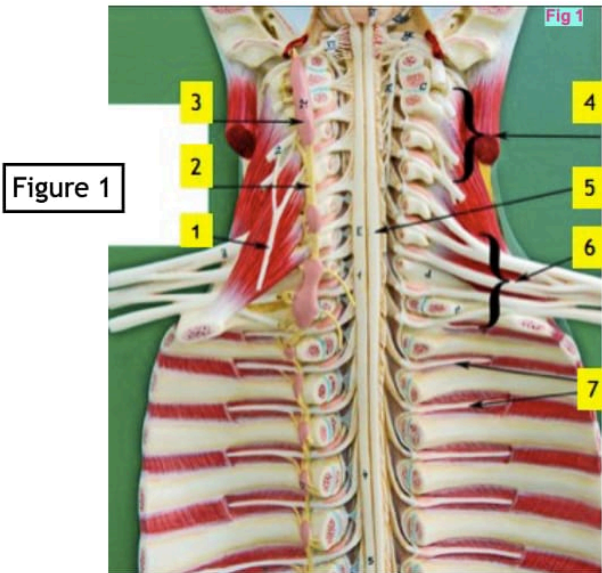


Figure 2.4.1: Anatomical model depicting the human spinal cord with surrounding muscles and nerves. It highlights muscles, bones, and other structures with seven numbered labels (1-7) for identification. (CC BY-NC-SA 4.0; via CUNY Academic Commons).

Figure 2.4.1 shows a posterior (back) view anatomical model of the vertebral column with the spinal cord and spinal nerves. The model includes multiple numbered labels (1 through 7) placed near structures on the left and right sides of the spine. The purpose is to be identification of spinal nerve structures as they exit the vertebral column. Model depicts:

- A central vertical structure representing the spinal cord within the vertebral canal.
- Repeating paired openings along the spine where spinal nerves emerge.
- Multiple nerve branches extending laterally from the spinal cord region into the body.
- Surrounding tissues of the back and trunk shown as layered anatomical structures.

Table 2.4.1: Identifying anatomical features of the spinal cord in the cervical and thoracic regions labeled 1 through 7 in Figure 2.4.1

Number	Key Anatomical features of spinal cord	Describe Functional Role(s)
	Phrenic nerve	
	Cervical enlargement	

Number	Key Anatomical features of spinal cord	Describe Functional Role(s)
	Sympathetic trunk (chain)	
	Thoracic nerve	
	Brachial plexus	
	Cervical plexus	
	Sympathetic trunk ganglion	

Instructions

- Carefully analyze the colored image provided, noting the numbered structures (8 to 15).
- Observe the 3D model to gain a spatial understanding of each structure's location and orientation.
- Compare the model with the image to visualize how these structures appear in three dimensions.
- Describe Functional Roles of each key structure identified.

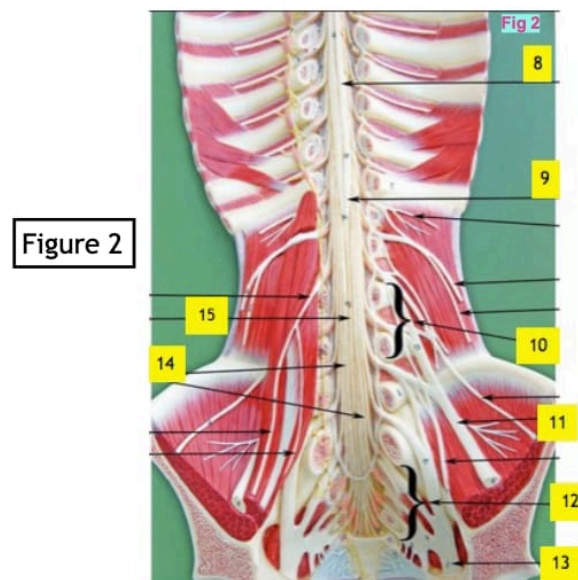


Figure 2.4.2: This image is a labeled anatomical diagram of the human back, highlighting muscles and nerves. It includes eight numbered labels (8 through 15) that correspond to different anatomical structures in the thoracic and upper back region. (CC BY-NC-SA 4.0; via CUNY Academic Commons).

Figure 2.4.2 shows a posterior (back) view anatomical model focused on the lower thoracic to lumbar region of the spine and the spinal nerve pathways extending laterally into the surrounding tissues.

- A central vertical structure representing the spinal cord and/or lower spinal canal region within the vertebral column.
- Multiple paired spinal nerves emerging from the vertebral column and branching outward.
- Surrounding anatomical structures of the posterior trunk, including layered tissues adjacent to the spine.

Table 2.4.2: Identifying Anatomical features of spinal cord 8 through 15.

Number	Identifying Anatomical features of spinal cord	Describe functional role(s)
	Femoral nerve	
	Conus medullaris	
	Sacral plexus	
	Lumbar enlargement	
	Cauda equina	
	Lumbar plexus	
	Filum terminale	
	Sciatic nerve	

2.5: Activity 3

Matching Spinal Cord Structures through Anatomical Descriptions

The objective of this lab activity is to enhance students' understanding of spinal cord anatomy by matching specific spinal cord structures with their corresponding anatomical descriptions. This exercise will help solidify knowledge of the location, structure, and function of key spinal components.

Instructions

- Review available resources and/or class notes on spinal cord anatomy, focusing on key structures and their functions.
- Carefully read each anatomical description provided.
- Match each spinal cord structure with its correct anatomical description based on your understanding and the resources available.

Table 2.5.1: Matching spinal cord structures with their anatomical descriptions.

Match	Structures/ Features	Description of spinal cord features
	Filum terminale	A. Extensions of pia matter that anchor cord laterally.
	Conus medullaris	B. Collection of nerve roots that extends from the lower end of the spinal cord down the spine, resembling a horse's tail.
	Subarachnoid space	C. The distal, conical part of the spinal cord. It typically lies around the level of the first lumbar vertebra (L1) in adults.
	Denticulate ligament	D. A thin, fibrous extension of the spinal cord that extends from the conus medullaris to the coccyx. It acts as a tether, anchoring the spinal cord and providing stability.
	Cauda equina	E. Space within the meninges that contains cerebrospinal fluid (CSF).

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2.6: Activity 4

Identifying Anatomical Features in a Cross Section of the Spinal Cord

The objective of this lab activity is to accurately identify and understand the anatomical features of a spinal cord cross section (Figure 2.6.1), which are marked by letters A through M. This exercise will enhance students' knowledge of spinal cord anatomy and improve their ability to recognize and describe key structures and their functions.

Instructions

- Review resources to familiarize yourself with the general layout and organization of the spinal cord in cross section.
- Examine the cross section carefully, noting the location and orientation of each labeled feature.
- Identify the anatomical structures corresponding to each letter (A through M). Refer to the key provided in the Table 2.6.1.

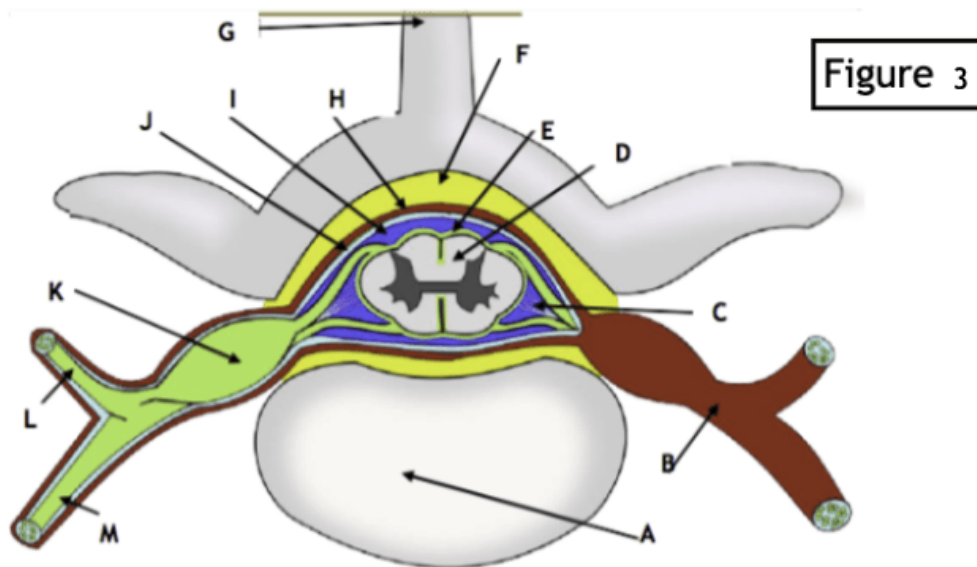


Figure 2.6.1: Cross-sectional diagram of the spinal cord with labeled anatomical structures. Key labels include: vertebral body, spinal nerve, dorsal root ganglion, dorsal and ventral roots, gray and white matter of the spinal cord, pia mater, arachnoid mater, dura mater, epidural space with fat and venous plexus, and vertebral processes (spinous and transverse). The diagram uses color coding to distinguish structures, aiding in understanding spinal anatomy and protective layers. (CC BY-SA 3.0; via [Wikimedia Commons](#)).

Figure 2.6.1 is a simplified cross-sectional diagram through the vertebral canal. It shows the spinal cord in the center, several layered coverings/spaces around it, and a spinal nerve pathway extending laterally and branching.

- Central spinal cord cross-section: A small central structure with a butterfly-shaped gray matter region surrounded by white matter.
- Surrounding layers: Multiple concentric bands around the spinal cord representing protective coverings and spaces within the vertebral canal.
- Lateral nerve pathway: A thick nerve structure extends away from the spinal cord region and then divides into branches.
- Vertebral anatomy context: Large surrounding shapes represent the bony vertebral canal region around the cord.

Table 2.6.1: Letter key for identifying anatomical features of the spinal cord.

Key Anatomical features of spinal cord	Identifying Letters
Arachnoid mater	
Body of vertebral bone	

Key Anatomical features of spinal cord	Identifying Letters
Spinous process of vertebral bone	
Denticulate ligament	
Dorsal root ganglion	
Dorsal ramus	
Dorsal white mater	
Spinal nerve	
Dura mater	
Subarachnoid space	
Ventral ramus	
Pia Mater	
Epidural space	

2.7: Activity 6

Spinal Nerve Plexus and Muscle Actions: Case Study

The objective of this activity is to develop students' critical thinking skills by analyzing case-based scenarios involving the spinal nerve plexus and associated muscle actions. Students will identify the roles of different nerve plexuses, understand their anatomical connections, and relate these to specific muscle functions and movements.

Introduction

The 31 pairs of spinal nerves are bundles of sensory and motor neurons wrapped in connective tissue. Since they carry both sensory and motor signals, the spinal nerves are “mixed” nerves, unlike the cranial nerves which can be sensory, motor or mixed. The sensory axons enter the spinal cord as the dorsal nerve root. The dorsal root ganglion for each nerve is an enlargement of the spinal nerve. The motor fibers, both somatic and autonomic, emerge as the ventral nerve root. A motor signal causes a response, such as signaling a muscle to contract. This signal may initiate from the motor cortex of the cerebrum, then travels down the spinal cord along a vertical tract (or column).

In the thoracic region, the ventral rami of spinal nerves T2-T12 form intercostal nerves that supply the ventral and lateral areas of the chest and superior abdomen. For every other spinal nerve, the axons of the ventral rami combine with those of nearby spinal nerves to form a plexus.

- Cervical plexus - innervates the head and neck, and extends from the cervical region of the spinal column.
- Brachial plexus - innervates the arm, and extends from the cervical region of the spinal column.
- Lumbar plexus - innervates the anterior and medial portions of the thigh and extends from the lumbar region of the spinal column.
- Sacral plexus - innervates the posterior of the thigh, the lower leg and most of the pelvis, and it includes nerves with extends from the lumbar region of the spinal column and from the sacrum.

Context

Understanding the spinal nerve plexus is crucial for comprehending how nerves facilitate muscle actions and movements throughout the body. Each plexus, such as the cervical, brachial, lumbar, and sacral plexuses, serves distinct regions and influences various muscular activities. Through case-based scenarios, students will explore real-world applications of this knowledge, enhancing their ability to diagnose potential nerve injuries and predict functional outcomes.

Instructions

- Review available online and offline resources on the anatomy and function of the spinal nerve plexuses, focusing on their connections to muscles and regions they innervate.
- Activate prior knowledge about skeletal muscles, their actions and innervation (specific prime mover and related plexus). Nerve plexuses are networks of these spinal nerves that redistribute nerve fibers, allowing for more complex muscle innervation patterns. Each muscle receives innervation from specific spinal nerves, and understanding these connections is crucial for diagnosing and treating neurological conditions

Case Study Analysis - link nerve, plexus, and muscle action

- Case 1 Scenario: Alex is unable to flex his elbow after an accident.
 - Question: Which muscle responsible for elbow flexion is likely affected in Alex's case? Identify the spinal nerve and plexus involved in innervating this muscle and discuss how loss of function impacts daily activities.
 - Discuss your findings and reasoning with peers to verify your conclusions.
- Case 2 Scenario: Jamie experiences difficulty in extending the knee, especially when standing up from a seated position.

- Question: What muscle is primarily responsible for knee extension? Identify the corresponding spinal nerve and plexus that innervate this muscle, and explain the significance of this movement in mobility and stability.
- Discuss your findings and reasoning with peers to verify your conclusions.
- Case 3 Scenario: Taylor notices an inability to raise their arm above shoulder height.
 - Question: Which muscle is likely responsible for shoulder abduction? Determine the relevant spinal nerve and plexus, and analyze how this limitation affects Taylor's ability to perform various tasks.
 - Discuss your findings and reasoning with peers to verify your conclusions.
- Case 4 Scenario: Morgan struggles to lift their leg when walking, particularly when trying to step up onto a curb.
 - Question: Identify the muscle responsible for hip flexion that may be impaired in Morgan's case. Discuss the spinal nerve and plexus associated with this muscle and how this loss of action influences ambulation.
 - Discuss your findings and reasoning with peers to verify your conclusions.
- Case 5: Scenario: Casey finds it difficult to lift their foot (dorsiflex) while walking, causing tripping hazards.
 - Question: Which muscle is involved in dorsiflexion of the foot? Identify the associated spinal nerve and plexus, and consider the implications of this impairment on balance and walking.
 - Discuss your findings and reasoning with peers to verify your conclusions.

2.8: Activity 7

Mapping Spinal Nerves and Their Associated Muscles

The objective of this lab activity is to map the spinal nerves and their corresponding muscle groups, enhancing students' understanding of how these nerves contribute to muscle innervation and movement. By identifying relationships between specific spinal nerves and muscle actions, students will gain a comprehensive understanding of the neuromuscular system.

Instructions

- Review resources to activate prior knowledge on spinal nerves and their anatomical pathways to innervate major muscle groups innervated by each spinal nerve.
- Examine the diagrams, focusing on the pathways of spinal nerves from the cervical, thoracic, lumbar, and sacral regions.
- Pick up the full body spinal cord model and identify the spinal nerves indicated in the figures. For each identified spinal nerve, relate to the nerve plexus and list one or two skeletal muscles that it innervates.
- Verify your mappings and descriptions with peers or reference materials to ensure accuracy.
- Discuss any discrepancies or uncertainties with your instructor or classmates for clarification.
- Use Figure 2.8.1 to complete the Tables 2.8.1 and 2.8.2 by matching each label (letter) to the correct structure name.

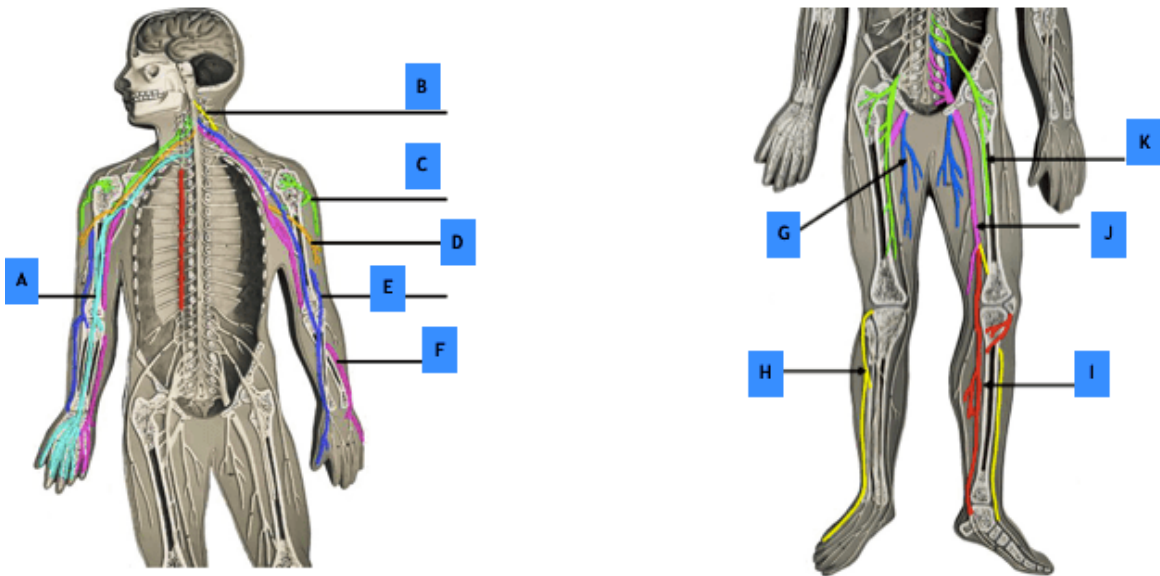


Figure 2.8.1: Upper Limb Spinal Nerves and Lower Limb Spinal Nerves. Image contains two anatomical diagrams showing nerve pathways in the human body. The left diagram focuses on the upper body and the right diagram shows the lower body. (CC BY-NC-SA 4.0; Gillian Backus; Heidi W. Wangerin; and Paula Rodgers via [Spinal Cord and Spinal Nerve Lab](#)).

Figure 2.8.1 contains two anatomical diagrams used for a labeling activity on the peripheral nervous system. Layout of the figure:

- Left diagram: Upper body view showing nerves of the neck, shoulder, arm, and hand.
- Right diagram: Lower body view focused on nerves of the pelvis, thigh, leg, and foot.

Table 2.8.1: *Spinal Nerve Identification, Associated Plexus, and Innervated Muscles of the Upper Limb (image on the left in Figure 2.8.1).*

Identifying Letters	Upper Limb Spinal nerves ID	Nerve plexus name and segments	Major Skeletal muscle(s) innervated
A			
B			

Identifying Letters	Upper Limb Spinal nerves ID	Nerve plexus name and segments	Major Skeletal muscle(s) innervated
C			
D			
E			
F			

Table 2.8.2: Spinal Nerve Identification, Associated Plexus, and Innervated Muscles of the Lower Limb (image on the right in Figure 2.8.1).

Identifying Letters	Upper Limb Spinal nerves ID	Nerve plexus name and segments	Major Skeletal muscle(s) innervated
G			
H			
I			
J			
K			

2.9: Activity 8

Exploring Spinal Reflexes

The objective of this lab activity is to understand the physiological mechanisms behind the spinal reflexes, with a focus on the patellar reflex, Achilles reflex and plantar reflex.

The spinal reflex is a fundamental neural mechanism that allows for quick responses to stimuli without the need for conscious thought. These reflexes play a critical role in maintaining posture, protecting the body from harm, and facilitating coordinated movements. In this lab, you will investigate various spinal reflexes, understand their pathways, and observe their physiological significance.

An absent or diminished patellar tendon reflex may be due to PNS pathology affecting either the afferent sensory neurons or the efferent motor neurons. If the reflex is absent or diminished combined with sensory loss, the lesion is likely in the afferent sensory nerves.

Conducting the patellar reflex - a somatic reflex

- Begin by familiarizing yourself with the components of a reflex arc.
- Pick up a reflex hammer from the supply cart.
- Have your lab partner sit on a high stool and rest their legs with their knees bent. The feet should not touch the floor. Ensure their knee is relaxed and slightly bent.
- Locate the patellar tendon (anatomically patellar ligament) about one inch below the bottom of the patella (knee cap).
- This is where you will apply the stimulus.
- Using the blunt reflex hammer, lightly but firmly tap the patellar ligament. Use the subjective grading system provided below to record the results in the Table 2.9.1.
 - 0 (absent): No visible or palpable quadriceps contraction; no lower-leg movement.
 - 1+ (diminished/trace): Minimal quadriceps twitch; slight or no leg movement. Hyporeflexia is generally associated with a lower motor neuron deficit. Example - Guillain-Barré syndrome.
 - 2+ (normal): Clear quadriceps contraction with knee extension; consistent and symmetric with the other side.
 - 3+ (brisk, super-normal): Larger-than-expected response; obvious kick. Hyperreflexia is often attributed to upper motor neuron lesions eg Multiple sclerosis.
 - 4+ (hyperactive with clonus): Repetitive, rhythmic beats after a single stimulation(tap).

Observation of a hyperactive patellar tendon reflex, on the other hand, generally suggests pathology to the CNS above the L2-L4 spinal cord level, where the patellar tendon reflex is mediated.

- Recorded as sustained clonus when last for several seconds or non - sustained clonus when occur immediately after the stimulus but stop quickly.

Table 2.9.1: Patellar Reflex Test Results for Left and Right Legs

Side	Movement Observed (Yes / No)	Grading (0 to 4+)
Left		
Right		

Post-Lab Activity

1. Name the receptor and the effector in the patellar reflex.
2. Explain why the reflex above is called an “ipsilateral reflex”.

Achilles Reflex Test: (spinal reflex that tests the integrity of spinal nerves L5—S2)

The Achilles (ankle jerk) reflex is a classic deep tendon reflex mediated primarily by the S1 nerve root via the tibial nerve. Tapping the Achilles tendon produces rapid plantar flexion by activating the gastrocnemius-soleus complex.

1. Position The Subject:
 - Seated: legs dangling with knees flexed 90°, ankles free.
 - Prone or supine: foot over edge of table with ankle free.
2. The foot should be visible and the leg must be free of restrictive clothing (i.e., a tightly rolled up pant leg). Expose the posterior ankle and heel; remove shoes/socks.
3. Support the forefoot with your non-dominant hand.
 - Gently bring the ankle into slight dorsiflexion (about a right angle) to preload the tendon.
 - Identify the Achilles tendon just proximal to its insertion on the calcaneus.
4. Hold the reflex hammer by the handle. Allow the reflex hammer to swing loosely between your thumb and forefinger through a 45 to 60 degree arc, while making certain the hammer moves in a horizontal plane (i.e., the broad end of the reflex hammer is perpendicular to the tendon).
5. Deliver a brisk, controlled tap just above the calcaneus at the level of the medial and lateral malleoli.
6. Deliver a brisk, controlled tap to the mid-portion of the Achilles tendon.
7. Observe and feel for plantar flexion at the ankle and contraction of the calf.

Use the subjective grading system (which is beginner-friendly) provided below to record the results in the Table 2.9.2.

- 0: absent
- 1+: diminished/trace (often only with reinforcement)
- 2+: normal
- 3+: brisk (no clonus)
- 4+: hyperactive with clonus

Table 2.9.2: Achilles Reflex Test Results for Left and Right Legs

Side	Movement Observed (Yes / No)	Grading (0 to 4+)
Left		
Right		

Plantar Reflex Test (spinal reflex that tests the corticospinal tracts of the spinal cord)

The Plantar Reflex is often used to test the integrity of the corticospinal tracts of the spinal cord which carry motor impulses to skeletal muscles. A normal response is curling DOWN of the toes (negative Babinski sign). An abnormal response is dorsiflexion of the big toe and flaring of the other four toes (positive Babinski sign). The presence of the Babinski sign is always abnormal in adults, possibly indicating upper motor neuron lesions such as corticospinal tract damage, multiple sclerosis or amyotrophic lateral sclerosis (Lou Gehrig's disease). It is normal in infants under 1 year of age.

Read the directions below and perform plantar reflex.

Directions:

1. Position The Subject:
 - Have the subject remove shoes and socks. Have the subject sit on a table or chair and lift the foot so that you are holding the weight of the leg.
2. Gently, but with firm pressure, use the handle side of the reflex hammer (the blunt side very near the metal tip of the reflex hammer) to begin.
3. Start on the sole of the foot beginning with the heel, slowly moving up to under the pinky toe, then arcing medially from under the pinky toe to end under the big toe in one slow, continuous maneuver (it should take about 5-6 seconds to complete this procedure).
4. Palpate and visually observe the response to the provided stimulus.

5. Document your observations (normal, hyporeactive, hyperreactive, anything interesting or odd). This should include whether the subject showed a positive or negative Babinski's sign.
6. Table 2.9.3 provides options to select from for the responses observed.

Table 2.9.3: Toe Response Assessment for Right and Left Feet

Foot	Great Toe Response	Other Toes
Right	up (extension) or down (flexion) or none	fan or flex or none
Left	up (extension) or down (flexion) or none	fan or flex or none

Key Terms and Definitions

- **Arachnoid Mater** – The middle membrane surrounding the spinal cord.
- **Autonomic Nervous System** – Controls involuntary bodily functions and regulates visceral activities.
- **Cauda Equina** – A bundle of spinal nerves at the end of the spinal cord.
- **Central Canal** – A small channel in the center of the gray matter, filled with cerebrospinal fluid.
- **Cerebrospinal Fluid (CSF)** – Clear fluid in the subarachnoid space that cushions and nourishes the brain and spinal cord.
- **Cervical Segments** – The first 8 segments of the spinal cord.
- **Coccygeal Segment** – The lowest segment of the spinal cord.
- **Dorsal Horn** – The posterior section of gray matter, processes sensory information.
- **Dorsal Root** – The sensory root of a spinal nerve, carrying information to the spinal cord.
- **Dura Mater** – The outermost membrane surrounding the spinal cord.
- **Gray Matter** – Contains neuron cell bodies, dendrites, and unmyelinated axons.
- **Homeostasis** – The process of maintaining stable internal conditions in the body.
- **Interneuron** – Connects sensory and motor neurons within the CNS.
- **Intervertebral Foramen** – Openings between vertebrae through which spinal nerves exit.
- **Lateral Horn** – Side projections of gray matter in thoracic and upper lumbar regions.
- **Lumbar Segments** – The next 5 segments of the spinal cord after thoracic.
- **Meninges** – The three protective membranes: dura mater, arachnoid mater, and pia mater.
- **Motor Neurons** – Transmit signals from the CNS to muscles and glands.
- **Pia Mater** – The innermost membrane surrounding the spinal cord.
- **Plexus** – A network of intersecting nerves (e.g., cervical, brachial, lumbar, sacral).
- **Posterior Median Sulcus** – A groove on the dorsal side of the spinal cord.
- **Reflex** – An involuntary and nearly instantaneous response to a stimulus.
- **Reflex Arc** – The neural pathway that mediates a reflex action.
- **Rootlets** – Small bundles of nerve fibers that form a spinal nerve.
- **Sacral Segments** – The 5 segments of the spinal cord after lumbar.
- **Sensory Neurons** – Carry signals from sensory receptors to the CNS.
- **Somatic Nervous System** – Responsible for voluntary movements and sensory information.
- **Spinal Cord** – Cylindrical structure of nervous tissue transmitting signals between brain and body.
- **Spinal Nerves** – Mixed nerves that carry sensory and motor information.
- **Spinal Cord Segments** – The 31 segments corresponding to spinal nerve pairs.
- **Thoracic Segments** – The 12 segments of the spinal cord after cervical.
- **Ventral Horn** – The anterior section of gray matter, contains motor neurons.
- **Ventral Root** – The motor root of a spinal nerve, carrying commands to muscles.
- **Vertebral Column** – Bony structure made of vertebrae that protects the spinal cord.
- **White Matter** – Composed of myelinated axons, carries signals up and down the spinal cord.

3: BRAIN STRUCTURE AND FUNCTION- EXPLORING WITH DISSECTION AND CRANIAL NERVES

Introduction

In this lab, we will be learning about the brain, a complex system, possessing more than a trillion cells many of which have more than a thousand connections. Students identify the various parts of the brain such as the lobes, cerebral and cerebellar hemispheres, ventricles, lobes, and more to establish structure-function relationships. Students will learn from images, laboratory models, dissection videos and to gain hands-on experience may dissect a sheep or pig brain to see internal structures, such as the corpus callosum, which connects the left and right hemispheres.

Learning Objectives

- Describe brain orientation applying the directional terms and plane.
- Identify and describe the layers of meningeal tissue that cover the brain on both an image and laboratory models and their function.
- Identify and describe the function(s) of parts of the brain on both an image and brain regions, cerebral and cerebellar lobes, and functional areas; brainstem subdivisions (medulla oblongata, pons and midbrain), and relating to functions and predict clinical outcome in case of damage.
- Describe the ventricular system of the brain by tracing the flow of cerebrospinal fluid (CSF) through the brain from its origin in the choroid plexus to where it collects in the superior sagittal sinus.
- Identify the 12 pairs of cranial nerves by name and number and their basic functions, and categorize each cranial nerve as sensory, motor, or both (mixed).
- Perform dissection of mammalian (sheep) brain paying close attention to the similarities and differences in structure with human brain.

3.1: Background Information

3.2: Terminology Checklist

3.3: Activity 1

3.4: Activity 2

3.5: Activity 3

3.6: Activity 4

3.7: Activity 5

3.8: Activity 6

3.9: Activity 7

3.10: Activity 8

3.11: Activity 9

3.12: Glossary

This page titled [3: Brain Structure and Function- Exploring with Dissection and Cranial Nerves](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by Lakshmikanta Sengupta and Susmita Sengupta.

3.1: Background Information

Overview

The adult brain is described in terms of four major regions: the cerebrum, the diencephalon, the brainstem, and the cerebellum. A person's conscious experiences are based on neural activity in the brain. The regulation of homeostasis is governed by a specialized region in the brain.

The brain is housed within the protective hard skull, layers of meninges, and cerebrospinal fluid. The adult brain weighs approximately 1200 grams to 1400 grams. The brain uses 20% oxygen and 25% glucose in our bodies. The brain is not fully developed until 16 to 17 years old with dramatic changes in the front lobes occurring through puberty. The human brain is extremely complex. It has to simultaneously deal with such diverse functions as emotions, receiving input from peripheral sensors, sending output to muscle and glands, memory, reasoning, coordinating movement, and others. Many of the brain's functions, in fact most of them, are concerned with the routine things we do every day without being aware of them: breathing, digesting food, regulating blood pressure, maintaining body temperature, coordinating eyeball movements. Others, such as hunger, thirst, or emotions, we are aware of but have little control over. Obviously, these are just as important as the functions which we have control over such as voluntary movement. Different functions are housed in specific regions of the brain which we will identify in this lab exercise, but you will find that few of these regions can be sharply differentiated from surrounding areas. Because the brain must integrate all of its various functions, there are many areas where two or more functions overlap.

Video

Context: This video introduces directional terms such as anterior, posterior, inferior, and superior in relation to both the cerebral hemispheres and brainstem. It also explains how terms like rostral, caudal, dorsal, and ventral vary depending on anatomical context. Using gross brain specimens, the video demonstrates sections in the frontal, axial, and sagittal planes, highlighting key features including the ventricular system.

Video Length: 8 minutes and 8 seconds

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

[View this YouTube Video online](#)



The Cells of the Brain

The primary cells of the brain are neurons which transmit electrical signals, and glial cells which support and nourish the neurons, with key types including astrocytes, microglia, oligodendrocytes, and ependymal cells; all playing crucial roles in brain function.

A brain tumor is a growth of abnormal cells in the brain. When a person is diagnosed with a brain tumor, known as an intracranial tumor, a biopsy may be done, in which tissue is removed from the tumor for identification purposes by a pathologist. Primary tumors are categorized as glial (composed of glial cells) or non-glial (developed on or in the structures of the brain, including nerves, blood vessels and glands) and benign or malignant. Brain tumors are dangerous because they can put pressure on healthy parts of the brain or spread into those areas. Metastatic brain tumors include tumors that arise elsewhere in the body (such as the breast or lungs) and migrate to the brain, usually through the bloodstream. Metastatic tumors are considered cancer and are malignant.

Protective Coverings of the Brain

The brain is protected by multiple structures. First, the bones of the skull enclose and house the brain. Underneath the skeletal

structures, the brain is protected by membranes made by connective tissue, called meninges as illustrated in Figure 3.1.1. In addition, the brain has a privileged blood supply, as suggested by the blood-brain barrier. The function of the tissue is crucial to the survival of the organism, so the contents of the blood cannot simply pass into the central nervous tissue. Between the skull and brain is the meninges, which consist of three layers of tissue. They are:

- **Dura Mater:** In the brain, the dura mater is made up of two layers of connective tissue. The periosteal layer, which is closest to the skull, and the meningeal layer, which is closest to the brain. The two layers are usually fused, but they separate in some areas to form dural sinuses. The two special folds of the dura in the brain are called the falx and the tentorium. The falx separates the right and left half of the brain and the tentorium separates the upper and lower parts of the brain.
- **Arachnoid mater:** The second layer of the meninges is the arachnoid. This membrane is avascular, thin and delicate and covers the entire brain and is involved in cerebrospinal fluid (CSF) metabolism via the subarachnoid space. Cerebrospinal fluid cushions and protects your brain and spinal cord. There is a space between the dura and the arachnoid membranes that is called the subdural space.
- **Pia Mater:** The layer of meninges closest to the surface of the brain is called the pia mater. The pia mater has many blood vessels that reach deep into the surface of the brain. The pia mater, which covers the entire surface of the brain, follows the folds of the brain. The major arteries supplying the brain provide the pia with its blood vessels.

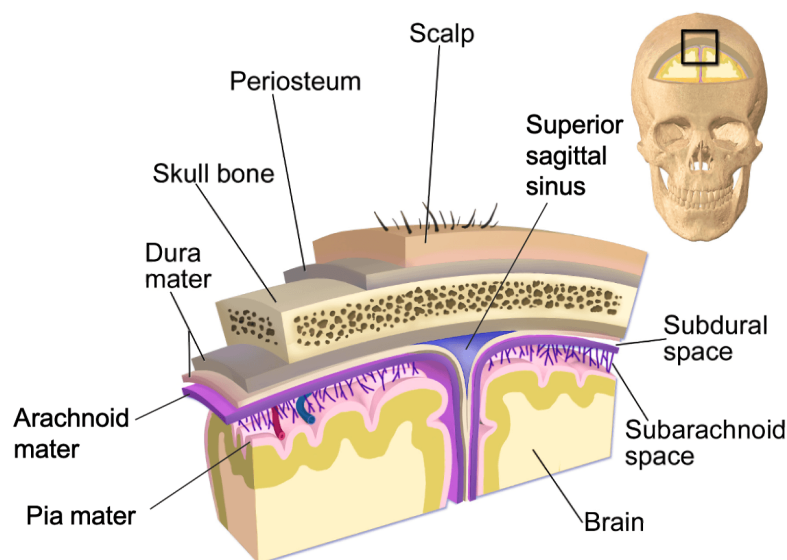


Figure 3.1.1: Superficially, the skin of the scalp and bones of the skull create the first layer of protection. (CC BY 4.0; Cranial meninges by Chiara Mazzasette via [Wikimedia Commons](#)).

Figure 3.1.1 is a labeled cross-sectional diagram of the human head that shows the protective layers surrounding the brain. From outermost to innermost, the layers include the scalp, periosteum, skull, dura mater, arachnoid mater, and pia mater. The diagram also identifies important spaces and structures associated with these layers, including the subarachnoid space, the superior sagittal sinus, and the brain tissue beneath the meninges.

Within this system, the cerebral vasculature includes blood vessels and dural venous sinuses that support blood circulation. Cerebrospinal fluid (CSF) circulates through the subarachnoid space and the ventricular system. The pia mater closely covers the surface of the brain. Together, the circulation of blood and CSF helps deliver nutrients, remove waste, and maintain the stable internal conditions needed for normal brain function. These layers also help protect the brain by providing both a physical barrier and shock absorption.

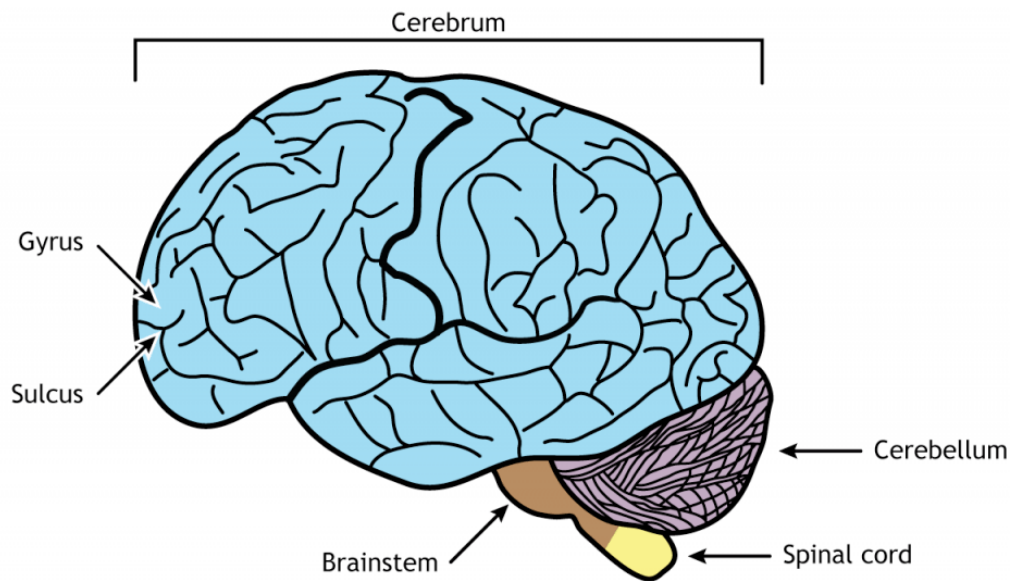


Figure 3.1.2: An external, side view of the parts of the brain. The cerebrum, the largest part of the brain, is organized into folds called gyri and grooves called sulci. The cerebellum sits behind (posterior) and below (inferior) the cerebrum. The brainstem connects the brain with the spinal cord and exits from the ventral side of the brain. (CC BY-NC-SA 4.0; Casey Henly via [Foundations of Neuroscience](#)).

Figure 3.1.2 shows a lateral (side) view of the brain with major structures labeled.

- Cerebrum: the largest region, occupying the superior and anterior portions of the brain. Its surface is highly folded.
 - Gyrus: a raised ridge (fold) on the cerebrum.
 - Sulcus: a groove between gyri.
- Cerebellum: located posterior and inferior to the cerebrum; smaller and densely folded.
- Brainstem: located inferior to the cerebrum and anterior to the cerebellum; connects the brain to the spinal cord.
- Spinal cord: extends inferiorly from the brainstem.

Cerebrum

The cerebrum is the largest part of the brain and is split into two hemispheres: the right and left. People often use "cerebrum" to refer to the whole brain. The longitudinal median fissure separates these two halves. The corpus callosum, connects the two hemispheres and allows them to communicate by passing messages between each side.

The surface of the cerebrum is covered with billions of nerve cells and support cells, which together make up the cerebral cortex. This part of the brain is grayish-brown and is known as "gray matter." The surface looks wrinkled because of its many small grooves (sulci), larger grooves (fissures), and raised areas between the grooves (gyri). Underneath the cerebral cortex, there are connecting fibers that form a white area known as "white matter."

The cerebral hemispheres feature several noticeable grooves. By identifying these landmarks, we can divide the brain into broad areas called "lobes." Each hemisphere includes a frontal lobe, temporal lobe, parietal lobe, occipital lobe, and insular lobe. These lobes work together in complex ways to perform various functions.

Frontal Lobes

These are the largest of the four lobes responsible for functions including motor skills such as voluntary movement, speech, intellectual and behavioral functions. The areas that produce movement in parts of the body are found in the primary motor cortex or precentral gyrus. The prefrontal cortex plays an important part in memory, intelligence, concentration, temper and personality. The premotor cortex guides eye and head movements and a person's sense of orientation. Broca's speech area, important in language production, is found in the frontal lobe, usually on the left side.

Occipital Lobes

Occipital lobes are located at the back of the brain and enable humans to receive and process visual information. They influence how humans process colors and shapes.

Parietal lobes

Parietal lobes are located near the back and top of the head. They are important for processing and interpreting somatosensory input. For example, they inform us about objects in our external environment through touch (i.e., physical contact with skin) and about the position and movement of our body parts (proprioception). A person's memory, and the new sensory information received, give meaning to objects.

Temporal lobes

Temporal lobes are located on each side of the brain at about ear level that processes sensory information, including auditory and visual stimuli, and is associated with memory (of events or facts), language (understanding the meaning of words and objects), and emotions like fear and anxiety).

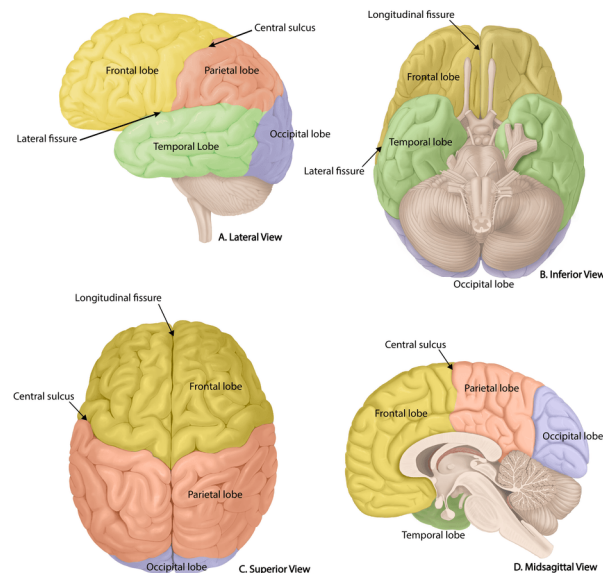


Figure 3.1.3: Lobes of the Cerebral Cortex . The cerebral cortex is divided into four lobes by the major sulci. The central sulcus separates the frontal and parietal lobes. The parieto-occipital sulcus separates the parietal and occipital lobes. The lateral sulcus separated the temporal and parietal lobes. Each lobe corresponds to specific functions of the cerebral cortex. (CC BY-NC-SA 4.0; Justin Greene and Jennifer Lange via [Brain - Cerebrum](#)).

Figure 3.1.3 is divided into four panels, each showing the brain with the major lobes and key grooves (sulci/fissures) labeled.

Panel A - Lateral (side) view: This panel shows the outer surface of the brain from the side.

- The frontal lobe is at the front (anterior).
- The parietal lobe is behind the frontal lobe.
- The temporal lobe is on the lower side.
- The occipital lobe is at the back (posterior).
- The central sulcus separates the frontal and parietal lobes.
- The lateral fissure separates the temporal lobe from the lobes above it.

Panel B - Inferior (bottom) view: This panel shows the underside of the brain.

- The frontal lobes are toward the front (anterior) of the view.
- The temporal lobes appear on both sides.
- The occipital lobe is toward the back (posterior).

- The longitudinal fissure runs along the midline, dividing the brain into left and right halves.

Panel C - Superior (top) view: This panel shows the top of the brain.

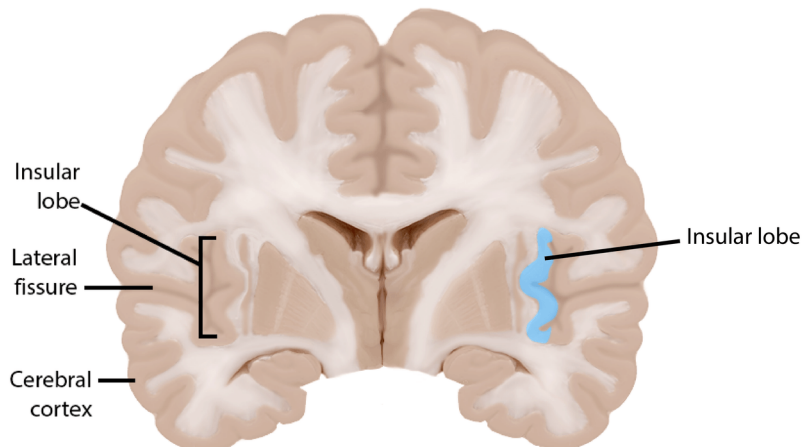
- The longitudinal fissure runs along the midline, dividing left and right hemispheres.
- The frontal lobes occupy the front (anterior) portion.
- The parietal lobes lie behind the frontal lobes.
- The occipital lobe is at the back (posterior).
- The central sulcus marks the boundary between the frontal and parietal lobes.

Panel D - Midsagittal (inner side) view: This panel shows a cut-away view of the inside of one hemisphere.

- The frontal lobe is anterior, followed by the parietal lobe.
- The temporal lobe appears lower and more internal.
- The occipital lobe is posterior.
- Additional internal brain structures and the cerebellum are visible beneath the lobes.

Insular Lobes

Insular lobes, also known as the insular cortex, are involved in processing many autonomic inputs, pain perception. It is a hidden structure located deep in the brain's lateral sulcus, or Sylvian fissure, and is only about 2% of the brain's cortical surface area.



Coronal section

Figure 3.1.4: Insular Lobe. The insula is one of the five lobes of the cerebral cortex and is located deep in the lateral fissure, between the parietal and temporal lobes. (CC BY-NC-SA 4.0; Justin Greene and Jennifer Lange via [Brain - Cerebrum](#)).

Figure 3.1.4 illustrates coronal section of the human brain highlighting the insular lobe, shaded in blue on one side and located deep within the lateral fissure. Labeled structures include:

- **Insular Lobe:** A region involved in sensory processing, emotion, and homeostasis.
- **Lateral Fissure:** The deep groove separating the frontal and parietal lobes from the temporal lobe.
- **Cerebral Cortex:** The outer layer of the brain responsible for higher cognitive functions.

Functional Areas of the Brain

In a general way, the cerebral cortex is divided into sensory, motor, and association areas. The sensory areas interpret sensory impulses, the motor areas control muscular movement, and the association areas are concerned with emotional and intellectual processes. The primary sensory (somesthetic) area is located directly posterior to the central sulcus of the cerebrum in the postcentral gyrus of the parietal lobe, it extends from the longitudinal fissure on the top of the cerebrum to the lateral cerebral sulcus as illustrated in Figure 3.1.5.

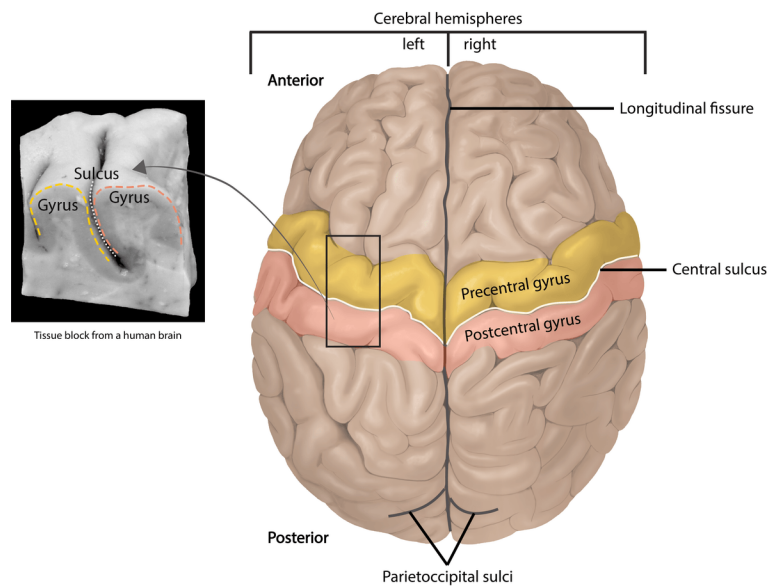


Figure 3.1.5: Superior View of the Brain. The cerebrum is medially divided by the longitudinal fissure into left and right hemispheres. The central sulcus is visible cutting the cerebrum in a coronal section. The gyrus anterior to the central sulcus is called precentral gyrus, while the posterior one is the postcentral gyrus. (CC BY-NC-SA 4.0; Justin Greene and Jennifer Lange via [Brain - Cerebrum](#)).

Figure 3.1.5 is a labeled diagram of the human brain. It highlights the following structures:

- **Cerebral Hemispheres:** The left and right halves of the brain.
- **Longitudinal Fissure:** The deep groove separating the cerebral hemispheres.
- **Central Sulcus:** A prominent groove dividing the frontal and parietal lobes.
- **Precentral Gyrus:** Located anterior to the central sulcus. The primary motor cortex, responsible for voluntary movement.
- **Postcentral Gyrus:** Located posterior to the central sulcus. The primary somatosensory cortex, responsible for processing sensory input.
- **Parietoccipital Sulci:** A small horizontal region at the posterior of the cerebrum that spans both hemispheres.

An inset photo of a tissue block from a human brain shows how the groove of the central sulcus is deeper than the grooves between gyri.

The primary sensory area receives sensations from cutaneous, muscular, and visceral receptors in various parts of the body. Each point of the area receives sensations from specific parts of the body. The size of the portion of the sensory area receiving stimuli from body parts is not dependent on the size of the part but on the number of receptors the part contains. For example, a larger portion of the sensory area receives impulses from the lips than from the thorax.

Sensory Areas

- **Primary visual area** - Located on the medial surface of the occipital lobe and occasionally extends around to the lateral surface. It receives sensory impulses from the eyes and interprets shape, color, and movement.
- **Visual association area** - Located in the occipital lobe. It receives sensory impulses from the primary visual area and the thalamus. It relates present to past visual experiences with recognition and evaluation of what is seen.
- **Primary auditory area** - Located in the superior part of the temporal lobe near the lateral cerebral sulcus. It interprets the basic characteristic of sound such as pitch and rhythm.
- **Auditory association area** - Inferior to the primary auditory area in the temporal cortex. It determine if a sound is speech, music, or noise. It also interprets the meaning of speech by translating words into thoughts.
- **Primary gustatory area** - Located at the base of the postcentral gyrus above the lateral cerebral sulcus in the parietal cortex. It interprets sensations related to taste.
- **Primary olfactory area** - Located in the temporal lobe on the medial aspect. It interprets sensations related to smell.
- **Gnostic area (Gnosis means knowledge)** - This common integrative area is located among the sensory, visual, and auditory association areas. It receives nerve impulses from these areas so that a common thought can be formed from the various sensory inputs. It then transmits signals to other parts of the brain to cause the appropriate response to the sensory signal.

Motor Areas

The primary motor area is located in the precentral gyrus of the frontal lobe. Like the primary sensory area, the primary motor area consists of regions that control specific muscles or groups of muscles. Stimulation of a specific point of the primary motor area results in a muscular contraction, usually on the opposite side of the body as illustrated in Figure 3.1.6.

The premotor area is anterior to the primary. It is concerned with learned motor activities of complex and sequential nature. For example, writing. Thus, the premotor area controls skilled movements. The frontal eye field area in the frontal cortex is sometimes included in the premotor area. This area controls voluntary scanning movements of the eye. Searching for a word in a dictionary, for instance.

The language areas are also significant parts of the motor cortex. The translation of speech or written words into thoughts involves sensory areas (primary auditory, auditory association, primary visual, visual association, and Gnostic). The translation of thoughts into speech involves the motor speech area, located in the frontal lobe just superior to the lateral cerebral sulcus. From this area, a sequence of nerve impulses is sent to the premotor region that controls the muscle of the larynx, pharynx, and mouth. The nerve impulses from the premotor area to the muscle result in specific, coordinated contractions that enable you to speak.

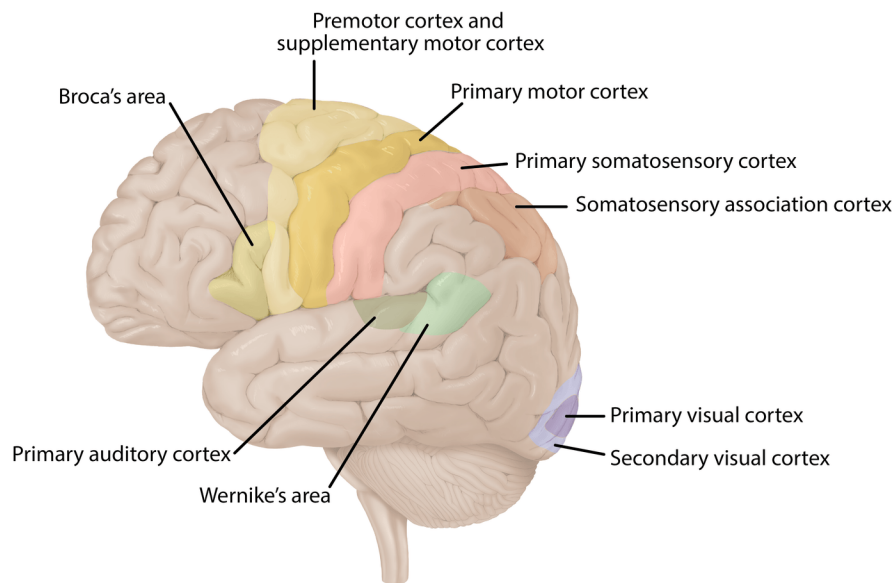


Figure 3.1.6: Functional Cortical Areas. The functions of the cerebral cortex are localized within their respective lobes. Although the exact boundaries can vary from person to person, their general area and their relative positions remain the same. (CC BY-NC-SA 4.0; Justin Greene and Jennifer Lange via [Brain - Cerebrum](#)).

Figure 3.1.6 is a labeled diagram of the human brain highlighting major cortical regions. The labeled areas include:

- **Broca's Area:** Typically located in the posterior part of the inferior frontal gyrus, associated with speech production and language processing.
- **Premotor and Supplementary Motor Cortex:** Located above Broca's area and anterior to the primary motor cortex. Involved in planning and coordinating movement.
- **Primary Motor Cortex:** Located in the frontal lobe, this area is responsible for the execution of voluntary muscle movements.
- **Primary Somatosensory Cortex:** Situated in the parietal lobe, this cortex processes sensory input from the body, such as touch, pressure, temperature, and pain.
- **Somatosensory Association Cortex:** integrates sensory information from the primary somatosensory cortex. Located posterior to the primary somatosensory cortex, it integrates sensory information from that region.
- **Primary Auditory Cortex:** Found in the temporal lobe, this cortex is responsible for processing sound information.
- **Wernicke's Area:** Located in the left temporal lobe for most people, this area is crucial for language comprehension. It helps in understanding spoken and written language, allowing us to make sense of words and sentences.
- **Primary Visual Cortex:** Situated in the occipital lobe, this area processes visual information.
- **Secondary Visual Cortex:** Surrounds the primary visual cortex and interprets visual data for recognition and understanding. Processes more complex aspects of vision, such as color, form, and motion, and helps in recognizing and identifying objects and faces.

Cerebellum

The cerebellum is located at the back of the brain beneath the occipital lobes. It is separated from the cerebrum by the tentorium (fold of dura mater). Similar to the cerebrum, the cerebellum contains an outer layer of gray matter, an inner layer of white matter and deep cerebellar nuclei illustrated in Figure 3.1.7. The white matter of the cerebellum is called arbor vitae ("tree of life") for its appearance that reminds that of branches of a tree. The folds of the cerebellar cortex are called folia, which means "leaf".

The cerebellum fine tunes motor activity or movement, e.g. the fine movements of fingers as they perform surgery or paint a picture. It helps one maintain posture, sense of balance or equilibrium, by controlling the tone of muscles and the position of limbs. The cerebellum is important in one's ability to perform rapid and repetitive actions such as playing a video game. In the cerebellum, right-sided abnormalities produce symptoms on the same side of the body.

There is also strong evidence of the cerebellar role in procedural memory. The two are not incompatible; in fact, procedural memory is motor memory, such as learning to ride a bicycle. Significant work has been performed to describe the connections within the cerebellum that result in learning. A movement disorder of the cerebellum is referred to as ataxia. It presents as a loss of coordination in voluntary movements. Ataxia can also refer to sensory deficits that cause balance problems, primarily in proprioception and equilibrium. When the problem is observed in movement, it is ascribed to cerebellar damage.

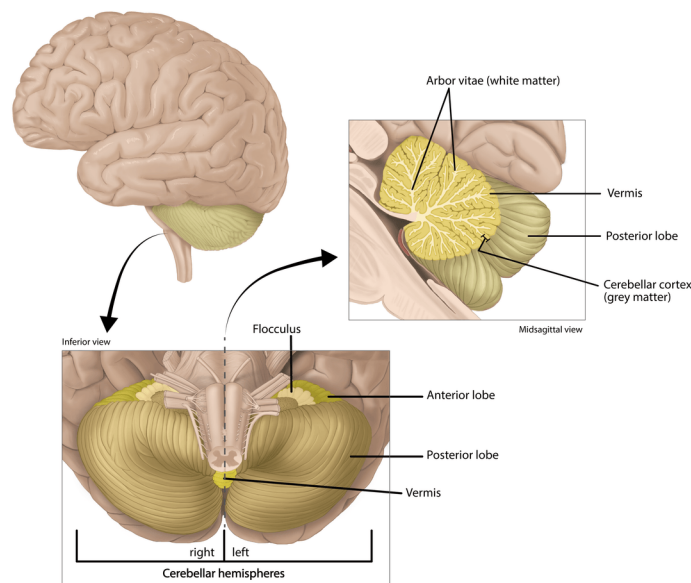


Figure 3.1.7: Cerebellum. The cerebellum is situated on the posterior surface of the brainstem. The midsagittal section shows the deep white matter forming the arbor vitae, which means "tree of life", while the cerebellar cortex is superficial. The major regions of the cerebellum are the anterior lobe, the posterior lobe, and the midline vermis. (CC BY-NC-SA 4.0; Justin Greene and Jennifer Lange via [Brain - Cerebrum](#)).

Figure 3.1.7 illustrated a detailed diagram of the brain focusing on the cerebellum. The labeled structures include:

Top left: Side view of the brain

- The cerebellum is shown beneath the cerebrum, and an arrow indicates a transition from the whole brain to a closer view of the cerebellum.

Top right - Midsagittal (inner side) view of the cerebellum. This cut-through view labels internal structures:

- Arbor vitae: a branching pattern representing internal white matter.
- Cerebellar cortex: the outer layer labeled as gray matter.
- Vermis: a midline region connecting the left and right sides.
- Posterior lobe: labeled toward the posterior portion of the cerebellum.

Bottom left - Inferior (bottom) view of the cerebellum. This view labels major external regions:

- Right cerebellar hemisphere and left cerebellar hemisphere.
- Vermis: runs along the midline between the hemispheres.

- Anterior lobe: labeled toward the anterior portion.
- Posterior lobe: labeled across most of the visible surface.
- Flocculus: a small structure labeled near the inferior surface.

Diencephalon

The diencephalon is the connection between the cerebrum and the rest of the nervous system, with one exception. The rest of the brain, the spinal cord, and the PNS all send information to the cerebrum through the diencephalon. Output from the cerebrum passes through the diencephalon. The single exception is the system associated with olfaction, or the sense of smell, which connects directly with the cerebrum. The diencephalon is deep beneath the cerebrum and constitutes the walls of the third ventricle. The major regions include the thalamus, hypothalamus, epithalamus, and subthalamus as illustrated in Figure 3.1.8.

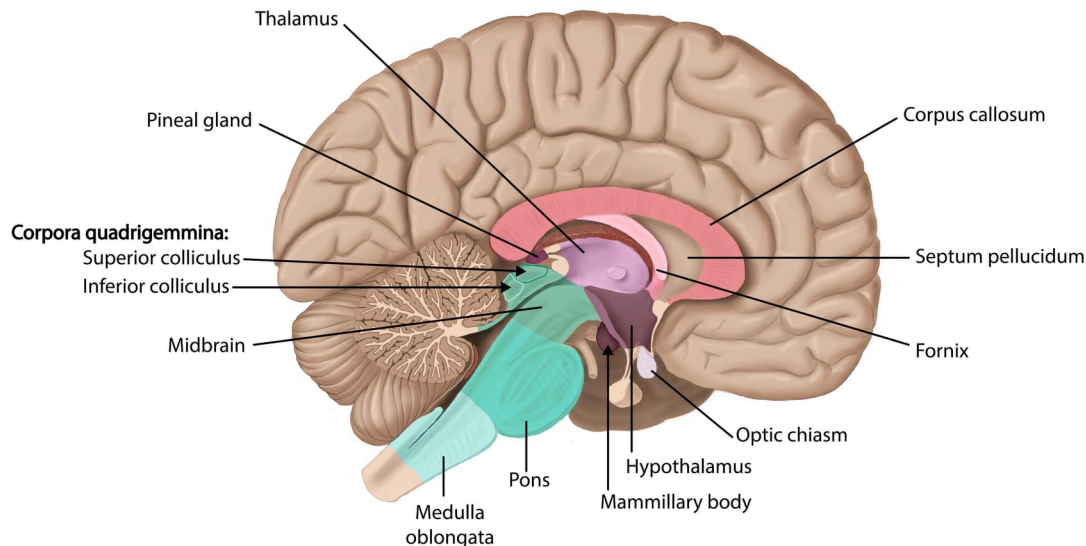


Figure 3.1.8: Midsagittal Section of the Brain. The diencephalon is composed of the thalamus, hypothalamus, and epithalamus. The brainstem comprises three regions: the midbrain, the pons, and the medulla oblongata. Two cerebral structures also visible here are white matter tracts - the corpus callosum and the fornix. (CC BY-NC-SA 4.0; Justin Greene and Jennifer Lange via [Brain - Diencephalon, Brainstem, Cerebellum and Limbic System](#)).

Figure 3.1.8 is a labeled diagram of the human brain highlighting major internal structures. The labeled components include:

- **Thalamus:** A pair of oval-shaped structures situated at the top of the brainstem, near the center of the brain, above the hypothalamus. Serves as a relay station for almost all sensory information (excepting olfactory sense) that comes and goes to the specific region of the cortex.
- **Pineal Gland:** A small endocrine gland located in the epithalamus, regulates circadian rhythms (day-night cycles).
- **Corpus Callosum:** A broad band of nerve fibers located beneath the cerebral cortex. Facilitates communication between the two hemispheres, allowing for the integration of sensory and cognitive information.
- **Septum Pellucidum:** Thin membrane separating the lateral ventricles.
- **Fornix:** An arching, C-shaped bundle of nerve fibers playing a key role in memory formation and retrieval.
- **Optic Chiasm:** Located at the base of the brain, where optic nerves cross.
- **Hypothalamus:** Located below the thalamus, forming the floor of the third ventricle of the brain. It plays a role in controlling functions such as eating, sexual behavior and sleeping; and regulates body temperature, emotions, secretion of hormones and movement.
- **Mammillary Body:** A pair of small, rounded protrusions that are found in the posteroinferior part of the hypothalamus. Involved in memory processing.
- **Pons (Latin for "bridge")** - Part of the brainstem, above the medulla oblongata and below the midbrain. Plays a vital role in connecting the cerebellum to the rest of the brain. It helps regulate breathing and sleep cycle.
- **Medulla Oblongata:** The lower part of the brainstem that controls vital involuntary functions like breathing, heart rate, and blood pressure. It is continuous with the spinal cord.
- **Midbrain:** Located between the pons and the thalamus in the brainstem, includes the superior and inferior colliculi for visual and auditory reflexes.

- **Corpora Quadrigemina:** Part of the midbrain, located on the dorsal aspect. Comprises four colliculi (two superior and two inferior) that play a role in visual and auditory processing and reflexes. The superior colliculi are involved in visual reflexes, while the inferior colliculi are involved in auditory processing.

Brainstem

Evolutionarily the oldest part of the brain, this region is the swelling at the base of the spinal cord. The brainstem holds many autonomic and survival functions critical for life. It has three main subparts: the most inferior part of the brainstem is called the **medulla oblongata**, primarily responsible for controlling vital bodily functions like breathing, heart rate, blood pressure, swallowing, and coughing through specialized centers within its structure; it acts as a conduit for motor and sensory signals between the brain and spinal cord. The anterior region of the medulla oblongata shows two longitudinal ridges called pyramids, which house motor projection tracts. In the posterior region of the medulla oblongata, these pyramids cross to the opposite side at a point called the decussation of pyramids. Due to this crossing, each hemisphere controls motor responses of the opposite side of the body. Destruction of these regions of the brain will cause “brain death.” The reticular activating system (RAS) is found in the midbrain, pons, medulla and part of the thalamus. It controls levels of wakefulness, enables people to pay attention to their environments and is involved in sleep patterns. Just above the medulla oblongata is a larger swelling called the **pons**. This structure serves as a bridge between the medulla and the midbrain. Primarily responsible for relaying sensory and motor information related to facial sensation and expressions, eye movement, hearing, balance, and breathing, while also playing a crucial role in sleep-wake cycles. The **midbrain**, located at the top of the brainstem, is a crucial structure responsible for processing visual and auditory information, controlling eye movements, and coordinating motor functions, particularly rapid reflexes. The cerebral aqueduct runs through the midbrain, connecting the third and fourth ventricles. The superior and inferior colliculi are visible on the posterior surface of the brainstem when the cerebrum and cerebellum are wedged apart. The two **superior** and two **inferior colliculi** make four small bumps that are collectively called the corpora quadrigemina. These structures are responsible for visual and auditory reflexes, respectively.

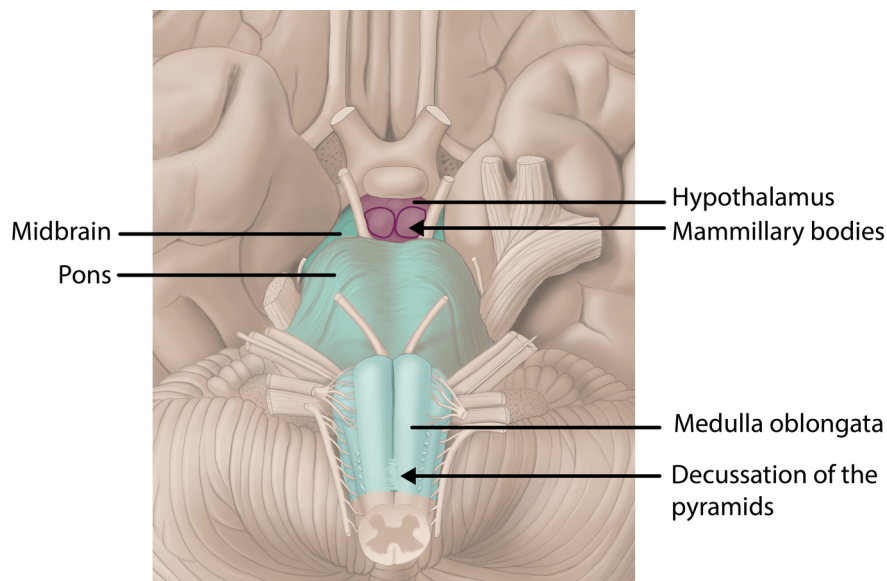


Figure 3.1.9: Inferior View of the Brain. The inferior view of the brain shows the brainstem and hypothalamus. From rostral to caudal, the midbrain, pons and medulla oblongata form the brainstem. Motor fibers from the precentral gyrus cross to the opposite side at the decussation of the pyramids in the medulla oblongata. The only part of the diencephalon visible is the hypothalamus. (CC BY-NC-SA 4.0; Justin Greene and Jennifer Lange via [Brain - Cerebrum](#)).

Figure 3.1.9 is an anatomical illustration of the human brainstem and surrounding structures, viewed from the front. Several key parts of the brain are labeled with black text and arrows pointing to their respective locations. Labeled Structures:

1. **Midbrain** – Located near the top center of the image, just below the hypothalamus.
2. **Pons** – Positioned below the midbrain, forming a rounded bulge in the brainstem.
3. **Hypothalamus** – Found at the upper part of the image, above the midbrain, near the center.
4. **Mammillary bodies** – Small rounded structures beneath the hypothalamus.
5. **Medulla oblongata** – Extends downward from the pons, forming the lower portion of the brainstem.
6. **Decussation of the pyramids** – Located at the very bottom of the medulla oblongata, where nerve fibers cross over.

The Limbic System

The limbic system is a collection of structures of the cerebrum and diencephalon involved in emotion, motivation and memory associated with emotions. Although still debated, the structures mostly recognized in this system are the cingulate gyrus, hippocampus, amygdala, olfactory structures, and various nuclei of the diencephalon. Here we will focus on the cingulate gyrus, the hippocampus and amygdala as major structures as illustrated in Figure 3.1.10.

The cingulate gyrus is located in the longitudinal fissure, superior to the corpus callosum, surrounding the diencephalon. The cingulate gyrus focuses the attention to events that are emotionally important. The hippocampus is a nucleus shaped like a seahorse, hence its name. The hippocampus is essential in forming memories and storing them long-term. Lastly, the amygdala is connected to the hippocampus and is involved in multiple aspects of emotions, especially fear.

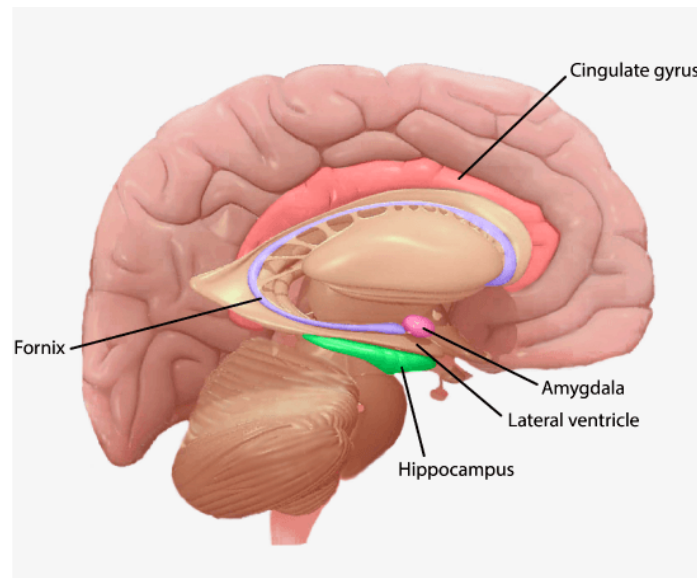


Figure 3.1.10: Limbic System. The limbic system regulates emotion and other behaviors. It includes parts of the cerebral cortex located near the midline of the brain, including the cingulate gyrus and the hippocampus and amygdala. The fornix is a tract connecting the hippocampus to the hypothalamus. (CC BY-NC-SA 4.0; Justin Greene and Jennifer Lange via [Brain - Diencephalon, Brainstem, Cerebellum and Limbic System](#)).

Figure 3.1.10 is a labeled diagram of the human brain highlighting key structures of the limbic system and nearby areas:

- Cingulate gyrus: a medial cortical region associated with aspects of emotion and behavior regulation.
- Fornix: a major fiber tract that connects limbic structures, including pathways associated with the hippocampus.
- Amygdala: a limbic structure above the hippocampus involved in processing emotion, including fear and threat-related responses.
- Lateral ventricle: a C-shaped cerebrospinal fluid-filled cavity that is part of the brain's ventricular system.
- Hippocampus: a limbic structure important for memory formation and spatial navigation.

The Ventricular System and Cerebrospinal Fluid (CSF)

Cerebrospinal fluid (CSF) is found within the brain and surrounds the brain and the spinal cord. It is a clear, watery substance with a limited amount of the constituents of blood (small molecules, and electrolytes) that helps to cushion the brain and spinal cord from injury. Oxygen and carbon dioxide are dissolved into the CSF, as they are in blood, and can diffuse between the fluid and the nervous tissue. It is within hollow spaces in the brain, called ventricles, that the fluid is produced. A specialized structure within each ventricle, called the choroid plexus, is responsible for the majority of CSF production.

Two ventricles enclosed in the cerebral hemispheres are called the lateral ventricles (first and second). They each communicate with the third ventricle through a separate opening called the foramen of Munro. The third ventricle is in the center of the brain, and its walls are made up of the thalamus and hypothalamus. The third ventricle connects with the fourth ventricle through a long tube called the cerebral aqueduct as illustrated in Figure 3.1.11. CSF flowing through the fourth ventricle flows around the brain and spinal cord by passing through another series of openings. The brain normally maintains a balance between the amount of

CSF that is absorbed and the amount that is produced. However, disruptions in this system may occur.

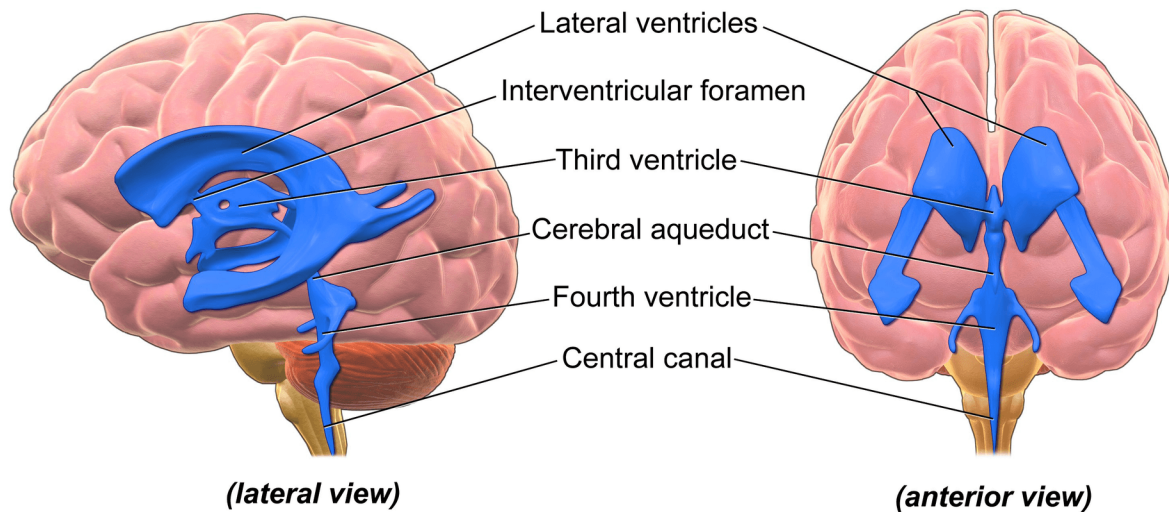


Figure 3.1.11: Ventricles. Within the brain, open spaces called ventricles are lined with ependymal cells that produce cerebrospinal fluid (CSF). Deep within the brain are the lateral ventricles, which are connected to the third ventricle by two openings called interventricular foramina. The third ventricle opens into a canal called the cerebral aqueduct which connects to the fourth ventricle. The fourth ventricle is connected to the central canal of the spinal cord. (Public Domain, CC0; Whitney Menefee, Julie Jenks, Chiara Mazzasette, Kim-Leiloni Nguyen via [Support and Protection of the Brain](#)).

Figure 3.1.11 illustrates the brain's ventricular system in two views. All ventricles and canals are highlighted in blue to indicate the cerebrospinal fluid (CSF) pathways.

Left image - Lateral (side) view: This view shows the ventricles from the side and emphasizes the pathway of flow through the system:

- Lateral ventricle: the largest cavity, curved within the cerebral hemisphere.
- Interventricular foramen: a short connecting channel from the lateral ventricle to the third ventricle.
- Third ventricle: a narrow midline space.
- Cerebral aqueduct: a thin passage extending from the third ventricle to the fourth ventricle.
- Fourth ventricle: located between the brainstem and the cerebellum.
- Central canal: continues inferiorly from the fourth ventricle into the spinal cord.

Right image - Anterior (front) view: This view shows symmetry and midline connections:

- The paired lateral ventricles appear on the left and right.
- Each connects toward the midline to the third ventricle.
- The cerebral aqueduct descends from the third ventricle to the fourth ventricle.
- The central canal extends inferiorly from the fourth ventricle.

Cranial Nerves

There are twelve pairs of cranial nerves, numbered 1 to 12, based on their attachment point on the left and right sides of the inferior side of the brain as illustrated in Figure 3.1.12. The twelve cranial nerves can be strictly sensory in function, strictly motor in function, or a combination of the two functions. Note that cranial nerve I (Olfactory) is at the anterior end of the inferior side of the brain, and that cranial nerve XII (Hypoglossal) is at the posterior end of the inferior side of the brain.

They are named with both a Roman numeral and a specific name. Their names are I. Olfactory, II. Optic, III. Oculomotor, IV. Trochlear, V. Trigeminal, VI: Abducens, VII: Facial, VIII. Vestibulocochlear, IX. Glossopharyngeal, X. Vagus, XI. Accessory, XII. Hypoglossal. These twelve pairs of nerves connect the brain to a variety of other organs in the body.

Some of the 12 cranial nerves carry only sensory information to the brain, and some carry only motor messages to other parts

of the body (particularly the muscles). Some cranial nerves are referred to as “mixed” as some of the neurons in the nerve carry sensory signals and other neurons carry motor output signals. Learning the functions of the cranial nerves requires knowing whether each cranial nerve is “sensory”, “motor” or “mixed function”. Memorizing which cranial nerve carries which type of information requires effort and some help from a mnemonic that can be used once you have learned the names of the cranial nerves in numerical order. For example, the trigeminal* nerve is a “mixed” nerve, as it carries both sensory nerve fibers and motor nerve fibers. The trigeminal nerve brings sensory signals from the face and mucous membranes to the cerebrum and supplies motor innervation to the muscles of the mouth involved in mastication (chewing).

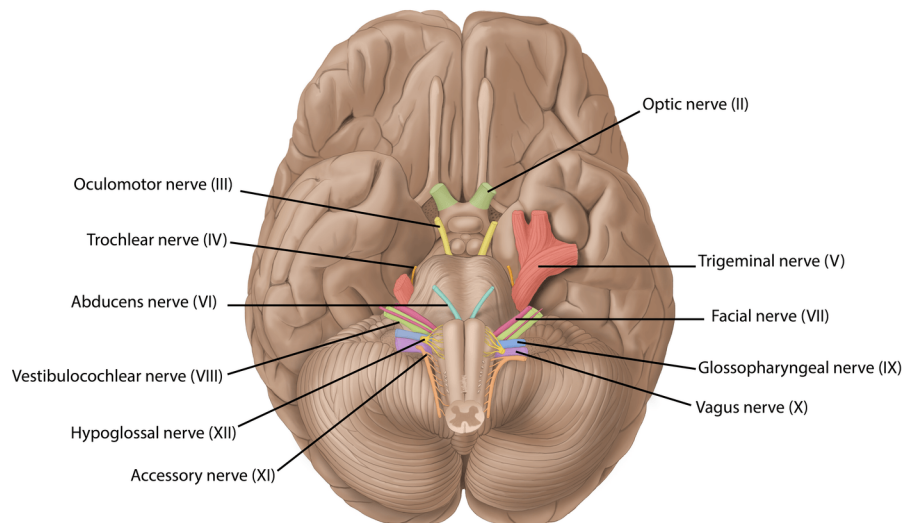


Figure 3.1.12: The anatomical arrangement of the roots of the cranial nerves observed from an inferior view of the brain. Cranial nerves are numbered with Roman numbers from I to XII based on their exit from the brain, from anterior to posterior (CN I is not indicated). (Public Domain, CC0; Jennifer Lange via Cranial Nerves).

Figure 3.1.12 shows the inferior, or underside, view of the brain. Visible structures include the cerebral hemispheres in the anterior portion, the brainstem in the center, and the cerebellum in the posterior lower portion. The cranial nerves are shown in left and right pairs and are labeled by name and Roman numeral. The description below follows the nerves in general order from anterior to posterior and from the upper brain regions to the lower brainstem.

- **Cranial Nerve II: Optic Nerve** - The optic nerves arise from the visual pathway at the base of the forebrain. In an inferior view, the right and left optic nerves converge at the optic chiasm near the midline before continuing posteriorly as the optic tracts.
- **Cranial Nerve III: Oculomotor Nerve** - The oculomotor nerves emerge from the ventral surface of the midbrain in the interpeduncular fossa, which is a space between the cerebral peduncles. One nerve is present on each side of the midline.
- **Cranial Nerve IV: Trochlear Nerve** - The trochlear nerves originate from the dorsal midbrain, making them unique among the cranial nerves. They wrap around to the ventral aspect of the brainstem and can be seen laterally in an inferior view as thin nerves coursing forward.
- **Cranial Nerve V: Trigeminal Nerve** - The trigeminal nerves are the largest cranial nerves visible in this image. They emerge from the lateral surface of the pons, with one large nerve on each side.
- **Cranial Nerve VI: Abducens Nerve** - The abducens nerves emerge at the pontomedullary junction, close to the midline. These small nerves arise from the groove between the pons and the medulla.
- **Cranial Nerve VII: Facial Nerve** - The facial nerves emerge at the pontomedullary junction, lateral to the abducens nerves. They are located in the region of the cerebellopontine angle.
- **Cranial Nerve VIII: Vestibulocochlear Nerve** - The vestibulocochlear nerves also emerge at the pontomedullary junction in the cerebellopontine angle. Each lies lateral to the facial nerve on its side.
- **Cranial Nerve IX: Glossopharyngeal Nerve** - The glossopharyngeal nerves arise from the postolivary sulcus of the medulla, which is a groove lateral to the olive. They are located inferior to cranial nerves VII and VIII.
- **Cranial Nerve X: Vagus Nerve** - The vagus nerves also arise from the postolivary sulcus of the medulla, just inferior to the glossopharyngeal nerves. They extend downward from the medulla toward the neck.
- **Cranial Nerve XI: Accessory Nerve** - The accessory nerves are formed by rootlets from the caudal medulla and the upper cervical spinal cord. In this view, they appear as a series of small rootlets inferior to the vagus nerves.
- **Cranial Nerve XII: Hypoglossal Nerve** - The hypoglossal nerves arise from the preolivary sulcus of the medulla, which is the groove between the pyramid and the olive. One nerve emerges on each side and courses forward.

Additional Structures:

- The brainstem extends vertically through the center of the image and includes the midbrain, pons, and medulla.
- The cerebellum appears posteriorly as paired rounded structures on either side of the lower brainstem.

To help students learn the names of the cranial nerves, there are a variety of mnemonics.

Numeric recall mnemonic:

Oh Once One Takes The Anatomy Final Very Good Vacations Are Heavenly

Oh, Oh, Oh, To Touch And Feel Very Green Vegetables, Such Healthy

Mnemonics based on modality:

The nerves can be either be sensory (S), motor(M) or both(B). So we use S, M and B for our mnemonics. Depending on their type, the initial letters that we get are 'S S M M B M B S B B M M'.

- Some Say Marry Money, But My Brother Says Big Brains Matter Most'
- Some Say Manage Money, But My Barber Says Big Brains Matter Most'
- Some Say Money Matters, But My Baker Says Baking Brownies Matter Most'

Students are encouraged to create their own mnemonics that is closer to their heart so they can easily remember them.

A neurologist can evaluate each of the twelve cranial nerves through a series of non-invasive diagnostic tests.

For example, procedure for trigeminal nerve (cranial nerve V) - a mixed nerve what the neurologist does

1. After asking the patient to close their eyes, the neurologist tests facial sensation by gently wiping a cotton ball across the frontal region (forehead). If the response is normal, the patient will feel the cotton ball.
2. The neurologist tests motor function by placing their hands on the patient's masseter muscles (both left and right) and asking them to clench their teeth. If the response is normal, muscle tension is generated equally on both sides.

Example 3.1.1: Procedure for Assessing the Hypoglossal Nerve (Cranial Nerve XII)

The hypoglossal nerve is a motor-only nerve responsible for tongue movements.

What the neurologist does:

1. The neurologist asks the patient to protrude the tongue at the midline.
2. Then, the patient is instructed to move the tongue side to side.
3. Normal response: The tongue moves symmetrically without deviation

3.2: Terminology Checklist

Regions of the Brain

When conducting the sheep or other mammalian brain dissection activity, be sure to identify and label all structures that are marked with an asterisk (*). These marked structures are important for your understanding and will help reinforce your knowledge of brain anatomy.

In addition to the structures marked for dissection, other items on the checklist should be identified using laboratory models and images. Focus on understanding the relationship between each structure's location, function, and role within the overall anatomy.

- Cerebrum*
 - Cerebral cortex*
 - Frontal lobe*
 - Insula
 - Occipital lobe*
 - Parietal lobe*
 - Temporal lobe*
- Diencephalon
 - Thalamus*
 - Epithalamus*
 - Pineal gland*
 - Hypothalamus*
- Brainstem*
 - Midbrain*
 - Corpora quadrigemina*
 - Inferior colliculi*
 - Superior colliculi*
 - Pons*
 - Medulla oblongata*
- Cerebellum*
 - Arbor vitae
 - Cerebellar cortex*
 - folia
 - vermis

Functional Areas of the Cerebrum

- Broca's area
- Primary motor cortex
- Primary somatosensory cortex
- Wernicke's area

Other Structures of the Brain

- Pituitary gland*
- Fissures
 - Lateral fissure
 - Longitudinal fissure*
 - Transverse fissure*
- Gray matter*
- Cerebral cortex
- Gyri*

- Precentral gyrus
- Postcentral gyrus
- Meninges and Spaces
 - Arachnoid matter
 - Dura matter
 - Epidural space
 - Pia matter
 - Subarachnoid space
 - Subdural space
 - Superior sagittal sinus
- Sulci*
 - Central sulcus
- White matter*
 - Corpus callosum*

Flow of Cerebrospinal Fluid

- Apertures
- Arachnoid granulations (villi)
- Central canal
- Cerebral aqueduct*
- Choroid plexus
- Fourth ventricle
- Interventricular foramen
- Lateral ventricles*
- Superior sagittal sinus
- Third ventricle

Cranial Nerves and associated structures

- CN I Olfactory Nerve*
 - Olfactory bulb*
- CN II Optic Nerve*
 - Optic chiasma*
- CN III Oculomotor Nerve
- CN IV Trochlear Nerve
- CN V Trigeminal Nerve
- CN VI Abducens Nerve
- CN VII Facial Nerve
- CN VIII Vestibulocochlear Nerve
- CN IX Glossopharyngeal Nerve
- CN X Vagus Nerve
- CN XI Accessory Nerve
- CN XII Hypoglossal Nerve

3.3: Activity 1

Case Study Warm-Up

In this activity, you will explore the fascinating complexities of the human brain through the lens of a case study. We will focus on the mysterious case of Alex, an individual experiencing unexpected memory loss. This case study will serve as a practical application of your knowledge about brain anatomy and function, particularly in relation to memory processing and storage.

Instructions

1. Revisit your notes and any assigned readings on brain anatomy, focusing specifically on structures involved in memory, such as the hippocampus, amygdala, and frontal lobes.
2. Refresh your understanding of how these structures interact to facilitate both short-term and long-term memory.
3. Carefully read the details of Alex's case. Pay attention to the symptoms described and any relevant medical history provided.
4. Identify which brain structures might be implicated in Alex's memory loss based on the symptoms presented.
5. Use the reflection prompts provided to connect your prior knowledge with new insights from the case study.
6. Join your peers in a group discussion to compare notes and hypotheses about Alex's condition.

Alex's Memory Loss

Alex Lewis, a 20-year-old college student, has always been energetic and sharp. One afternoon, while playing soccer, he accidentally collided with another player and hit his head. After the incident, Alex noticed he was having trouble recalling recent events, like what he ate for breakfast or details from a lecture just hours before. Concerned, his roommate took him to the campus clinic.

The physician, Dr. Wu, suspected a concussion but wanted to understand which part of Alex's brain might be affected. The doctor explained that different regions of the brain have specific roles in memory, movement, and decision-making. To help Alex and his roommate visualize this, Dr. Wu showed them diagrams of the brain, highlighting the cranial anatomy including the skull bones, meninges and four parts of the brain - the cerebrum, cerebellum, diencephalon and brain stem. He emphasized on the deep brain structures such as the thalamus (relays sensory information), hypothalamus (regulates hormones and autonomic functions), hippocampus (key for forming new memories and learning), amygdala (regulates emotions), and basal ganglia (regulates movement). The frontal lobes (for decision-making and planning), and the parietal lobes (for processing sensory information).

Reflection Questions:

1. Reflect on what you already know about the brain and its functions. How does this prior knowledge help you understand Alex's case of memory loss? Identify any specific brain structures or functions you recall that might relate to memory.
2. After reading the background information, what are the three most important concepts you have learned about memory and its relation to brain anatomy? What questions do you still have about how these concepts connect to Alex's memory loss?
3. Think about a time when you or someone you know experienced forgetfulness. Based on the background information, how might the brain's structures and functions explain this memory lapse? How does this relate to the case study of Alex's memory loss?
4. What advantages do hands-on activities, like dissection offer for learning about complex brain anatomy?

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3.4: Activity 2

Structure - Function Relationships of Brain Meninges

In this lab activity, you will explore the protective layers surrounding the brain, known as the meninges. These layers—dura mater, arachnoid mater, and pia mater—serve essential roles in safeguarding the brain and spinal cord. Understanding these structures, along with key anatomical terms, is foundational for studying brain anatomy and physiology.

Provide a one line definition for the following terms

- Gyri
- Sulcus
- Fissure

For the meninges, rank them from the most superficial layer to the deepest layer.

- Deepest
- Middle
- Most superficial

Reflection prompts

1. The dura mater, arachnoid mater, and pia mater each have unique structures and positions. How do the physical characteristics of each meningeal layer relate to its specific function in protecting and supporting the brain and spinal cord?
2. Conditions such as meningitis and subdural hematoma affect the meninges. Based on what you have learned about the location and function of each meningeal layer, predict which layer(s) might be most affected in these conditions and explain why. What symptoms might you expect if each layer is compromised?

3.5: Activity 3

Identifying Key Structural and Functional Parts of the Human Brain

In this lab activity, you will explore the intricate structures of the human brain and their associated functions. Understanding the anatomy of the brain is crucial for comprehending how it controls various bodily functions and processes sensory information. This activity will focus on identifying major brain regions and understanding their roles in cognition, emotion, and physiological regulation. By examining brain models and images, you will gain insights into the complexity and organization of this vital organ.

Instructions

1. Begin with an overview of resources provided by your instructor, highlighting the significance of each brain region and its contribution to overall brain function.
2. Work with lab partners to identify each structure on the models and images.
3. Discuss the functions of each structure as you identify them, reinforcing your understanding of their roles.
4. Fill in the table to demonstrate your knowledge.

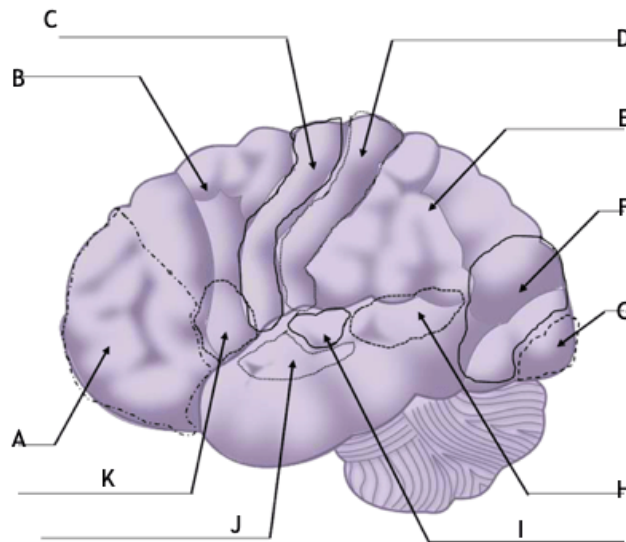


Figure 3.5.1: The image is a diagram of the human brain with arrows pointing to 11 key regions or parts indicated by letters for identification purpose (CC BY-NC-SA 4.0; Rosanna Hartline via Laboratory Activities and Assignment).

Figure 3.5.1 shows a lateral (side) view of the brain with multiple leader lines pointing to structures labeled with letters A through K. The diagram is designed for identification, where students match each letter to the correct anatomical structure name and fill Table 3.5.1.

Table 3.5.1: Identification of the brain parts as indicated by letters on the image

Letter	Key Areas/Structures
	Broca's area
	Wernicke's area
	Primary motor cortex
	Visual association area
	Auditory association area

Letter	Key Areas/Structures
	Primary sensory cortex
	Somatic motor association area
	Somatic sensory association area
	Prefrontal cortex
	Auditory cortex
	Visual cortex

3.6: Activity 4

Identifying Brain Structures in the Sagittal Section

The brain is a complex organ with various structures that perform critical functions essential for life and cognition. Viewing the brain in a sagittal section provides a unique perspective that reveals the internal organization and connectivity of its structures. This lab activity focuses on identifying and understanding the major brain structures indicated by numbers, such as the fornix (diencephalon), pons (brain stem), midbrain, arbor vitae (cerebellum), corpus callosum, thalamus (diencephalon), medulla oblongata (brain stem) and optic chiasm visible in a sagittal section.

Instructions

1. Use the brain models and diagrams provided in the lab to identify structures in the sagittal section. Pay attention to their locations and relationships to one another.
2. Discuss how the anatomical structures observed in the sagittal section relate to their functions (Activity 5).
3. Document identification in the Table 3.6.1.

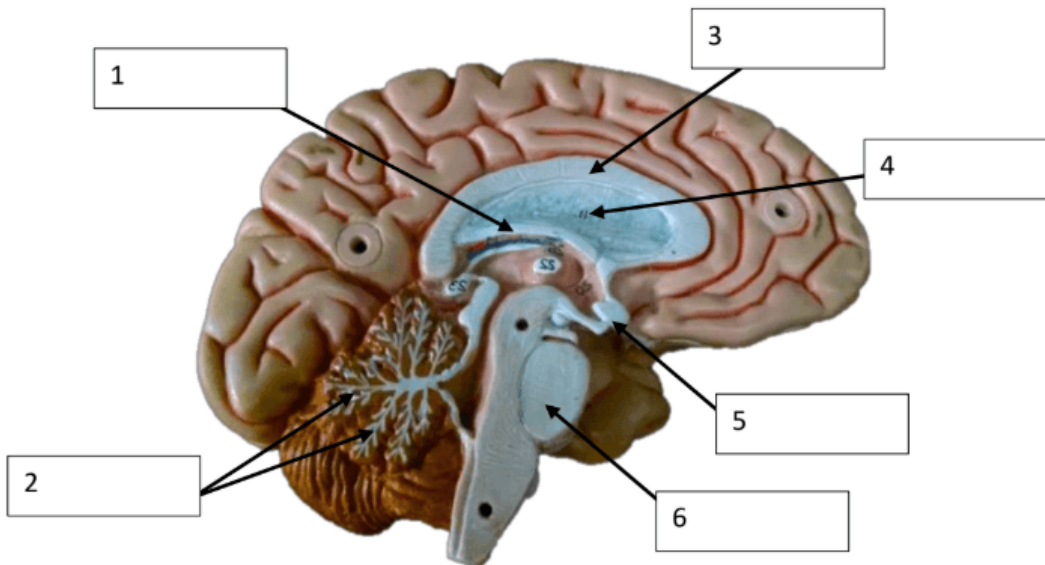


Figure 3.6.1: Cross-sectional view of the human brain with six labeled regions. Each label corresponds to a distinct functional area—such as motor, sensory, auditory, or visual processing centers supporting the identification and study of brain anatomy. (CC BY-NC-SA 4.0; Yancy Aquino via [BIOL 250 Human Anatomy](#)).

Figure 3.6.1 shows a midsagittal (inner side) view of a brain model.

- The cerebrum in midsagittal section, showing internal spaces and midline structures.
- The cerebellum at the posterior-inferior portion, with a branching internal pattern visible.
- The brainstem extending inferiorly from the brain.

Table 3.6.1: Identification of the brain parts as indicated by numbers in sagittal section

Number	Key Structure identified
1	
2	
3	
4	

Number	Key Structure identified
5	
6	
7	
8	

3.7: Activity 5

Matching Brain Structures to Their Functions

Understanding the relationship between brain structures and their functions is fundamental to grasping how the brain operates. Each structure within the brain has a specific role, contributing to the overall functioning of the nervous system. In this lab activity, students will engage in a hands-on matching exercise to connect numbered brain structures with their corresponding functions, indicated by letters. This activity reinforces anatomical knowledge and functional understanding, highlighting the integration of structure and function in the brain.

Instructions

1. Carefully examine each numbered structure on the diagram or model. Use your knowledge and any provided resources to determine the function of each structure.
2. Match each numbered structure with the correct letter that represents its function. Record your answers on the provided worksheet.
3. After completing the matching exercise, participate in a group discussion to review the answers. Discuss any discrepancies or uncertainties and clarify the functional roles of each brain structure.

Table 3.7.1: Matching Brain structures (indicated by number) to respective functions (indicated by letters)

Matching letter of the Brain	Major function
1. Cerebellum	A. Regulates most autonomic nervous system control including body temperature, hunger, and hormones (oxytocin and antidiuretic hormone), regulates most autonomic nervous system
2. Thalamus	B. Located in the midbrain; contains centers for visual reflex and auditory reflex.
3. Hypothalamus	C. Contains more than half of all the neurons in the brain; coordinates complex muscular movement, speech, and motor functions.
4. Mamillary bodies	D. Lies directly superior to the medulla oblongata and anterior to the cerebellum; relays volitional information to the effector; also help control breathing.
5. Pineal gland	E. A large mass of gray matter deeply situated in the forebrain. It relays information received from the olfactory senses, to the cerebral cortex.
6. Corpora quadrigemina	F. Lowermost part of the brain stem; houses the cardiac regulatory center, respiratory center, and centers for vomiting, coughing, sneezing, and swallowing.
7. Pituitary gland	G. Secretes melatonin, a hormone derived from tryptophan that regulates circadian rhythm

Matching letter of the Brain	Major function
8. Cerebral cortex	H. A pair of small round bodies, located on the undersurface of the brain, that, as part of the limbic system. It relays the olfactory senses to the cerebral cortex.
9. Medulla oblongata	I. A small bilobed structure rests in the sella turcica, a depression in the sphenoid bone, connected to the hypothalamus by a slender stalk called the infundibulum. Secretes multiple hormones to regulate development, metabolism, reproduction.
10. Pons	J. Sheet of neural tissue; plays a key role in memory, attention, perceptual awareness, thought, and consciousness.

3.8: Activity 6

Exploring Cerebrospinal Fluid Storage and Circulation in the Brain

Cerebrospinal fluid (CSF) is a clear, colorless fluid that flows through the brain and spinal cord, playing a crucial role in cushioning the brain, removing waste, and maintaining homeostasis. Understanding the anatomy of CSF circulation and storage is essential for comprehending how the brain protects itself and maintains its internal environment. In this lab activity, students will identify key brain structures involved in the production, storage, and circulation of CSF, focusing on the ventricles and associated pathways.

Instructions

- Using brain models or diagrams provided in the lab, locate and identify the following structures involved in CSF circulation and storage:
 - The KEY structures/parts (arachnoid granulation, superior sagittal sinus, lateral ventricle, interventricular foramen, third ventricle, cerebral aqueduct, fourth ventricle, central canal) are indicated on the image by letters.
- Note the flow of CSF from production in the choroid plexus to its absorption into the venous system.
- Document identification in the lab worksheet Table 3.8.1.

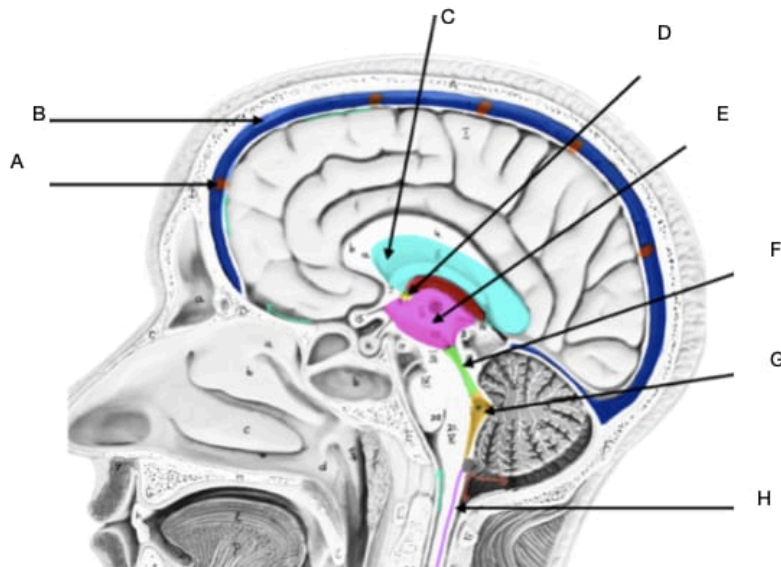


Figure 3.8.1: Labeled diagram of a sagittal section of the human brain. Various regions and structures are marked with letters to assist in identifying their anatomical location and function. (CC BY-NC-SA 4.0; via [Brain and Cranial Nerves Lab](#)).

Figure 3.8.1 shows a midsagittal (side cut) view of the head and brain. Several internal brain regions are highlighted.

- An outline of the head and brain in midsagittal view.
- The cerebellum is visible posteriorly with a folded texture.
- A vertical structure inferior to the brain represents the brainstem/spinal cord region.
- Multiple leader lines connect the letter labels (A–H) to specific anatomical targets.

Table 3.8.1: Identification of Brain Structures and Ventricular System Components by Number and Letter Codes

Number	Key Structures/Parts
	Third ventricle

Number	Key Structures/Parts
	Central canal
	Cerebral aqueduct
	Interventricular foramen
	Superior sagittal sinus
	Lateral ventricle
	Arachnoid granulation
	Fourth ventricle

4. Critical Thinking and Discussion:

- Reflect on the importance of CSF circulation for brain health. Consider how blockages or malfunctions in this system might lead to medical conditions such as hydrocephalus.
- Participate in a group discussion to share insights and clarify any uncertainties about CSF dynamics and the role of each structure.

3.9: Activity 7

Analysis of Cranial Nerve Damage and Its Impact on Motor and/or Sensory Functions

Cranial nerves are essential for various sensory and motor functions, connecting the brain to different parts of the head, neck, and body. Damage to these nerves can lead to specific deficits, affecting a person's ability to see, smell, taste, hear, or move facial muscles. Understanding the implications of cranial nerve damage is crucial for diagnosing and managing neurological conditions. In this lab activity, students will analyze real-world clinical scenarios to identify which cranial nerves are affected and interpret the resulting impact on motor or sensory activity.

Instructions

1. Review the anatomy and functions of the 12 cranial nerves, focusing on their roles in sensory and motor activities.
2. You are provided with a series of clinical case studies below, each describing symptoms experienced by a hypothetical patient. Carefully read each scenario and note any specific symptoms or deficits mentioned.
3. For each case study, determine which cranial nerve(s) is likely affected based on the symptoms presented. Use your knowledge of cranial nerve functions to support your identification.
4. Record your findings on the provided worksheet, including the affected cranial nerve(s) and the rationale for your conclusion.
5. Participate in a group discussion to compare your findings with those of your peers. Discuss any discrepancies and clarify your understanding of how specific cranial nerve damage translates to clinical symptoms.

Case Scenarios

Scenario 1: A 45-year-old patient presents with sudden weakness on one side of the face, making it difficult to smile or close their eye on that side. Which cranial nerve is likely affected in this case? What is the rationale for your conclusion?

Scenario 2: A 50-year-old reports sudden hearing loss in one ear, accompanied by tinnitus (ringing in the ear). Which cranial nerve is likely affected, and what specific function is impaired? What is the rationale for your conclusion?

Scenario 3: A 60-year-old patient reports a loss of taste on the anterior two-thirds of the tongue and difficulty with facial sensation. Which cranial nerve(s) are responsible for taste and sensation in this area? What is the rationale for your conclusion?

3.10: Activity 8

Brain anatomy in 3D with Dissection

The purpose of this activity is to build concrete understanding of brain structure–function relationships by identifying major external and internal features on a real specimen and comparing them to human brain anatomy.

Objective

Students who complete a sheep brain dissection should be able to:

- Identify the principal external features (e.g., meninges, cerebrum, cerebellum, medulla oblongata, pons, pituitary gland, cerebral lobes, gyri, sulci) and internal structures of the sheep brain (e.g., midbrain including corpora quadrigemina, corpus callosum, ventricles, septum pellucidum, choroid plexus, epithalamus, thalamus, hypothalamus, pineal gland, lobes, gray matter, white matter, cerebral cortex, arbor vitae).
- Understand the direct relationship between an anatomical structure's form (e.g., the folded gyri and sulci that increase surface area) and its function.
- Relate specific structures (e.g., optic chiasm, olfactory bulbs) to their corresponding sensory or motor functions.
- Differentiate between gray matter and white matter, and understand their composition and roles in neural communication (cell bodies/dendrites vs. myelinated axons).
- Understand and apply anatomical terminology (e.g., dorsal, ventral, anterior, posterior, sagittal, coronal, longitudinal fissure, transverse fissure) to describe the location and orientation of brain structures.
- Compare and contrast the size, proportion, and orientation of the sheep brain structures to those of a human brain, and infer the functional implications of these differences (e.g., relative size of olfactory bulbs).
- Develop an appreciation for the complexity of the brain and gain hands-on experience with scientific observation and dissection techniques.

Background Information

Mammalian brain dissection, particularly using sheep brains, is a foundational hands-on learning activity in neuroscience and biology courses. Sheep brains are ideal specimens because they are readily available from biological supply vendors at reasonable cost, require minimal equipment, and closely mirror human brain anatomy in most respects. The sheep brain is highly homologous to the human brain across most structures. The major divisions—cerebrum, cerebellum, brainstem, and internal features like the corpus callosum, thalamus, and ventricles—are anatomically similar between sheep and humans. The primary difference lies in cortical surface features (sulci and gyri), which vary across mammalian species but do not significantly limit the educational value of the dissection. This homology means that knowledge gained from dissecting a sheep brain readily generalizes to understanding mammalian neurobiology, including human brain organization.

Materials

- Preserved sheep brains (1 per 2–3 students)
- Dissection tools (Scalpels with replaceable blades, Dissection scissors (blunt), forceps/tweezers, blunt probes/teasing needles)
- T-pins or colored map pins for labeling
- Dissection tray for each group
- Nitrile gloves (multiple sizes), splash goggles, lab coats/aprons
- Dissection guide or atlas (laminated) per group
- Paper towels
- Disinfectant solution
- Biohazard bags for waste disposal
- Cameras/tablets or phones for annotated photos (if permitted)
- Accessibility and alternatives - Virtual dissection software/link or high-resolution dissection photo set

Instructions

1. Obtain a preserved sheep brain from the bucket in the front of the classroom.
2. Place the brain down so the flatter side, with the spinal cord at one end, rests on the dissection pan.

Step 1 - External anatomy Structures for observation

- Cerebrum (right and left hemispheres): The largest part, responsible for higher functions.
 - Cerebellum: Located at the back, coordinates movement and balance.
 - Brainstem (includes midbrain, pons, medulla oblongata): Controls basic life functions.
 - Spinal Cord: Extends from the brainstem.
 - Olfactory Bulbs: Involved in sense of smell, found on the underside of the brain.
 - Optic Chiasma: Where the optic nerves cross, visible on the ventral side.
 - Gyri and Sulci: Ridges and grooves on the brain's surface.
 - Dura Mater: Tough outer covering (may need to be removed).
 - Pituitary gland (embedded within the dura matter).
1. Observe the layer of protective tissue covering the brain. This is made up of the meninges (dura mater, arachnoid mater, and pia mater). Are these protective layers present? Can you identify the three layers? Can you see the dark blood vessels just beneath the meninges?
 2. Look for "folding" on the outer layers (the cerebral cortex) of the cerebrum. Identify ridges (called gyri) and grooves (sulci) in the cerebral cortex. What functions might this "folding" provide for the brain? What does this tell you about the importance of the gray matter in the cerebral cortex?
 3. Turn the brain over. You'll probably be able to identify the medulla oblongata, pons, two optic nerves at the optic chiasm (where they cross to opposite hemispheres), and olfactory bulbs. The olfactory bulbs are slightly smoother and a different shade than the tissue around them. The olfactory bulbs control the sense of smell.

Documentation - external anatomy

1. Use paper labels, colored pins, or tape flags to mark each structure as you identify it.
 2. Take clear photographs of both the dorsal and ventral views with all labels visible and non-overlapping.
- Labeling Key External Structures (Dorsal and Lateral Views)
 - Cerebrum - frontal lobe, parietal lobe, occipital lobe, Gyri (ridges) and sulci (grooves)
 - Cerebellum
 - Brainstem - pons, and medulla oblongata
 - Labeling Key External Structures (Ventral View)
 - Gently turn the brain to expose the ventral (underside) surface.
 - Olfactory bulbs
 - Optic chiasma
 - Pituitary gland

Go ahead with Dissection

Step 2 - Internal Anatomy - Structures for observation

- Corpus Callosum - White matter band connecting the two hemispheres.
- Septum pellucidum - a thin, triangular, double-layered membrane located in the midline of the brain, separating the anterior horns of the left and right lateral ventricles
- Lateral Ventricles (right and left) - Space within each hemisphere.
- Fourth ventricle - forms a diamond-shaped cavity located between the brainstem (pons and upper medulla oblongata) and the cerebellum.
- Fornix - Fiber tract below the corpus callosum.

- Thalamus - Made up of numerous specialized nuclei, each dedicated to relaying specific types of information, such as touch, vision, hearing, or movement
 - Hypothalamus - located just below the thalamus and forming the basal part of the diencephalon, serves as a critical link between the nervous and endocrine systems, largely through its control of the pituitary gland.
 - Epithalamus - a small, dorsal-posterior segment of the diencephalon in the brain, located just above and behind the thalamus and contains the pineal gland (produces melatonin, regulating sleep-wake cycles and circadian rhythms).
 - Arbor Vitae - Tree-like white matter in the cerebellum.
 - Superior and Inferior Colliculi (corpora quadrigemina) - Parts of the midbrain, involved in visual and auditory processing.
1. Place the brain so you can see the longitudinal fissure clearly.
 2. Use a scissors to cut through the meninges (these tissues are quite tough). Carefully "peel" the meninges away from the brain, trying not to pull other structures away with them.
 3. Place the brain with the curved top side of the cerebrum facing up.
 4. Using a sharp scalpel or knife, cut straight down the center of the brain from the dorsal side, following the longitudinal fissure. Press firmly to cut through the entire brain, including the pons, medulla oblongata, cerebellum, and spinal cord at the back, in one smooth stroke if possible.
 5. Separate the two halves (hemispheres) of the brain and lay them with the inside facing up.
 6. Identify and label (with colored pins) corpus callosum, lateral ventricle, fourth ventricle, thalamus, hypothalamus, pineal gland, arbor vitae, superior and inferior colliculi.
 7. Take a photograph of the labeled specimen to turn in as the document of your work.
 8. Finally, a section of the brain is cut to examine the difference between white matter and gray matter (cerebral cortex).

Step 3: Coronal cuts (side-to-side)

1. Make coronal sections - With one hemisphere of the brain, make a series of cuts from front to back, about 0.5 to 1 cm thick. Hold the scalpel as level as possible for each cut.
2. Examine the cross-section - Observe the difference between the outer gray matter (cell bodies) and the inner white matter (nerve fibers).

Photographing Sheep Brain Dissection as Evidence of Your Work

- Capturing clear and informative photographs during your sheep brain dissection is essential for documentation and sharing your findings.
- Take close-up photos of major structures - Corpus callosum, Fourth ventricle, Thalamus, Hypothalamus, Pineal gland, Superior and inferior colliculi, Cerebellum with arbor vitae. Include labels in your photographs or overlay text after taking the photos to identify structures.
- Attach the photograph as part of worksheet.

Disposal

1. Place the dissected brain specimen, gloves, and any disposable tools into a designated biohazard bag/container.
2. Throw used paper towels in the regular trash.
3. Remove gloves and place them in the regular trash

Clean the Work Surface

1. Sanitize your work surface with a disinfectant spray (like isopropyl alcohol) and paper towels. Allow the disinfectant to sit for the recommended time to ensure it is effective.
2. Be thorough, ensuring you cover all areas where biological materials may have come into contact.

Clean up tools

1. Always handle sharp instruments with extreme care.
2. Rinse all tools and the tray under warm running water to remove any visible debris or tissue remnants. Wash the tools and tray with warm, soapy water. Use a brush or sponge for sharps and never clean them with your fingers.

Wash hands

- Thoroughly wash your hands with soap and warm water for at least 30 seconds.

3.11: Activity 9

Insights from Sheep Brain Dissection

1. Which brain structures did you find most interesting, and why? Reflect on specific structures you identified (e.g., corpus callosum, cerebellum, thalamus). What surprised you about their appearance or function?
2. Did you encounter any difficulties in identifying structures or handling tools? How did you adapt to these challenges?
3. How can you apply what you learned from this dissection to your future studies or career in the biological sciences?

Key Terms and Definitions

- **Aphasia** - loss of language function
- **Arachnoid matter** - a fine, delicate membrane, the middle one of the three membranes (meninges) that surround the brain and spinal cord, situated between the dura matter and the pia matter.
- **Association area** - region of cortex connected to a primary sensory cortical area that further processes the information to generate more complex sensory perceptions.
- **Association tract** - white matter tract that connect different regions within the same hemisphere.
- **Basal nuclei** - nuclei of the cerebrum (with a few components in the upper brainstem and diencephalon) that are responsible for assessing cortical movement commands and comparing them with the general state of the individual through broad modulatory activity of dopamine neurons; largely related to motor functions, as evidenced through the symptoms of Parkinson's and Huntington's diseases.
- **Broca's area** - region of the frontal lobe associated with the motor commands necessary for speech production and located only in the cerebral hemisphere responsible for language production, which is the left side in approximately 95 percent of the population.
- **Central canal** - a cerebrospinal fluid (CSF)-filled space in the spinal cord that's part of the brain's ventricular system.
- **Central sulcus** - surface landmark of the cerebral cortex that marks the boundary between the frontal and parietal lobes.
- **Cerebral aqueduct** - a fluid-filled canal that runs through the midbrain connecting the third and fourth ventricles of the brain.
- **Cerebral cortex** - outer gray matter covering the forebrain, marked by wrinkles and folds known as gyri and sulci.
- **Cerebral hemisphere** - one half of the bilaterally symmetrical cerebrum.
- **Cerebrum** - region of the adult brain that develops from the telencephalon and is responsible for higher neurological functions such as memory, emotion, and consciousness.
- **Choroid plexus** - a network of blood vessels in each ventricle of the brain. It is derived from the pia matter and produces the cerebrospinal fluid.
- **Commissural tract** - white matter tract that extend between the two hemispheres to connect left and right regions of the cerebrum.
- **Corpus callosum** - large white matter structure that connects the right and left cerebral hemispheres.
- **Dura mater** - the outer, thick, strong membrane layer located directly under skull and vertebral column.
- **Dural sinus** - are a group of sinuses or blood channels that drains venous blood circulating from the cranial cavity.
- **Epidural space** - a potential space extending from the base of the skull to the sacral hiatus, just outside the dura of the spinal canal; contains blood vessels, fatty tissue, and fibrous tissue.
- **Falx cerebri** - a sickle-shaped fold of dura mater that separates the cerebral hemispheres of the brain.
- **Falx cerebelli** - a small midline fold of dura mater projecting anterior-ward from the skull and into the space between the cerebellar hemispheres.
- **Fourth ventricle** - the most inferiorly located ventricle (within the pons or in the upper part of the medulla oblongata, draining directly into the central canal of the spinal cord.
- **Gyrus** - ridge formed by convolutions on the surface of the cerebrum or cerebellum.
- **Insula** - small region of the cerebral cortex located deep within the lateral sulcus.
- **Interventricular foramina** - are two small channels that connect the brain's lateral ventricles to the third ventricle.
- **Lateral ventricles** - a pair of C-shaped cavities in the brain's cerebral hemispheres that are filled with cerebrospinal fluid (CSF)
- **Longitudinal fissure** - large separation along the midline between the two cerebral hemispheres
- **Occipital lobe** - region of the cerebral cortex directly beneath the occipital bone of the cranium.
- **Parietal lobe** - region of the cerebral cortex directly beneath the parietal bone of the cranium.
- **Postcentral gyrus** - ridge just posterior to the central sulcus, in the parietal lobe, where the primary somatosensory cortex is located.
- **Precentral gyrus** - ridge just anterior to the central sulcus, in the frontal lobe, where the primary motor cortex is located.
- **Prefrontal lobotomy** - Surgical operation where connections between the prefrontal cortex and other regions of the brain are severed.
- **Premotor cortex** - region of the frontal lobe responsible for planning movements that will be executed through the primary motor cortex.
- **Primary auditory cortex** - region of the cerebral cortex within the temporal lobe responsible for the perception of sounds.
- **Primary gustatory cortex** - region of the cerebral cortex within the insula responsible for the perception of taste.
- **Primary motor cortex** - located in the precentral gyrus and responsible for the movement of skeletal muscles.

- **Primary olfactory cortex** - region of the cerebral cortex within the temporal lobe responsible for the perception of smell.
- **Primary somatosensory cortex** - located in the postcentral gyrus and responsible for the perception of soma to sensation.
- **Primary visual cortex** - region of the cerebral cortex within the occipital lobe responsible for the perception of vision.
- **Sensory homunculus** - topographical representation in the postcentral gyrus of somatosensory neurons that sense the respective body regions.
- **Soma to sensation** - general senses related to the body, usually thought of as the senses of touch, which would include pain, temperature, and proprioception.
- **Subarachnoid space** - the area between the arachnoid and pia mater of the brain and spinal cord that contains cerebrospinal fluid (CSF) and other component.
- **Sulcus** - groove formed by convolutions in the surface of the cerebral cortex.
- **Subdural space** - a potential space between the dura mater and arachnoid mater that surrounds the brain and spinal cord. Under normal conditions, there is no occurring space between the dura and arachnoid mater. After a trauma or a pathological condition, this space can come into existence.
- **Temporal lobe** - region of the cerebral cortex directly beneath the temporal bone of the cranium.
- **Tentorium cerebelli** - crescent-shaped fold of dura matter that separates the brain's cerebellum and brainstem from the cerebral hemispheres.
- **Third ventricle** - forms a narrow midline space between the right and left thalamus, and communicates with the lateral ventricles and the fourth ventricle through duct or aperture.
- **Ventricles** - a network of fluid-filled cavities in the brain that are responsible for cushioning the brain and circulating cerebrospinal fluid (CSF)
- **Visual association area** - region of cortex connected to the primary visual cortex that further processes the information to generate more complex sensory perceptions.
- **Wernicke's area** - region at the posterior end of the lateral sulcus in which speech comprehension is localized.

4: EXPLORING GENERAL AND SPECIAL SENSES

Introduction

In this lab, we will explore the fascinating world of human senses, focusing on both general and special senses. Our primary objectives are to understand the anatomy and physiology of sensory organs, investigate the mechanisms by which we perceive stimuli, and learn how these senses contribute to our overall experience of the environment.

- General Senses: These include touch, temperature, pain, and proprioception, which are detected by receptors distributed throughout the body.
- Special Senses: These include vision, hearing, taste, smell, and balance, which are associated with specific organs and complex structures.

Learning Objectives

- Identify and differentiate between general senses (touch, temperature, pain) through hands-on experiments.
- Conduct neurological tests to analyze the functionality of special senses (sight, hearing).

4.1: Background Information

4.2: Activity 1

4.3: Activity 2

4.4: Activity 3

4.5: Activity 4

4.6: Activity 5

4.7: Activity 6

4.8: Activity 7

4.9: Activity 8

4.10: Activity 9

4.11: Activity 10

4.12: Activity 11

4.13: Activity 12

4.14: Activity 13

4.15: Activity 14

4.16: Activity 15

4.17: Glossary

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4.1: Background Information

Overview

Human bodies are continually exposed to an onslaught of sensory information, both externally from the environment and internally within the body. These changes in the external or internal environment are called stimuli. Our conscious awareness of incoming sensory information is called sensation. Only a stimulus that reaches the cerebral cortex of the brain results in a sensation of that stimulus. Thus, although our bodies are constantly bombarded by sensory stimuli, we are consciously aware of only a fraction of these stimuli. Stimuli are detected by receptors. This lab focuses on receptors for the general senses (temperature, pain, touch, stretch, and pressure) and receptors for the special senses (gustation, olfaction, vision, equilibrium, and hearing). There are different types of sensory receptors that respond to stimuli:

- Mechanoreceptors respond to mechanical forces such as pressure, vibration, and stretching. Examples include tactile receptors like Meissner's and Pacinian corpuscles, which detect touch and vibration, and baroreceptors, which monitor changes in blood pressure.
- Thermoreceptors detect temperature changes. Cold receptors respond to decreasing temperatures, while warm receptors respond to increasing temperatures.
- Nociceptors are responsible for detecting pain. They respond to potentially harmful stimuli—thermal, mechanical, or chemical—to alert the body to possible injury.
- Photoreceptors respond to light. Rods allow vision in low-light conditions, while cones provide color vision and visual acuity.
- Chemoreceptors detect specific chemicals. They are primarily located in taste buds on the tongue, enabling the sense of taste, and in the nasal passages, where they contribute to the sense of smell.

General Senses

General senses are all associated with touch and lack special sense organs. These receptors allow us to react to stimuli. Slowly adapting receptors continue sending impulses to the brain for a relatively long time when a constant stimulus is applied. Rapidly adapting receptors fire at the time a stimulus begins and sometimes again when it is removed, but they do not continue firing to a constant stimulus. Having receptors with different preferences and different “reporting” capabilities allows us to tune in more acutely to our environment and distinguish a wide variety of sensations.

Table 4.1.1: Overview of Skin Receptors - Types, Stimuli Detected, Sensation Types, and Adaptation Rates when Stimulated.

Receptor	Stimulus	Sensation	Adaptation
Free nerve endings	Painful stimuli, hot and cold, light touch	Pain, Slow thermal and light touch	Slow
Merkel disc	Vibrations at low frequencies (5 to 15 Hz), tissue displacement	Spatial details (Braille for reading)	Slow
Meissner corpuscle	Low frequency vibration	Light touch receptors	Rapid
Ruffini's corpuscle	Rapid indentation, direction and force	Touch, Skin Stretch	Slow

Receptor	Stimulus	Sensation
Pacinian corpuscle	Vibration frequency: 100 Hz to 300 Hz	Touch Vibration
Hair receptor	Hair deflection; direction and velocity	Hair movement and skin deflection

Using our tactile sense, we detect superficial and deep pressure and sensations we describe as brushing, vibration, flutter, and indentation. As mentioned before, our skin is also sensitive to temperature and pain, which we sense with different sets of receptors. These skin senses, along with muscle/joint position awareness or proprioception, make up the somatic senses.

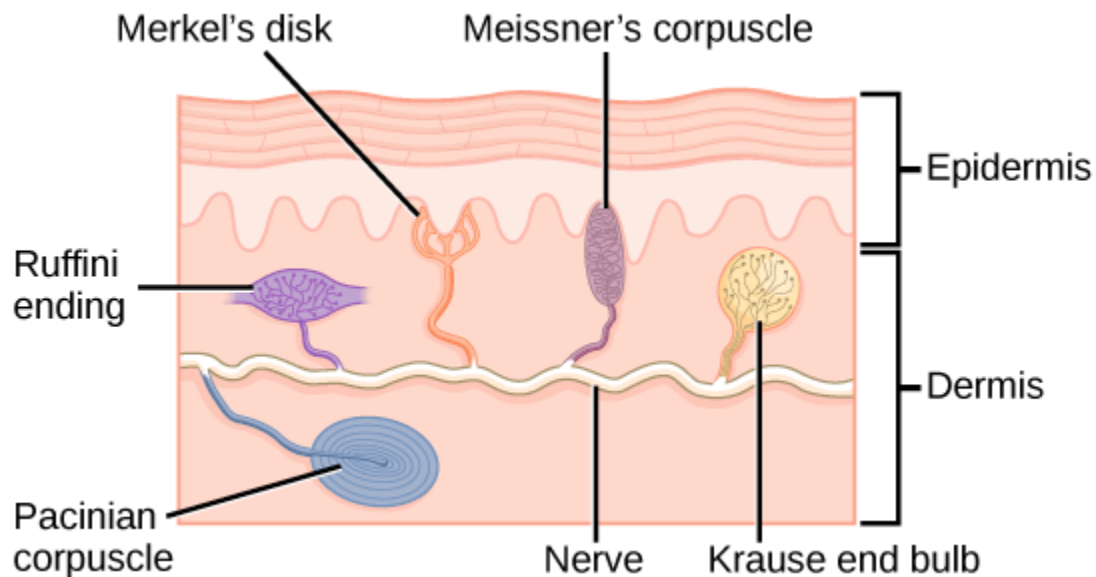


Figure 4.1.1: Distribution of major cutaneous sensory receptors within the epidermis and dermis of the skin. (CC BY-SA 4.0; via [Somatosensation - Somatosensation Receptors](#)).

Figure 4.1.1 is illustrating the four primary mechanoreceptors found in human skin. The diagram shows a cross-section of skin with two main layers labeled on the right: epidermis (outer layer) and dermis (deeper layer). Several sensory receptors are labeled to show where different touch-related receptors are located within the skin. Labeled structures:

- Merkel's disk: a touch receptor shown near the boundary between the epidermis and dermis.
- Meissner's corpuscle: a touch receptor shown in the upper dermis, close to the epidermis.
- Ruffini ending: a receptor shown deeper in the dermis.
- Pacinian corpuscle: a large, layered receptor shown deep in the dermis.
- Krause end bulb: a receptor shown in the dermis.
- Nerve: a nerve fiber shown extending through the dermis toward the receptors.

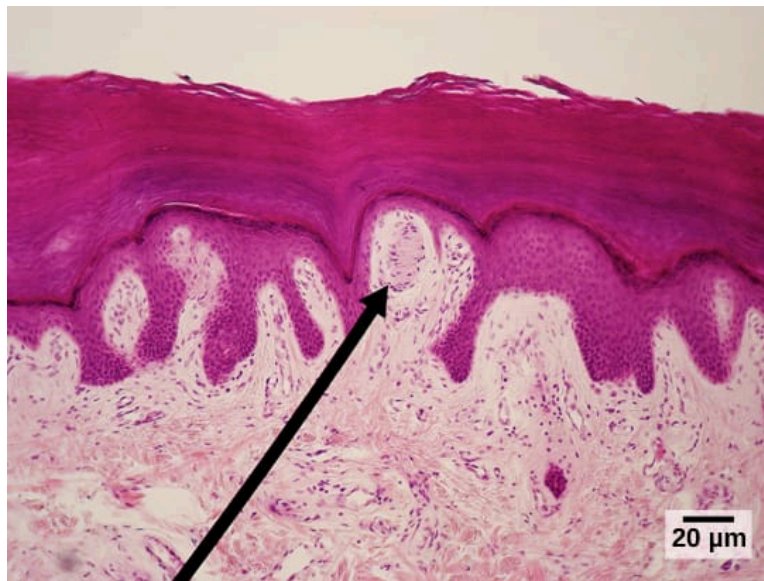


Figure 4.1.2: Meissner corpuscles: Meissner corpuscles in the fingertips, such as the one viewed here using bright field light microscopy, allow for touch discrimination of fine detail. (CC BY-SA 4.0; via [Somatosensation - Somatosensation Receptors](#)).

Figure 4.1.2 is a right field light microscopy image of Meissner corpuscles located in the fingertips. The image highlights these specialized mechanoreceptors, which are responsible for touch discrimination of fine detail. The structure of the Meissner corpuscle is visible, showcasing its encapsulated form and close association with the sensory nerve fibers, underscoring its role in tactile sensation.

Touch receptors such as Meissner's corpuscles and Pacinian corpuscles are abundant in the skin. The density of these touch receptors varies greatly over the surface of the body, giving certain areas greater ability to "feel." Note the image below that shows the areas of sensory cortex allocated to various regions of the body, and where the information is processed in the somatosensory gyrus.

There are a few main similarities and differences to be aware of regarding pain vs. touch pathways. The dorsal column terminates neuron one in the nuclei of the medulla, then separates into two component tracts, targeting specific fibers. The fasciculus gracilis (contains axons from the legs and lower body) targets the nucleus gracilis, while the fasciculus cuneatus (contains axons from the upper body and arms) targets the nucleus cuneatus.

The spinothalamic tract neurons extend their axons to the dorsal horn, where they synapse with the second neuron. Axons from these second neurons then decussate within the spinal cord and ascend to the brain and enter the thalamus, where each synapses with the third neuron in its respective pathway. In the dorsal column system, this decussation takes place in the brainstem; in the spinothalamic pathway, it takes place in the spinal cord at the same spinal cord level at which the information entered. Not only does pain projects to the contralateral primary somatosensory cortex, but it does to the limbic system as well. If you want to motivate a strong reaction from someone, the limbic system is a good target!

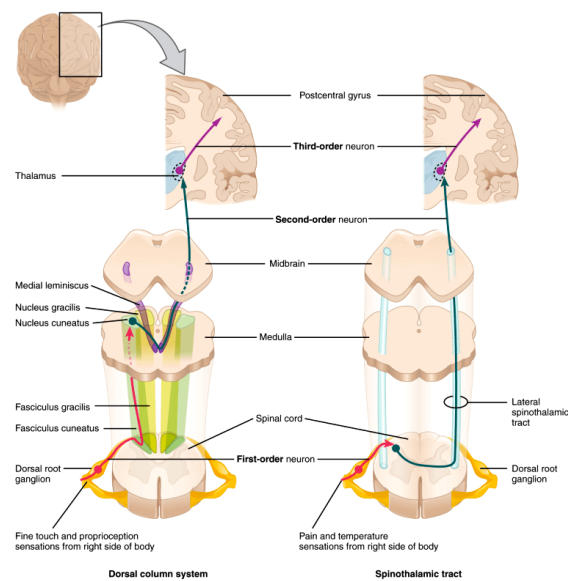


Figure 4.1.3: Ascending sensory pathways of the spinal cord. The dorsal column system and spinothalamic tract are the major ascending pathways that connect the periphery with the brain. (CC-BY 4.0; Dr.Cheryl Olman via [Pain Pathways in the Brain](#)).

Figure 4.1.3 compares two ascending sensory pathways that carry information from the body to the brain. The left side shows the dorsal column system (fine touch and proprioception). The right side shows the spinothalamic tract (pain and temperature). Both pathways are shown as a sequence of first-order, second-order, and third-order neurons projecting from the spinal cord to the thalamus and then to the postcentral gyrus (primary somatosensory cortex).

Left panel - Dorsal column system (fine touch and proprioception)

Sensory modality: fine touch and proprioception from the right side of the body.

1. First-order neuron: begins in the periphery with the cell body in the dorsal root ganglion and enters the spinal cord.
2. The axon ascends in the fasciculus gracilis and/or fasciculus cuneatus (dorsal columns).
3. Second-order neuron: synapses in the nucleus gracilis and nucleus cuneatus in the medulla.
4. The pathway continues upward through the brainstem as the medial lemniscus toward the thalamus.
5. Third-order neuron: relays from the thalamus to the postcentral gyrus.

Right panel: Spinothalamic tract (pain and temperature)

Sensory modality: pain and temperature from the right side of the body.

1. First-order neuron: begins in the periphery with the cell body in the dorsal root ganglion and enters the spinal cord.
2. Second-order neuron: synapses in the spinal cord and then ascends in the lateral spinothalamic tract through the spinal cord and brainstem.
3. The pathway projects to the thalamus.
4. Third-order neuron: relays from the thalamus to the postcentral gyrus.

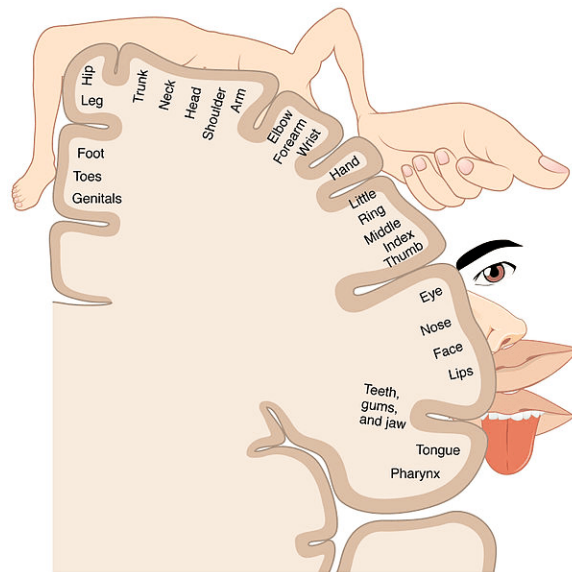


Figure 4.1.4: Homunculus (Latin for "little man" or "little person"): Image representing the cortical sensory homunculus. It shows how the anatomical portions of the body, such as the tongue, elbow, and hip, are mapped out on the homunculus. The surface area of cortex dedicated to a body part correlates with the amount of somatosensory input from that area. (CC-BY 4.0; via [The Somatosensory system](#)).

Figure 4.1.4 presents the cortical sensory homunculus, a map of body regions on the primary somatosensory cortex (postcentral gyrus), emphasizing the relationship between body part representation and sensory processing in the brain. Different body parts are represented by different amounts of cortical area, with the size of each part on the homunculus (an abstracted human body) corresponding to the amount of somatosensory input and sensitivity from that region. Areas with greater sensitivity—such as the hands, lips, and face—occupy more cortical space than less sensitive areas.

Moving from within the groove that separates the left and right hemispheres (longitudinal fissure) clockwise to the termination of the postcentral gyrus, we see ridges and folds labeled with groupings of body parts, as noted here:

- Foot, toes, genitals
- Leg, hip
- Trunk, neck, head, shoulder, arm
- Elbow, forearm, wrist
- Hand - by far the largest element on the homunculus
- Fingers and thumb, with the thumb shown as much larger than the fingers on the homunculus
- Eye, nose, face, lips. The lips are the largest part of this grouping on the homunculus.
- Teeth, gums, and jaw. These parts are labeled with a fold of the gyrus.
- Tongue, pharynx. The pharynx is not represented on the homunculus, while the tongue is shown as proportional to the lips.

Special Senses

Vision

Vision, or sight, is the ability to sense light and see. The eye is the special sensory organ that collects and focuses light and forms images. However, the eye is not sufficient for us to see. The brain also plays a necessary role in vision.

Anatomy of the Human Eye

The eye is located within the orbit and surrounded by soft tissues that protect and support its function. The orbit is surrounded by cranial bones of the skull. The human eye is a complex organ responsible for vision, which involves the reception of light and the processing of visual information. Understanding the anatomy of the eye is essential for comprehending how it functions in the visual system. The human eye's structure is intricately designed to optimize its function as a sensory organ, enabling clear vision and the ability to adapt to varying light conditions.

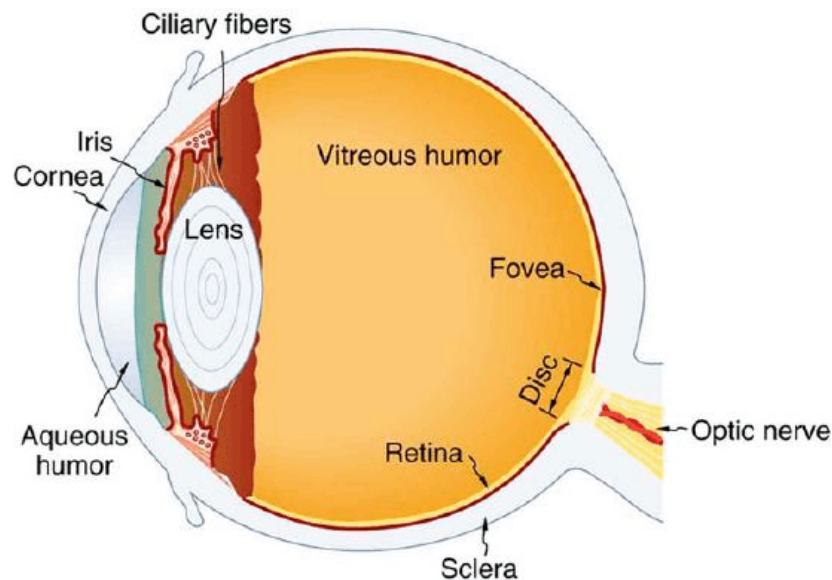


Figure 4.1.5: A simple cross-section showing how light enters through the cornea and lens, passes through the eye's fluids, and reaches the retina at the back of the eye, where visual signals are sent to the brain through the optic nerve. (CC By-SA 4.0; via [The Human Eye](#)).

Figure 4.1.5 is a diagram showing the structure of the human eye, illustrating its division into the anterior cavity, which contains aqueous humor (a clear fluid), and the posterior cavity, filled with vitreous humor (a clear gel). The wall of the eye is composed of three layers: the fibrous tunic (sclera), the vascular tunic (choroid), and the neural tunic (retina). The image highlights how the cornea and lens work together to form a real image on the retina, which has the densest concentration of photoreceptors in the fovea and a blind spot over the optic nerve.

Understanding the Design

The eye is a fluid-filled sphere enclosed by three layers of tissue. Most of the outer layer is composed of a tough white fibrous tissue, the sclera. At the front of the eye, however, this opaque outer layer is transformed into the cornea, a specialized transparent tissue that permits light rays to enter the eye. The cornea's curvature and its ability to maintain its shape are vital for proper visual acuity.

The middle layer of tissue includes three distinct but continuous structures: the iris, the ciliary body, and the choroid. The iris is the colored portion of the eye that can be seen through the cornea. It contains two sets of muscles with opposing actions, which allow the size of the pupil (the opening in its center) to be adjusted under neural control (adapting to bright and dim conditions).

The ciliary body is a ring of tissue that encircles the lens (refines the focus by changing shape, a process called accommodation) and includes a muscular component that is important for adjusting the refractive power of the lens, and a vascular component (the so-called ciliary processes) that produces the fluid that fills the front of the eye. The choroid is composed of a rich capillary bed that serves as the main source of blood supply for the photoreceptors of the retina. Only the innermost layer of the eye, the retina, contains neurons that are sensitive to light and are capable of transmitting visual signals to central targets.

En route to the retina, light passes through the cornea, the lens, and two distinct fluid environments. The anterior chamber, the space between the lens and the cornea, is filled with aqueous humor, a clear, watery liquid that supplies nutrients to these structures as well as to the lens. Aqueous humor is produced by the ciliary processes in the posterior chamber (the region between the lens and the iris) and flows into the anterior chamber through the pupil. A specialized meshwork of cells that lies at the junction of the iris and the cornea is responsible for its uptake. Under normal conditions, the rates of aqueous humor production and uptake are in equilibrium, ensuring a constant intraocular pressure. Abnormally high levels of intraocular pressure, which occur in glaucoma, can reduce the blood supply to the eye and eventually damage retinal neurons. The space between the back of the lens and the surface of the retina is filled with a thick, gelatinous substance called the vitreous humor, which accounts for about 80% of the volume of the eye. In addition to maintaining the shape of the eye, the vitreous humor contains phagocytic cells that remove blood and other debris that might otherwise interfere with light transmission.

Eyelids protect the eye from injury and help to keep the surface of the eye moist by spreading tears over the surface during blinking. The lacrimal apparatus - includes the lacrimal glands, which produce tears, and the lacrimal ducts, which drain tears into

the nasal cavity. Tears help to keep the eye lubricated and provide nutrients to the cornea.

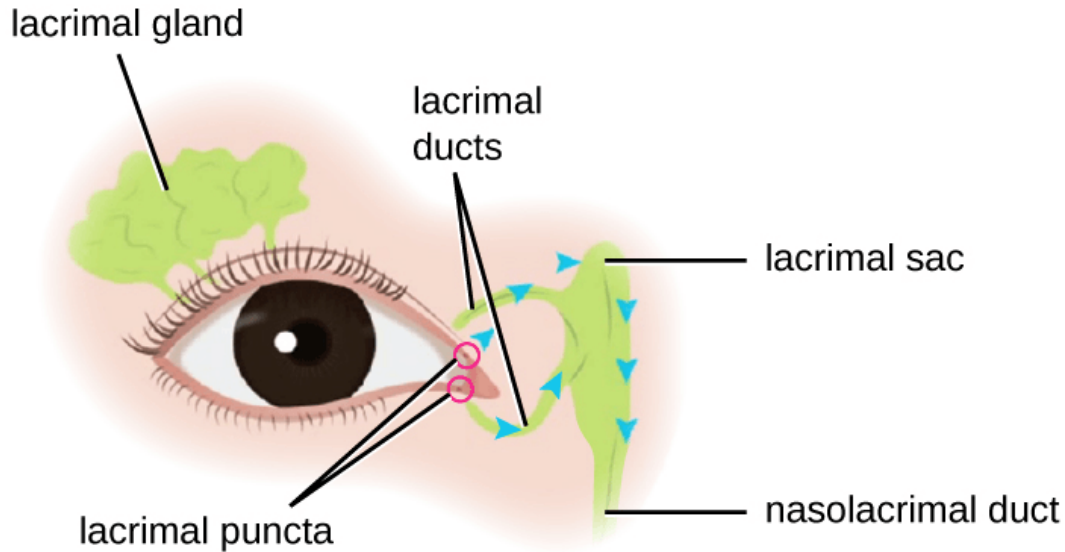


Figure 4.1.6: Frontal view of the lacrimal apparatus showing the flow of tears from the lacrimal glands to the nasolacrimal duct and nasal cavity. Note that the lacrimal canaliculi are shown as lacrimal ducts in the figure. (CC-BY 4.0; via [Wikimedia Commons](#)).

Figure 4.1.6 is a frontal view of the lacrimal apparatus illustrating the pathway of tear flow from the lacrimal glands to the nasolacrimal duct and into the nasal cavity. The diagram highlights the lacrimal canaliculi, labeled as lacrimal ducts, which collect tears from the eye. This visual representation emphasizes the anatomical relationships and functions of the various components involved in tear production and drainage that help maintain ocular health. This image is a labeled diagram of the lacrimal (tear) system, showing where tears are produced and how they drain from the eye. Labeled structures and flow:

- Lacrimal gland: produces tears.
- Lacrimal ducts: carry tears from the lacrimal gland to the surface of the eye.
- Lacrimal puncta: small openings near the inner corner of the eyelids where tears enter the drainage system.
- Lacrimal sac: collects tears after they pass through the puncta and associated drainage channels.
- Nasolacrimal duct: carries tears from the lacrimal sac downward into the nasal cavity.

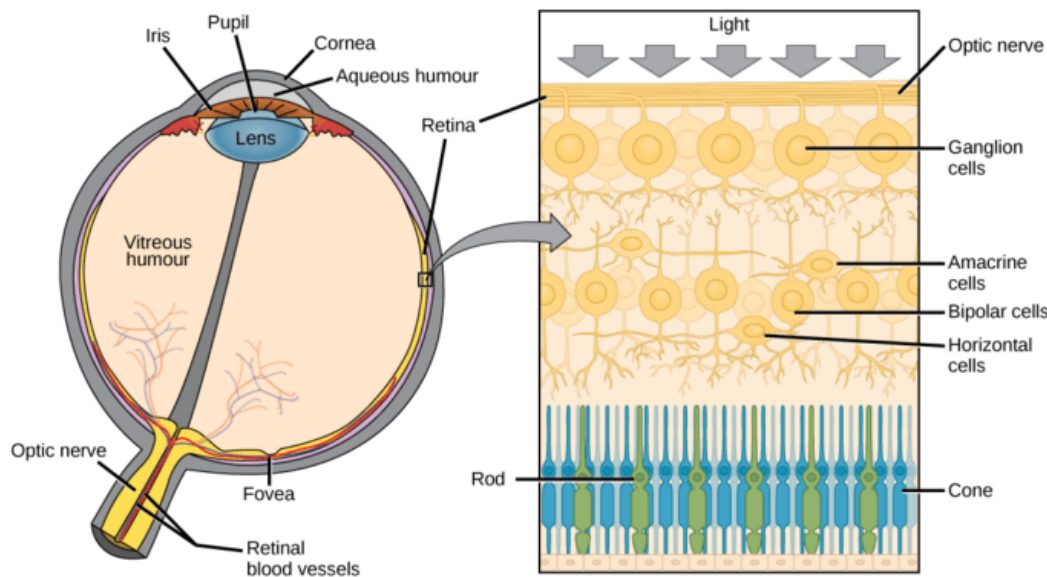


Figure 4.1.7: Retina: (a) The human eye is shown in cross section. The human eye contains structures, such as the cornea, iris, lens, and fovea, that process light so it can be deciphered by the retina. Other structures like the aqueous humor and the vitreous humor help maintain the shape of the eye. (b) A blowup shows the layers of the retina. The retina contains photoreceptive cells. In the retina, light is converted into neural signals sent to the brain. (CC BY-SA 4.0; via [Anatomy of the Eye](#)).

Figure 4.1.7 is a cross-sectional illustration of the human eye, displaying key structures such as the cornea, iris, lens, and fovea, which work together to process light for interpretation by the retina. The diagram also shows the aqueous humor and vitreous humor, which help maintain the eye's shape. Additionally, a magnified view reveals the layers of the retina, highlighting the presence of photoreceptive cells responsible for converting light into neural signals that are transmitted to the brain for visual processing.

Fovea centralis is a small depression in the retina where visual acuity is highest. It contains a high concentration of cones and is responsible for sharp central vision. Optic disc is the point where the optic nerve exits the eye. It is also known as the blind spot because it lacks photoreceptors; thus, no visual information is detected at this point.

Extraocular Eye Muscles: Structure, Location, and Actions

There are six extraocular skeletal muscles composed of striated muscle fibers, which allow for rapid and precise movements of the eye. Each muscle is relatively short and originate from the bony orbit (the eye socket) and insert onto the sclera of the eyeball. They work together to maintain binocular vision, ensuring that both eyes move in a coordinated manner. This coordination is essential for depth perception and a single, unified visual field. The primary action of these muscles is summarized:

- Elevation: The superior rectus and inferior oblique muscles elevate the eye.
- Depression: The inferior rectus and superior oblique muscles depress the eye.
- Adduction: The medial rectus moves the eye toward the nose.
- Abduction: The lateral rectus moves the eye away from the nose.
- Rotation: The superior and inferior oblique muscles facilitate rotational movements.

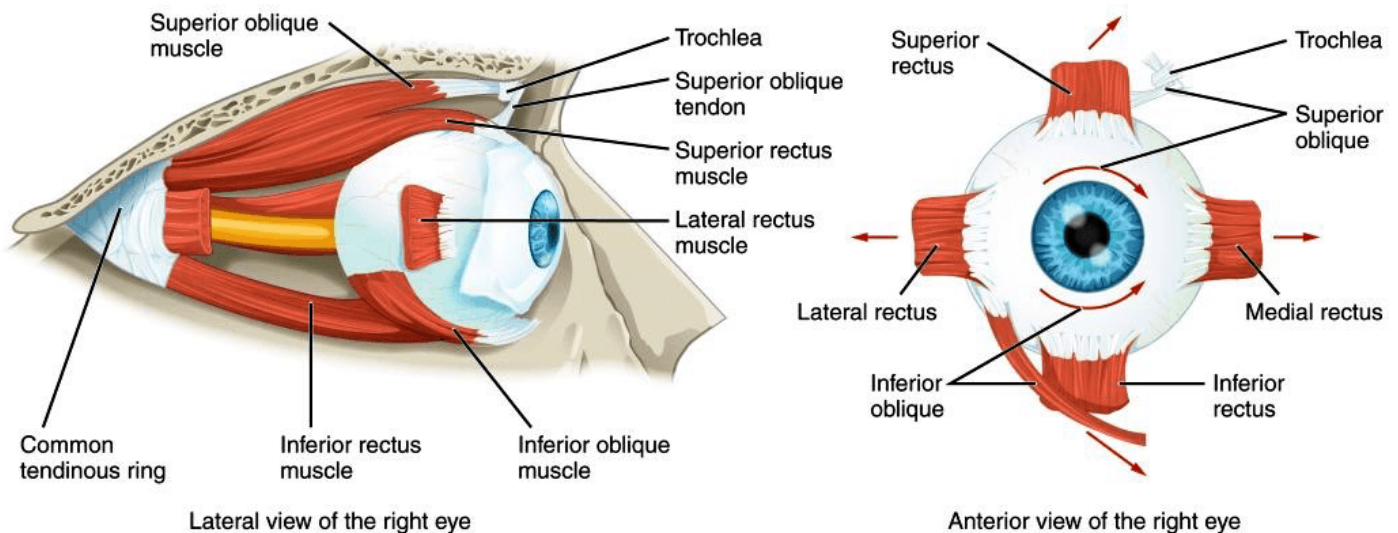


Figure 4.1.8: Extraocular Muscles. The image displays the six extraocular muscles responsible for eye movement, presented in lateral view (superior oblique, superior rectus, lateral rectus, inferior oblique, inferior rectus) and frontal view (superior oblique, medial rectus, inferior rectus, inferior oblique, lateral rectus and superior rectus). (CC BY 4.0; via Physiopedia).

Figure 4.1.8 is a lateral and frontal views of the six extraocular muscles responsible for eye movement. The lateral view displays the superior oblique, superior rectus, lateral rectus, inferior oblique, and inferior rectus muscles. The frontal view highlights the superior oblique, medial rectus, inferior rectus, inferior oblique, lateral rectus, and superior rectus muscles. This dual perspective provides a comprehensive understanding of the muscles' positions, attachments, and functions in relation to eye movement. The trochlea, a structure involved in the function of the superior oblique muscle, is also depicted in both views, enhancing the anatomical context of eye movement.

These muscles are innervated by three cranial nerves: the oculomotor (CN III), trochlear (CN IV), and abducens (CN VI) nerves, with the mnemonic "LR6 SO4 O3" helping to remember their innervation. The mnemonic "LR6 SO4 O3" helps remember the innervation of the extraocular muscles:

- LR6: Lateral rectus muscle is innervated by the abducens nerve (CN VI).
- SO4: Superior oblique muscle is innervated by the trochlear nerve (CN IV).
- O3: The remaining extraocular muscles (superior rectus, inferior rectus, medial rectus, and inferior oblique) are innervated by the oculomotor nerve (CN III).

Audition (Hearing)

Hearing, or audition, is the transduction of sound waves into a neural signal that is made possible by the structures of the ear. The large, fleshy structure on the lateral aspect of the head is known as the auricle or pinna. The C-shaped curves of the auricle direct sound waves toward the auditory canal. The canal enters the skull through the external auditory meatus of the temporal bone. At the end of the auditory canal is the tympanic membrane, or eardrum, which vibrates after it is struck by sound waves. The auricle, ear canal, and tympanic membrane are often referred to as the external ear. The middle ear consists of a space spanned by three small bones called the 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 stapes is then attached to the inner ear, where the sound waves will be transduced into a neural signal. 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.

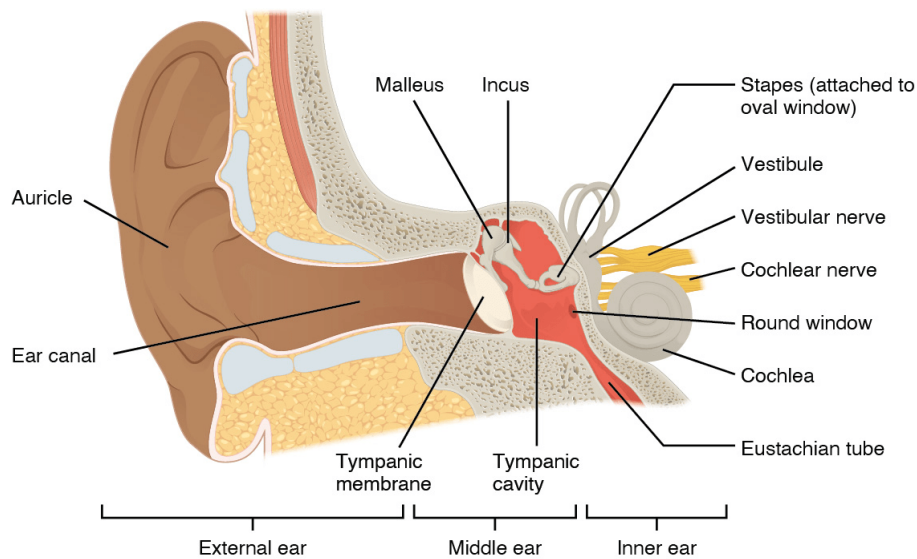


Figure 4.1.9: A simple cross-section showing how sound travels from the outer ear through the ear canal and middle-ear bones to the inner ear, where it is converted into nerve signals sent to the brain. (CC BY 4.0; via Audition).

Figure 4.1.9 illustrates the structures of the ear, including the external ear, middle ear, and inner ear. The external is composed of the auricle (the visible part of the ear), the ear canal, and the tympanic membrane (eardrum) deep within the ear canal. Behind the tympanic membrane is the tympanic cavity of the middle ear. The ossicles (malleus, incus, and stapes) are within this cavity, and are described above the figure. The stapes is attached to the inner ear via the oval window, and the round window is shown just below it. The inner ear region includes, in order as shown in the diagram:

- the vestibule, with the vestibular nerve
- the cochlear nerve runs parallel to the vestibular nerve, with the cochlea just below it

The vestibule and cochlea are connected, looking somewhat like a snail, with the cochlea similar to the shell and the vestibule like the body and head - but with two delicate loops instead of eye stems. The cochlea is responsible for hearing (audition), and the vestibule is responsible for balance (equilibrium).

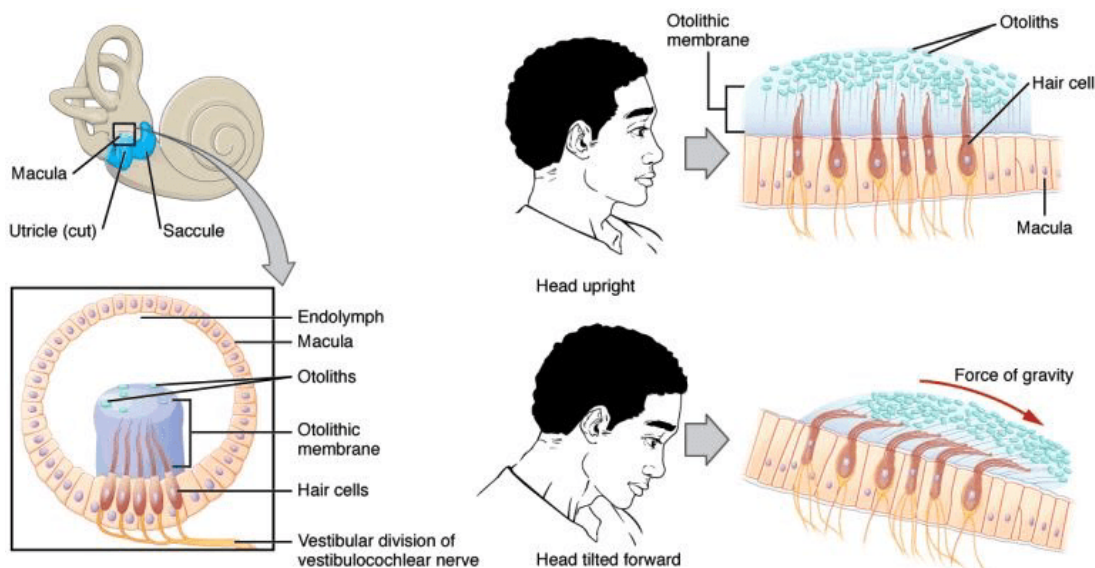


Figure 4.1.10: Linear Acceleration Coding by Maculae: The maculae are specialized for sensing linear acceleration, such as when gravity acts on the tilting head, or if the head starts moving in a straight line. The difference in inertia between the hair cell stereocilia and the otolithic membrane in which they are embedded leads to a shearing force that causes the stereocilia to bend in the direction of that linear acceleration. (CC BY-SA 4.0; via Anatomy & Physiology).

Figure 4.1.10 includes four diagrams that illustrate the vestibular system in the inner ear, which is responsible for detecting head position and maintaining balance.

Top Left: The vestibule and cochlea are shown with a region highlighted just below the loops of the vestibule. In this region we see two small structures, the utricle and saccule. They meet at the macula, a sensory region within the utricle and saccule that detects linear acceleration and head position.

Bottom Left: This simplified diagram shows a macula as a sphere filled with endolymph, a fluid that surrounds the sensory structures within. The macula is lined by the otolithic membrane, a gelatinous layer that moves in response to head tilts, stimulating hair cells beneath it. These hair cells are sensory receptors that convert mechanical movement into neural signals that are transmitted to the brain by the vestibular division of the vestibulocochlear nerve. Tiny calcium carbonate crystals called otoliths sit atop the otolithic membrane and shift with gravity or movement.

The top right and bottom right diagrams show how the otoliths within the macula shift when a man's head is moved from upright position to tilting forward. As gravity moves the otoliths, the underlying hair cells bend in response, altering the signals sent to the brain. This mechanism helps the body detect orientation and maintain equilibrium.

The diagram compares two head positions upright and tilted forward, to show how the otoliths shift, bending the hair cells differently and altering the signal sent to the brain. This mechanism helps the body detect orientation and maintain equilibrium.

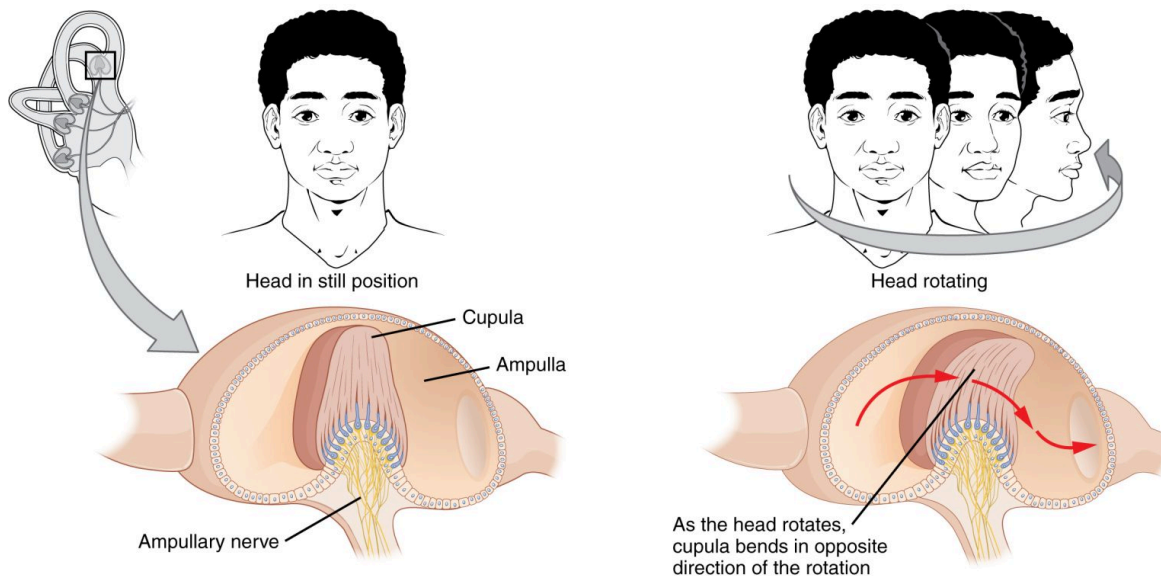


Figure 4.1.11: Semicircular canal ampulla during head rotation: cupula bends opposite rotation, stimulating the ampullary nerve. (CC BY-SA 4.0; via [Anatomy & Physiology](#)).

Figure 4.1.11 illustrates the rotational coding by semicircular canals in the inner ear. The image shows the semicircular canals and their associated hair cells located at the base, which are responsible for detecting rotational movements of the head. As the head moves in an arc, the internal fluid in the canals moves in the opposite direction, causing the cupula and stereocilia to bend. This bending indicates the direction of head movement. The diagram emphasizes that the activation of two canals within a plane provides information about head movement, while the simultaneous activation of all six canals offers precise indications of head movement in three-dimensional space. Labels highlight key structures involved in this sensory process.

Overview of the Neurological Exam

The neurological exam is a clinical assessment tool used to rapidly determine which specific parts of the CNS are affected by damage or disease. There are many aspects of this exam, including an assessment of motor and sensory skills, balance and coordination, mental status (the patient's level of awareness and interaction with the environment), reflexes, and functioning of the nerves. The extent of the exam depends on many factors, including the initial problem that the patient is experiencing, the age of the patient, and the condition of the patient. The exam can be broken down into the following subsets:

- Mental status exam assesses the higher cognitive functions such as memory, orientation, and language.

- Cranial nerve exam tests the function of the 12 cranial nerves and, therefore, the central and peripheral structures associated with them.
- The sensory exam tests the sensory functions associated with the spinal nerves.
- The motor exam tests the motor functions associated with the spinal nerves
- The coordination exam tests the ability to perform complex and coordinated movements.
- The gait exam specifically assesses the motor function of walking and can be considered part of the coordination exam because walking is a coordinated movement.

Reflex testing is an important diagnostic tool for assessing the condition of the nervous system. Distorted, exaggerated, or reflexes that are absent may indicate degeneration or pathology of portions of the nervous system, often before other signs are apparent. If the spinal cord is damaged, then reflex tests can help determine the area of injury. For example, motor nerves above an injured area may be unaffected, whereas motor nerves at or below the damaged area may be unable to perform the usual reflex activities. Closed head injuries, such as bleeding in or around the brain, may be diagnosed by reflex testing.

4.2: Activity 1

Two Point Discrimination Test

Two point discrimination is the ability to discern that two nearby objects touching the skin are truly two distinct points, not one. It is often tested with two sharp points during a neurological examination and is assumed to reflect how finely innervated an area of skin is. In clinical settings, two-point discrimination is a widely used technique for assessing tactile perception. It relies on the patient's ability and/or willingness to report what they are feeling subjectively and should be completed with their eyes closed. The purpose is to investigate pathological alteration in spatial acuity due to trauma or chronic pain or predictive measure of treatment effectiveness like nerve repairs, carpal tunnel release surgery or replant of amputated finger.

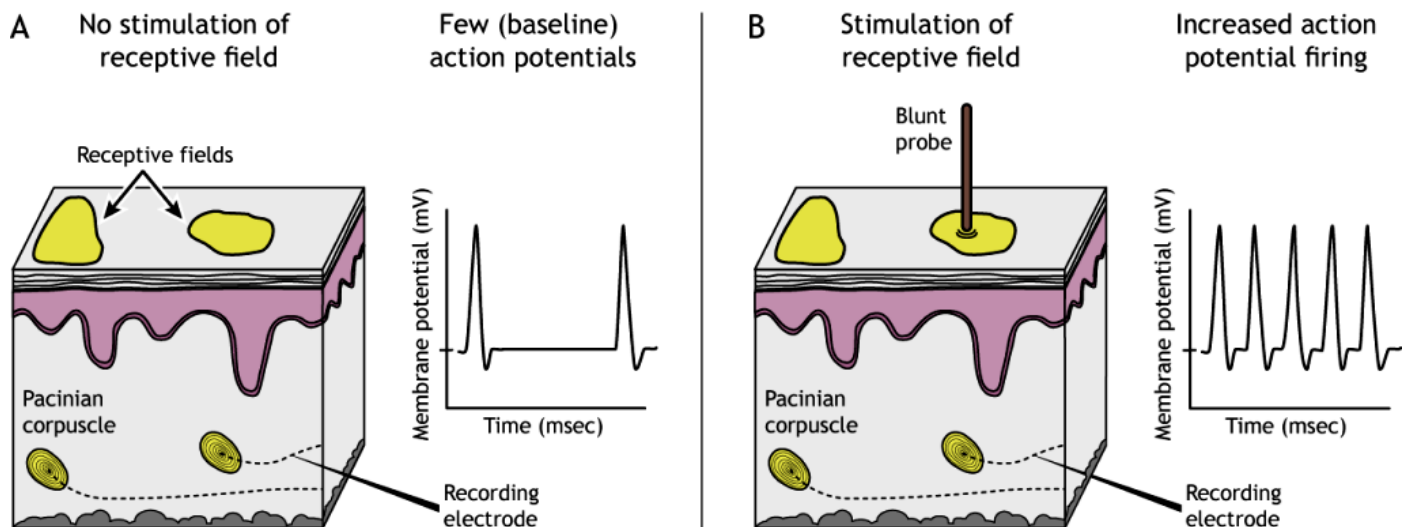


Figure 4.2.1: Touch receptor receptive field vs. firing rate: baseline activity without stimulation, increased spikes with pressure. (CC BY-NC-SA 4.0; Casey Henely via Touch: The Skin).

Figure 4.2.1 has two panels (A and B) comparing Pacinian corpuscle receptor activity with and without stimulation. In Panel A, the receptive field is not stimulated, and the recording trace shows only a few action potentials over time (baseline firing). In Panel B, a blunt probe presses on the receptive field in the skin, and the recording trace shows a higher frequency of action potentials (increased firing). The diagram labels the receptive field at the skin surface, the Pacinian corpuscle deeper in the tissue, and a recording site. The key message is that mechanical stimulation increases action potential frequency.

The examiner uses a paper clip, two-point discriminator, or calipers to apply pressure on two adjacent points in a longitudinal direction or perpendicular to the long axis of the finger. The minimal distance with which the patient can distinguish between two stimuli is found by moving from proximal to distal. This distance is called the threshold for discrimination. The area being tested must not be seen by the patient and the patient must concentrate on feeling the points. For accurate results, the hand must be immobile on a hard surface and it must be ensured that the two points are simultaneously touching the skin. The patient is asked to report whether one or two points were felt. The smallest distance between two points that still results in the perception of two distinct stimuli is recorded as the patient's two-point threshold. Performance on the two extremities can be compared for discrepancies. Although the test is still commonly used clinically, it has been roundly criticized by many researchers as providing an invalid measure of tactile spatial acuity, and several highly regarded alternative tests have been proposed to replace it. There must be no skin blanching as it indicates too much pressure being applied. There may be an increase or decrease in the distance between the points depending on the patient's response.

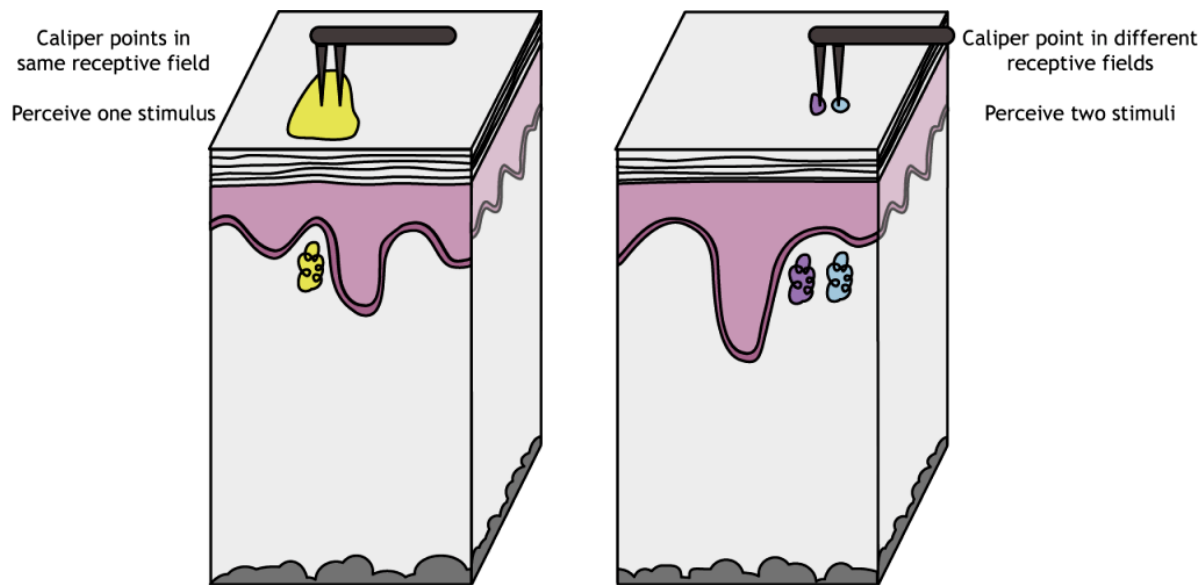


Figure 4.2.2: Illustration of two-point discrimination: perception of one stimulus when points fall in the same receptive field, and two stimuli when points fall in different receptive fields. (CC BY-NC-SA 4.0; Casey Henely via [Touch: The Skin](#)).

Figure 4.2.2 is an illustration showing the relationship between receptive field size and skin sensitivity using the two-point discrimination test. The image features tools like calipers and a paperclip assessing the skin's ability to distinguish between two separate points. It explains that feeling one point indicates activation of a large receptive field, while feeling two distinct points suggests activation of two smaller receptive fields, highlighting how receptive field size impacts tactile perception.

Normal and Impaired performance

Body areas differ both in tactile receptor density and somatosensory cortical representation. Normally, a person should be able to recognize two points separated by 2 to 8 mm on fingertips. On the lips, it is 2 to 4 mm, and on the palms, it is 8 to 12 mm and 30 to 40 mm on the shins or back. The posterior column-medial lemniscus pathway is responsible for carrying information involving fine, discriminative touch. Therefore, two-point discrimination can be impaired by damage to this pathway or to a peripheral nerve.

T Discrimination Value

- Normal <6 mm
- Fair 6 to 10 mm
- Poor 11 to 15 mm
- Protective where only one point is perceived.
- Anesthetic where points are not perceived.

Testing Procedure

1. Explain and demonstrate the procedure to the patient with their eyes open. "I am going to touch parts of your arms (or other body part) with this instrument. I will touch you with either one or two points, and tell me if you feel one or two points when you feel the touch."
2. The patient closes their eyes, or vision is otherwise occluded during the procedure.
3. Begin the test with the points of the aesthiometer opened greater than the mean value for the body part being tested.
4. Provide the stimulus by applying light and equal pressure across the two points.
5. Have the patient identify if they feel one or two points.
6. Move the two points closer together across consecutive trials until the patient cannot distinguish the two points as separate.
7. Measure the distance between the two points using the aesthiometer ruler.
8. Repeat the test for the areas indicated and record the values in the table.

Table 4.2.1: Two-Point Discrimination Test Results: Sensory Thresholds Across Different Body Areas

Area Tested	Forehead	Dorsum of hand	Palm of hand	Back of Shin	Fingertips
Two Point Threshold (mm)	7 - 10 mm	15 - 17 mm	8 - 12 mm	30 - 40 mm	2 - 8 mm
Your Data					
Variance from threshold					

Reflection and Analysis

1. Which skin areas have smallest two-point distances or largest two-point distances?
2. Explain the anatomical differences with emphasis on the structure-function-location relationships?

4.3: Activity 2

Tactile Localization Test

The tactile localization test looks at the relative distribution of tactile receptors in particular areas of the skin. Remember that sensitivity is a function of the number appropriate receptors present in an area. The more appropriate receptors there are, the more likely it is that the subject will be able to accurately localize (point to) an area that was touched. As you test each area, consider the survival advantages to being able to localize touch accurately.

Procedure

1. Obtain two markers/pens of different colors and a small millimeter ruler.
2. Have your subject close their eyes or look away, so that they cannot see where you are touching the skin.
3. For each of the areas listed in Table below, follow these steps:
 - a. Use your marker to place an ink dot on the skin in that area.
 - b. Now, have the subject use a different colored marker and place their ink dot where they felt you place a dot. Try to do this quickly.
4. Repeat Steps 3a and 3b in the same general area
 - Measure the distance between the pairs of ink dots. Record the results in the table and calculate the average.
5. After you complete the procedure for all areas
 - Put a double circle around the name of the area that you deem most sensitive based on the tactile localization tests.
 - Put a single circle around the area that you deem least sensitive based on the results of the tactile localization tests.

Table 4.3.1: Tactile Localization Test Results: Accuracy of Sensory Perception Across Body Regions

Body Area	Trial 1 Distance Between Ink Dots (mm)	Trial 1 Distance Between Ink Dots (mm)	Trial 1 Distance Between Ink Dots (mm)	Trial 1 Distance Between Ink Dots (mm)	Average Distance Between Ink Dots (mm)
Thigh or calf (anterior or posterior)					
Wrist (anterior)					
Palm (anterior)					
Upper arm					
Tip of the thumb					
Tip of the index finger					
Cheek					
Posterior neck					

Analysis of results

1. Are the results consistent across participants/volunteers?
2. On which body parts are participants most accurate?
3. Are there any regions where localization is consistently poor?

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4.4: Activity 3

Special Senses Laboratory Activities

We will explore the fascinating world of our special senses with engaging activities. Special senses allow us to interact with our environment and are essential for our daily experiences. Through hands-on experiments and observations, you will deepen your understanding of how these senses function and how they contribute to our perception of the world.

Dissection of the Mammalian Eye for Insight into Structure and Function

(If time permits, students will perform the dissection, otherwise, the instructor will use the dissected Cow eye to demonstrate this activity)

Checklist of eye structures to identify during the dissection of Cow's eye and relating to functions are choroid, ciliary body, cornea, iris, lens, optic disc (blind spot), optic nerve, pupil, retina, sclera, tapetum lucidum, vitreous humor.

Instructions

- Work in pairs or small groups to facilitate discussion and shared learning.
- Use a scalpel and scissors carefully to expose different layers of the eye—observe their textures and colors.
- Document your observations in a lab report, including labeled diagrams of the structures you examined.
- Discuss the functions of each part of the eye with your group.

Materials

Cow eye, Disposable gloves; Dissecting tray and tools (scissors, scalpel, forceps, blunt probe); Lab apron; Safety goggles/glasses.

Background

Cow eyes are larger than human eyes and yet they have many of the same structures. You will notice the squarish pupil (as opposed to the round pupil typical of humans), and you will notice an iridescent lining (usually purple) located at the back of the eye. This is not the retina, but part of the choroid. This iridescent structure is called the tapetum lucidum and it allows the eye to reflect light, especially at night. This helps animals see in dim light. You may have seen the tapetum lucidum when you shine a light into the eyes of cows, cats, dogs, deer, and other nocturnal animals. In humans, the choroid is red, rather than iridescent.

Procedure

Students must wear lab gloves, a lab apron and safety goggles for this dissection.

1. Obtain a dissecting tray, dissecting tools, and an eye.
2. Examine the external structures of the eye and identify the cornea, sclera and the optic nerve.
3. Make a frontal section through the sclera using a scalpel. A gel-like fluid will leak out of the posterior half. This is the vitreous humor.
4. In the posterior half of the eye, locate the retina. Use caution as layer easily peels away. Where it remains attached is the optic disc.

Observations

- Cornea: The cornea was clear and dome-shaped, allowing light to enter the eye. Its curvature is essential for focusing light.
- Lens: The lens was flexible and transparent, allowing for adjustments in focus. We learned about accommodation and how the lens changes shape to focus on near or distant objects.

- Retina: The retina appeared thin and delicate. Upon closer inspection, we observed the presence of blood vessels and the optic disc, where the optic nerve exits the eye.
 - Vitreous Humor: The jelly-like vitreous humor maintained the shape of the eye and provided support to the retina.
 - Tapetum lucidum - A reflective layer of tissue located at the back of the eye in many animal species, including cats, dogs, and deer. It acts as a mirror, reflecting light back onto the retina, enhancing vision in low-light conditions and causing the characteristic "eyeshine" effect. Humans do not have a tapetum lucidum.
5. Take a photograph. The labeled photograph (with the structures mentioned above) will be part of completed lab worksheet submission.
 6. To clean up
 - Place the eye parts and the used paper towels in the "dissection waste" container.
 - Remove and rinse the blue dissecting pad from the dissecting tray and place it in the drying rack. Rinse the dissecting tray separately and leave them on the cart.
 - Careful! Tools are sharp! Thoroughly clean your dissecting tools with soap and water. Dry them with paper towels and once dry, put them away neatly.
 - Wipe down your lab bench with disinfectant.

4.5: Activity 4

Identify Parts of Eye

Identify and describe the function of each of the structures, layers, cavities, and chambers of the eye indicated by letters on the image. Use the laboratory eye model.

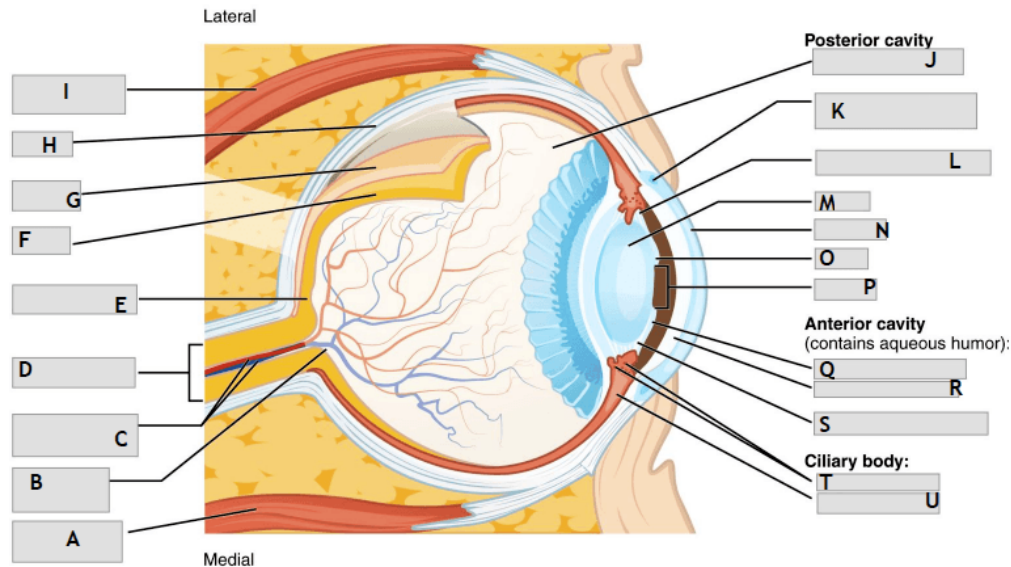


Figure 4.5.1: Cross-sectional diagram of the human eye with labeled parts: posterior cavity, anterior cavity (contains aqueous humor), and ciliary body. (CC BY 3.0; via [Wikipedia Commons](#)).

Figure 4.5.1 is a detailed cross-sectional diagram of the human eye. It labels key structures, including the posterior cavity, anterior cavity (which contains aqueous humor), and the ciliary body.

- Outer wall of the eye: multiple layers forming the outer boundary of the eyeball.
- Internal structures: a large central cavity filled with gel-like material, and a focusing structure near the front of the eye.
- Anterior and posterior cavities: the diagram labels a posterior cavity and an anterior cavity (contains aqueous humor).
- Ciliary body region: the diagram includes a labeled area for the ciliary body, which is associated with lens support and fluid dynamics.

Table 4.5.1: Letter identification of eye structures.

Letter	Identification of the structures
	Ciliary process
	Ciliary muscle
	Cornea
	Anterior chamber
	Aqueous humor
	Iris
	Lens
	Posterior chamber
	Pupil

Letter	Identification of the structures
	Sclera

Table 4.5.2: Letter identification of posterior eye structures and associated components.

Letter	Identification of the structures
	Vitreous humor in posterior cavity
	Retina
	Choroid
	Suspensory ligament
	Fovea centralis
	Optic disc (Blind spot)
	Optic nerve (Cranial nerve II)
	Medial rectus muscle
	Lateral rectus muscle
	Central retinal artery and vein
	Scleral venous sinus

4.6: Activity 5

Match the Descriptions

Match the Column A with the structures in Column B to establish structure - function relationships

Table 4.6.1: Matching letters to eye structure descriptions.

Matching Letter	Column A (Description)	Column B
	Outer layer of wall of eye	A. Aqueous humor
	Middle vascular layer of wall of eye	B. Blind spot
	Inner light-sensitive layer of wall of eye	C. Choroid
	Fluid between lens and cornea	D. Ciliary body
	Fluid between lens and back of eye	E. Cornea
	Small pit in retina of eye	F. Conjunctiva
	Small area at back of eye that lacks photoreceptors	G. Fovea centralis
	Membrane that lines eyelid and covers cornea	H. Iris
	Drain tubes for tears in eyelids	I. Lacrimal ducts
	Tube that drains tears to nasal cavity	J. Nasolacrimal ducts
	Transparent front portion of eyeball	K. Pupil
	Region containing muscle to regulate lens shape	L. Retina
	Opening in the center of the iris	M. Sclera
	Connective tissue holding lens in place	N. Suspensory ligament
	Circular band of smooth muscle around lens	O. Vitreous body

4.7: Activity 6

Determine Dominant Eye

Basically, your dominant eye is the one that makes the object appear centered between your thumbs and pointer fingers when only that eye is open. Dominant eye tests are also a great tool if you take part in certain activities, including work and leisure.

- A doctor will use their dominant eye to examine a patient's ears with an otoscope and their eyes with an ophthalmoscope.
- If you play any sport with a physical goal or basket, you may rely more on your dominant eye to achieve accuracy — and points! Think along the lines of basketball, soccer, golf, and hockey.

Not sure which of your eyes is dominant? You can perform a basic assessment.

- Hold your arms out in front of you and create a triangular shape between your two thumbs and two pointer fingers.
- While keeping both eyes open, center or frame the triangle shape you've created around a distant object, such as a doorknob or light switch.
- Bring the "triangle" of your hands closer to your face.
- Now, close your left eye and keep your right eye open.
- If the object you chose was centered in the triangle while only your right eye was open, you are right-eye dominant.
- If the object appeared outside the triangle while only your right eye was open, you may be left-eye dominant.
- Now try again. This time, close your right eye and leave your left eye open.
- If the object you chose remained centered in the triangle while only your left eye was open, you are left-eye dominant.

Reflection:

Which is your dominant eye? _____

There is a statistical association between dominant eye and handedness, but the correlation is moderate and not absolute. Most right-handed individuals are right-eye dominant, and most left-handed individuals are left-eye dominant, although a significant proportion of left-handers are right-eye dominant and some right-handers are left-eye dominant.

- About 70% of people are right-eye dominant, and the majority of these are also right-handed.
- Meta-analyses report that 34 to 36% of right-handers are left-eye dominant and 57% of left-handers are left-eye dominant; thus, the association is present but far from perfect.
- Studies show that the concordance (same side dominance) odds ratio is about 2.5 times greater than expected by chance, but many individuals display crossed dominance (e.g., right-handed but left-eye dominant).
- Some sources report no strong correlation and emphasize that eye and hand dominance do not always match, reflecting independent lateralization process.

Are you right or left handed? _____

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4.8: Activity 7

Understanding and Demonstrating Blind Spot

The blind spot is the region of the optic disk that contains no photoreceptor cells. Even though the blind spot is technically part of the retina, it cannot detect light because there is no photoreceptor. It is in this region that the optic nerve exits the eye on its way to the brain. Usually, when light hits the blind spot, the brain must “fill in the gaps”. Here you will have a chance to observe your own blind spot.



Figure 4.8.1: A simple diagram showing a black circle on the left side and a black cross on the right side within a rectangular frame. (CC BY-NC-SA 4.0; LakshimiKanta Sengupta).

Figure 4.8.1 depicts a minimalist diagram with two distinct shapes inside a rectangle. On the left side, there is a solid black circle, while on the right side, there is a solid black cross. The shapes are positioned against an otherwise plain white background.



Figure 4.8.2: A simple diagram showing a black circle on the right side and a black cross on the left side within a rectangular frame. (CC BY-NC-SA 4.0; LakshimiKanta Sengupta).

Considerations

- Ensure that you are in a well-lit area to avoid straining your eyes.
- Do not rush the process; take your time to observe the changes in your vision.
- To find your blind spot, look at the image below or draw it on a piece of paper: Left Eye open focus on the + sign and Right Eye open focus on the + sign
- Keep the visual (a piece of paper or the computer screen) 45 cm away from your eyes.
- Cover your right eye, keep the left eye open focusing on the + sign and slowly move closer (Keep looking at the +) until the circle vanishes from your peripheral vision. (If it doesn't disappear, concentrate harder on the +).
- Measure the distance between the paper/computer screen and LEFT eye, Record (cm). _____
- Repeat this for your RIGHT eye. Cover your left eye, keep the right eye open focusing on the + sign and slowly move closer

(Keep looking at the +) until the circle vanishes from your peripheral vision. (If it doesn't disappear, concentrate harder on the +).

- Measure the distance between the paper/computer screen and RIGHT eye, Record (cm). _____

The blind spot demonstration illustrates an important aspect of human vision. Understanding the blind spot helps in comprehending how the eye and brain work together to create a complete visual experience. This experiment not only shows the anatomical limitations of the eye but also enhances awareness of the complexities involved in vision.

4.9: Activity 8

Histology of the Retina - Microscopic View

Take out the microscope and the prepared slide of the retina. Draw the histology of retina under high power magnification (Total magnification 400 times), and label the following structures: choroid, pigmented epithelium, photoreceptors, bipolar cells, and ganglion cells.

1. Gather necessary materials: microscope, prepared slides of the retina.
2. Place the prepared retina slide on the microscope stage. Start with the lowest power objective (4 times) to locate the general structure of the retina.
3. Gradually increase the magnification to 10 times and then to 40 times.
4. Carefully observe and identify the following layers and cells (Total magnification 400 times): choroid, pigmented epithelium, photoreceptors, bipolar cells, and ganglion cells.
5. Sketch the retina and label the identified layers and cells. Alternately, take a photomicrograph that can be the evidence of your work.
6. Discuss your observations with your peers or instructor, focusing on the functional significance of each layer in the context of vision.

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4.10: Activity 9

Visual Acuity Testing with Snellen Chart

Visual acuity is the clarity with which one sees fine detail. It is a measure of the resolving power of the eye as determined by the spacing of the cones, and on the accuracy with which the refracting system of the eye focuses an image on the retina. The latter depends on the shape of the eyeball, lens and cornea, on the diameter of the pupil, and on the transparency of the elements of the refracting system.

Visual acuity is generally tested with a Snellen eye chart, which consists of letters of various sizes printed on a white card. This test is based on the fact that letters of a certain size can be seen clearly by the eyes with normal vision at a specific distance. The distance at which the normal eye can read a line of letters is printed at the end of that line.

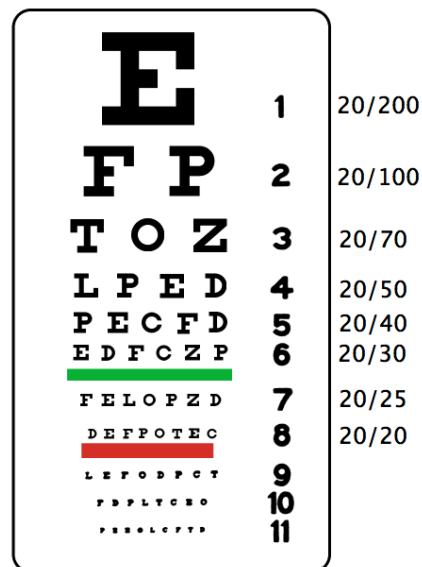


Figure 4.10.1: A Snellen eye chart used for measuring visual acuity. (Public Domain; via [Wikimedia Commons](#)).

Figure 4.10.1 This image is a Snellen eye chart used for testing vision. It consists of eleven rows of letters that decrease in size as you move down the chart. Each row is labeled with a number on the right side indicating the visual acuity level, starting at 20/200 for the largest letter at the top and ending at 20/20 for the smallest letters at the bottom.

For this activity, the subject will cover first one eye and then the other and be asked to read a chart with decreasing letter sizes from 20 feet away. From this we learn whether you are “normal” or nearsighted. We can then assess the extent of the curvature of concave lens required to correct your vision.

Test Sequence

Each student should perform the test in the following order:

- Both eyes, with glasses (if worn)
- Both eyes, without glasses
- Right eye, with glasses
- Right eye, without glasses
- Left eye, with glasses
- Left eye, without glasses

Step by Step Instructions:

1. Subject standing exactly 20 ft from the Snellen eye chart posted on the wall of the lab. 20/20 is considered “perfect” vision.
2. Have the lab mate stand at the Snellen chart to guide you as you take this test.
3. Take off your glasses if you have them. Close or cover one eye. With the open eye, read as far as you can down the chart.
4. You are permitted one mistake. Once you make more than 1 mistake, stop. This is the level for your eyesight measurement.
5. Repeat the test by closing or covering the other eye and opening the one that was closed.
6. If you choose, repeat the test with your glasses on, being sure to keep one eye closed each time. With glasses, your eyesight should be 20/20.
7. Interpretation of the visual acuity test with Snellen eye chart
 - 20/20: This indicates that the patient sees at 20 feet what most people will see at the same distance
 - 20/40: This indicates that what the patient sees at 20 feet most people will see at 40 ft. This is considered poor distance vision.
 - 20/15: This indicates that the patient sees at 20 feet what most people will see at 15 ft. This is considered better than average distance vision.
8. Record your results:
 - Without Glasses/Lenses
 - Left eye: 20/____
 - Right eye: 20/____
 - Normal? _____
 - With Glasses/Lenses (if applicable)
 - Left eye: 20/____
 - Right eye: 20/____
 - Normal? _____

Caution: A classroom Snellen test is for learning, not a diagnostic test. Only qualified eye care professionals can perform a comprehensive eye exam, make a diagnosis, and prescribe corrective lenses.

4.11: Activity 10

Exploring Color Blindness

Color blindness is the decreased ability to see color or color differences and is due to a lack of functional cones (photoreceptor proteins) on the retina. Although a given color wavelength of visible light strikes the retina, it is not detected since there are no functional cones to detect it, no stimulus is sent to the brain and the person is 'color blind.' The genetic condition is more common in males versus females since the genes responsible for most forms of color blindness are on the X chromosome (females have two copies, so if one is defective, and the second copy functions, the individual would not be color blind). The Ishihara test is a widely recognized tool for detecting color blindness, particularly red-green deficiencies. It consists of a series of plates with colored dots forming numbers or paths, which are seen differently depending on whether an individual has normal color vision or a color vision deficiency. The full test typically includes 38 plates, but a shorter version with 14 plates is also commonly used.

Procedure

1. Ensure adequate and consistent lighting (diffuse daylight or daylight-simulating lamps are ideal).
2. To Position the test plates approximately 75 cm from the participant, ensuring the plate surface is perpendicular to their line of sight.
3. Observe plates 1-14 with both eyes. Plates will contain numbers, lines or patterns distinct from the surrounding dots. Allow no more than three seconds for each response.
4. Count the number of plates you can clearly read.
5. Start with the demonstration/control plate (usually plate 1, displaying the number "12"), which should be visible to everyone regardless of color vision status.
6. Plates 1-11 determine normal/defective color vision. Plates 12-14 determine the type and degree of color vision deficiencies.
7. Look up explanations provided with the Ishihara book.
8. Report the results of your colorblindness test: No colorblindness ____ Colorblindness ____

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4.12: Activity 11

Test for Astigmatism

- Astigmatism is a common eye condition that causes blurry or distorted vision at all distances. It occurs when the cornea (the clear, front surface of the eye) or the lens (inside the eye) has an uneven or irregular curvature.
- Using the image of lines fanning out from a single point, close the right eye and stare at the image.
- If any of the lines appear wavy, this indicates a curvature of the cornea called astigmatism. If the lines all appear straight, then no astigmatism is present. Repeat the test with the left eye closed and the right eye open.
 - Left eye: _____
 - Right eye: _____

4.13: Activity 12

Test for Near Point of Accommodation

The near point of accommodation (NPA) test assesses the closest distance at which an individual can clearly focus on an object. It measures the eye's ability to adjust its focus for near vision, which is crucial for tasks like reading. The test involves bringing a target closer to the eye until it blurs, then measuring the distance. Normal NPA values are typically around 7-10 centimeters, but this can vary with age and individual differences.

1. Hold a dissecting pin or unfolded paper clip at arm's length in front of one of your eyes while keeping the other eye closed or covered.
2. Slowly bring the dissecting pin or paper clip closer to your open eye until it just starts to become blurry. Stop and have your lab partner measure the distance from your eye to the pin with a metric ruler in cm. This is your near point of accommodation. It reflects the point beyond which your lens cannot bend any further to focus light on your retina.

Table 4.13.1: Near Point Distance by Age

Age (Years)	8	15	20	25	30	35	40	45
Near Point (cm)								

3. Repeat the procedure using the other eye, being sure to have your lab partner measure the distance (in cm) from the pin to your eye. Report your near point of accommodation results:
 - Right eye _____ cm
 - Left eye _____ cm
4. Compare your near point accommodation with values from the chart below. Determine the “age” of your eye.
5. The near point of accommodation is normal at 25 cm or closer. A person with hyperopia (farsightedness) or presbyopia (age-related farsightedness) has a near point of accommodation greater than 25 cm.
6. Based on the results of your near point of accommodation test, do you have normal eyes or hyperopia?

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4.14: Activity 13

Anatomical Features of Human Ear

1. Pick up the Ear model. Locate each of the structures on your terminology sheet.
2. Fill in the chart to help you summarize the information you learned.
3. Carefully observe and Identify the anatomical features of the human ear indicated by numbers: Auricle, External Acoustic meatus, Pharyngotympanic tube, Vestibule, Semicircular canals, Tympanic membrane, Middle ear, Cochlea.

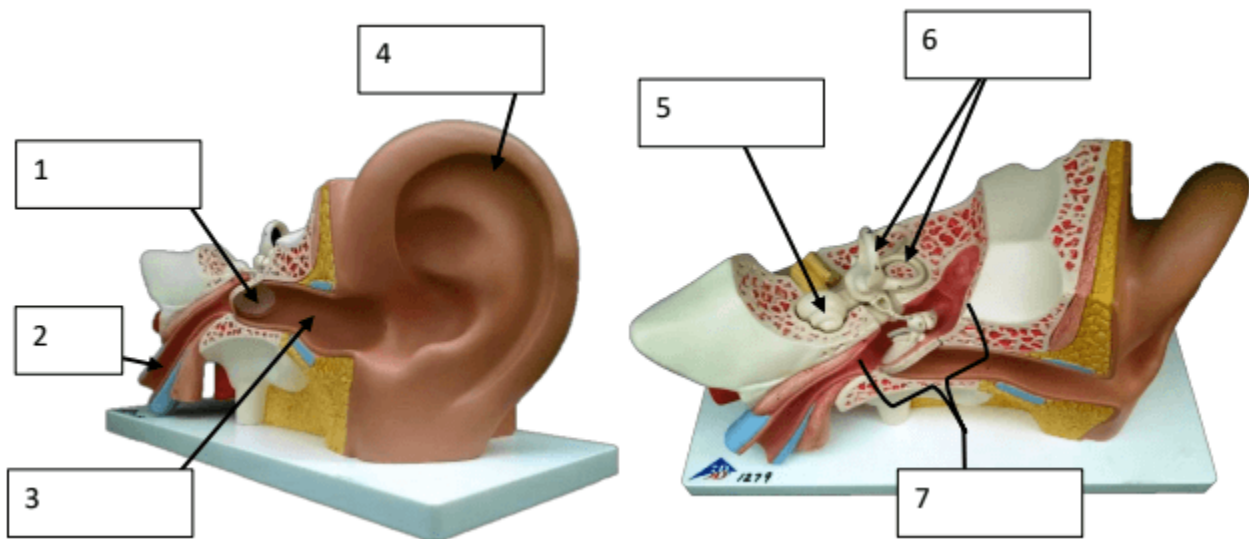


Figure 4.14.1: Anatomical model of the human ear showing labeled different parts of outer and inner ear. (CC BY-NC-SA 4.0; Yancy Aquino via Human Anatomy Lab Manual).

Figure 4.14.1 is an anatomical model of the human ear with various parts labeled from 1 to 7. These labels identify key components of the ear: pinna, ear canal, eardrum, malleus, incus, stapes, cochlea, vestibule, semicircular canals, Eustachian tube, and outer ear. The detailed labeling supports understanding of the ear's structure and auditory function. The numbers are used as prompts to fill Table4.14.1.

Table 4.14.1: Identification of Anatomical Features of the Human Ear

Number	Identified Parts
1	
2	
3	
4	
5	
6	
7	

Carefully observe Figure 4.14.2 and Identify the anatomical features of the human ear indicated by numbers: Cochlea (uncoiled), Round window, Scala vestibuli, Scala tympani, Scala media, Spiral ganglion, Cochlear nerve (part of the vestibulocochlear nerve), Vestibular membrane, Basilar membrane, Tectorial membrane, Organ of Corti.

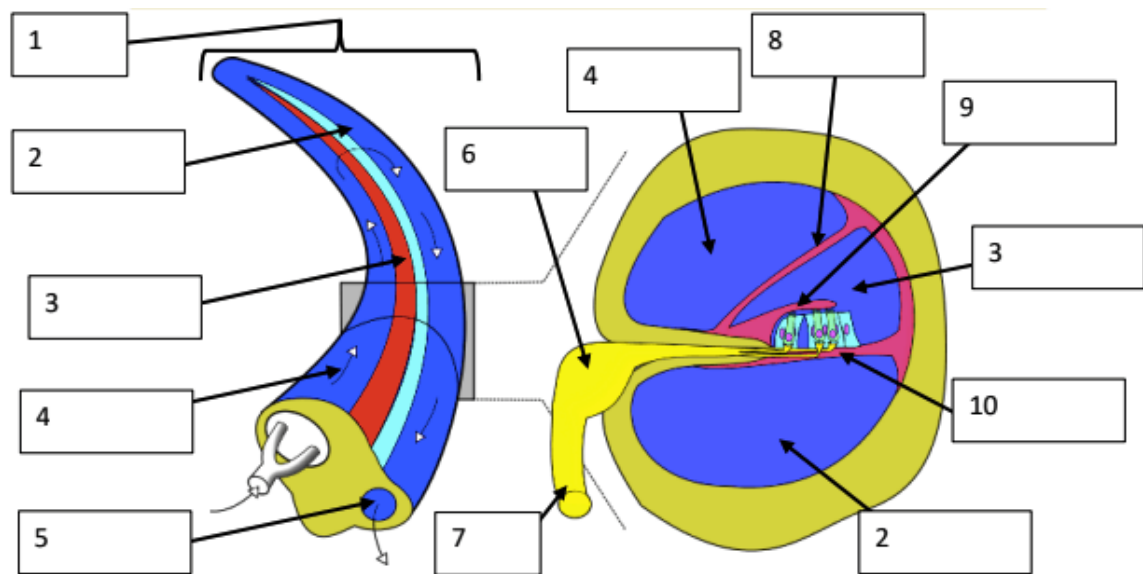


Figure 4.14.2:Sectional representation of the cochlea illustrating the arrangement of the scala vestibuli, scala media, and scala tympani, along with the associated membranes and the organization of the organ of Corti. (CC BY-NC-SA 4.0; Yancy Aquino via Human Anatomy Lab Manual).

Figure 4.14.2 This image is a two-part anatomy diagram of the ear. The left portion shows the inner ear structures, and the right portion shows a cross-sectional view of the cochlea. The numbers are used as prompts to fill Table4.14.2.

Table4.14.2: Identification of Anatomical Features of the Human Ear

Number	Identified Parts
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

4.15: Activity 14

Exploring Human Body Balance and Equilibrium

A laboratory activity exploring human body balance and equilibrium could involve investigating the body's response to changes in posture and balance. This could include observing the body's ability to compensate for imbalances, such as tilting the body while standing on one leg or walking a straight line with eyes closed.

Balance and Equilibrium Test

- **Safety:** Ensure a safe environment for students to perform the activities, such as using soft mats or having someone nearby for assistance.
- **Individual Variation:** Be aware that individuals may have different baseline levels of balance and coordination, and it's important to take this into account when interpreting results.
- **Procedure:** Student volunteers can be tested on their ability to maintain balance in various postures, such as standing on one leg, walking a straight line, or with eyes open and closed.
- **Observation:** Record the time they can maintain balance and the number of times they stumble or lose balance.

Table 4.15.1: Balance Assessment Results: Duration and Sway While Standing on One Leg (Eyes Open and Closed)

	Duration (minutes) maintained balance	Did you sway at all, slightly, a lot, or significantly? (0, +, ++, +++)
Standing on one leg (Eyes open)		
Standing on one leg (Eyes close)		

Analysis of Results

Do you think vision plays a role in balance? Justify your response.

4.16: Activity 15

Weber and Rinne Test for hearing

The Weber and Rinne tests help distinguish between a Conductive Hearing Loss (CHL) and Sensorineural Hearing Loss (SHL). In conduction deafness, transmission of sound waves through the middle ear is impaired. In nerve deafness, transmission of nerve impulses from the cochlea to the auditory cortex is impaired. Performing just one of the tests will not allow diagnose a hearing problem: it is necessary to do them both and then comparing the results.

Weber test

- Purpose: To quickly screen for hearing loss and to help determine whether the hearing loss is due to a problem in the outer/middle ear (conductive hearing loss) or the inner ear (sensorineural hearing loss).
- How it works: A vibrating tuning fork is placed on the center of the forehead or the top of the head.
- Interpretation of results:
 - Normal hearing: The sound is heard equally in both ears.
 - Conductive hearing loss: The sound localizes to the affected ear. This is because the affected ear perceives the sound as louder due to the lack of ambient noise interference (the impairment is in the outer or middle ear).
 - Sensorineural hearing loss: The sound localizes to the unaffected ear. The affected ear is less sensitive to sound vibrations, hence perceives it as quieter (the inner ear is not converting sound as well)

Rinne Test

- Purpose: To compare a person's ability to hear sound transmitted via air conduction versus bone conduction in a single ear.
- How it works: A vibrating tuning fork is first placed on the mastoid bone behind the ear (bone conduction), then moved to the front of the ear canal (air conduction).
- Interpretation of results:
 - Normal hearing (Rinne positive): Air conduction is louder and lasts longer than bone conduction—this is expected in healthy ears.
 - Conductive hearing loss (Rinne negative): Bone conduction is heard longer or louder than air conduction, suggesting a problem in the ear's sound-conducting pathway.
 - Sensorineural hearing loss: Air conduction is still better than bone conduction, but both may be reduced; the Weber test helps clarify this.

Materials Needed

The test is best performed in a quiet environment to avoid masking the subtle sounds.

- Tuning fork (512 Hz is commonly used)
 - Stopwatch or timer
1. Weber Test (Conductive Hearing Loss): This test should be performed in a room with a normal noise level (not quiet).
 - A. Strike the tuning fork (512 Hz is commonly used) against the rubber heel.
 - B. Place the base of the vibrating tuning fork at the center of the participant's forehead or on the top of their head.
 - C. Then ask the patient: "Do you hear the sound louder in one ear than the other?"
 - If so, in which ear is it louder?
 - If the patient is unclear, you may ask if they hear it "everywhere."
 - D. Interpret Results:
 - If the sound is heard equally in both ears, this indicates normal hearing or symmetrical sensorineural hearing.
 - If the sound is louder in one ear, this can indicate conductive hearing loss in the ear where the sound is louder (sound is transmitted through bone better in that ear).
 - E. Record results.
 2. Rinne Test (Sensorineural Hearing Loss):

- A. Strike a tuning fork (typically 512 Hz) against the rubber heel, and place it on the mastoid process (behind the ear).
- B. Ask the patient to indicate when they can no longer hear the sound.
- C. Immediately move the vibrating tuning fork near the patient's ear canal (2.5 cm away).
- D. Ask the patient to indicate when they can no longer hear the sound.

Compare the results of the Weber and Rinne tests to determine the type of hearing loss - A normal (positive) Rinne test means the patient can hear the sound longer through air conduction than through bone conduction ($AC > BC$). A negative Rinne test suggests bone conduction is better than air conduction ($BC > AC$), which can indicate conductive hearing loss. Compare the results of the Weber and Rinne tests to determine the type of hearing loss.

Table 4.16.1: Expected Weber and Rinne test results for different types of hearing conditions.

	Normal Result	Sensorineural Hearing Loss	Conductive Hearing Loss
Weber	Sound is heard equally in both ears (midline).	Sound lateralizes to the unaffected ear.	Sound lateralizes to the affected ear.
Rinne	Positive: Air conduction is louder/ lasts longer than bone conduction.	Positive: Air conduction is still better than bone conduction.	Negative: Bone conduction is louder/ lasts longer than air conduction.

Recording Results in a Table - A table is an effective way to organize the information.

Table 4.16.2: Individual Weber and Rinne test results for each ear and interpretation of hearing condition.

Test	Left Ear	Right Ear	Interpretation
Weber			
Rinne	$AC > BC$ (Positive) / $BC > AC$ (Negative)	$AC > BC$ (Positive) / $BC > AC$ (Negative)	

Key Terms and Definitions

- **Amacrine cell** – type of cell in the retina that connects to the bipolar cells near the outer synaptic layer and provides the basis for early image processing within the retina
- **Ampulla** – structure at the base of a semicircular canal that contains hair cells and cupula for transduction of rotational movement
- **Aqueous humor** – watery fluid in the anterior chamber of the eye
- **Audition** – sense of hearing
- **Auricle** – fleshy external structure of the ear
- **Basilar membrane** – structural element in the cochlea that responds to sound waves
- **Bipolar cell** – retinal cell connecting photoreceptors to retinal ganglion cells
- **Chemoreceptor** – sensory receptor sensitive to chemical stimuli (e.g., taste, smell, pain)
- **Choroid** – vascular tissue in the eye wall supplying the outer retina
- **Ciliary body** – smooth muscle controlling lens shape
- **Cochlea** – auditory portion of the inner ear
- **Cochlear duct** – space in the cochlea containing the organ of Corti
- **Cone photoreceptor** – retinal cell specialized for color vision
- **Cornea** – transparent covering of the anterior eye
- **Cupula** – structure in semicircular canals that bends stereocilia during head rotation
- **Encapsulated ending** – sensory neuron with dendrites surrounded by specialized structures
- **Equilibrium** – sense of balance and head movement
- **External ear** – outer ear structures including auricle and ear canal
- **Exteroceptor** – receptor interpreting external stimuli
- **Extraocular muscle** – one of six muscles that move the eye
- **Fibrous tunic** – outer layer of the eye (sclera and cornea)
- **Fovea** – center of the retina for sharpest vision
- **Free nerve ending** – sensory neuron with exposed dendrites sensitive to various stimuli
- **General sense** – sensory systems distributed throughout the body
- **Gustation** – sense of taste
- **Gustatory receptor cells** – taste bud cells transducing chemical stimuli
- **Hair cells** – mechanoreceptors in the inner ear for hearing and balance
- **Incus (anvil)** – middle ear bone connecting malleus to stapes
- **Inferior oblique** – muscle for lateral eye rotation
- **Inferior rectus** – muscle for downward eye movement
- **Inner ear** – structure in the temporal bone for hearing and balance
- **Inner segment** – part of photoreceptor with nucleus and organelles
- **Inner synaptic layer** – retinal layer where bipolar cells connect to ganglion cells
- **Interoceptor** – receptor interpreting internal organ stimuli
- **Iris** – colored part of the eye surrounding the pupil
- **Lacrimal duct** – duct draining tears into the nasal cavity
- **Lacrimal gland** – gland producing tears
- **Lateral rectus** – muscle for eye abduction
- **Lens** – eye component that refracts and focuses light
- **Macula** – structure in semicircular canal for equilibrium transduction
- **Malleus (hammer)** – ossicle attached to the tympanic membrane
- **Mechanoreceptor** – receptor transducing mechanical stimuli (*corrected*)
- **Medial rectus** – muscle for eye adduction
- **Middle ear** – space between ear canal and inner ear containing ossicles
- **Neural tunic** – layer of the eye containing the retina
- **Nociceptor** – receptor sensitive to pain stimuli
- **Odorant molecules** – chemicals that stimulate olfactory neurons
- **Olfaction** – sense of smell
- **Olfactory bulb** – target of the first cranial nerve
- **Olfactory epithelium** – nasal region with olfactory neurons
- **Olfactory sensory neuron** – receptor cell for smell

- **Optic disc** – spot on retina where axons and blood vessels exit
- **Optic nerve** – second cranial nerve for vision
- **Optic tract** – fiber structure posterior to the optic chiasm
- **Organ of Corti** – cochlear structure where hair cells transduce sound
- **Osmoreceptor** – receptor sensing fluid concentration via osmotic pressure
- **Ossicles** – three small bones in the middle ear
- **Otolith** – gelatinous substance in the inner ear with calcium crystals
- **Outer segment** – photoreceptor section with opsin molecules
- **Outer synaptic layer** – retinal layer where photoreceptors connect to bipolar cells
- **Oval window** – membrane at cochlea base where stapes attaches
- **Palpebral conjunctiva** – membrane covering the inner eyelid and cornea
- **Papilla** – tongue projection containing taste buds
- **Photon** – individual packet of light
- **Photoreceptor** – receptor cell responding to light stimuli
- **Proprioception** – sense of body position and movement
- **Proprioceptor** – receptor sensing kinesthetic changes
- **Pupil** – central opening in the iris for light entry
- **Receptor cell** – cell transducing environmental stimuli into neural signals
- **Retina** – nervous tissue of the eye for phototransduction
- **Rhodopsin** – photopigment in rod cells
- **Rod photoreceptor** – retinal cell for low-light vision
- **Round window** – membrane marking the end of the scala tympani
- **Saccule** – inner ear structure for vertical acceleration
- **Scala tympani** – cochlear portion from apex to round window
- **Scala vestibuli** – cochlear portion from oval window to apex
- **Sclera** – white of the eye
- **Semicircular canals** – inner ear structures for rotational movement
- **Sensory homunculus** – body map in the somatosensory cortex
- **Sensory modality** – system for interpreting environmental stimuli
- **Somato-sensation** – general body senses including touch and pain
- **Special sense** – sensory systems tied to specific organs
- **Spiral ganglion** – auditory neuron cell bodies
- **Stapes (stirrup)** – ossicle attached to the inner ear
- **Stereocilia** – membrane extensions in hair cells for movement transduction
- **Sub-modality** – specific sense within a broader category
- **Superior oblique** – muscle for medial eye rotation
- **Superior rectus** – muscle for upward eye movement
- **Taste buds** – tongue structures containing gustatory cells
- **Tectorial membrane** – organ of Corti component over hair cells
- **Thermoreceptor** – receptor specialized for temperature stimuli
- **Transduction** – conversion of environmental stimulus into neural signals
- **Trochlea** – pulley-like structure for the superior oblique muscle
- **Tympanic membrane** – ear drum
- **Umami** – taste submodality for amino acids (savory)
- **Utricle** – inner ear structure for horizontal acceleration
- **Vascular tunic** – middle eye layer with blood supply
- **Vestibule** – inner ear portion for equilibrium
- **Visceral sense** – sense associated with internal organs
- **Vision** – special sense of sight
- **Visual acuity** – sharpness of focus in vision
- **Vitreous humor** – fluid in the posterior eye chamber
- **Zonule fibers** – fibrous connections between ciliary body and lens

5: BLOOD ANATOMY, BLOOD GROUPING, AND HEMATOCRIT ANALYSIS

Introduction

In this lab, we will explore the fascinating world of blood anatomy, blood grouping, and hematocrit analysis. Blood is a vital component of the cardiovascular system, which serves to deliver oxygen and nutrients to tissues, remove wastes, distribute heat, and transport hormones and other essential chemicals to cells. It also serves to deliver immune system cells, antibodies, and other defense proteins to tissues. Erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (platelets) are suspended in the liquid matrix (plasma). Understanding blood is not just a scientific exercise; it has real-world implications for transfusions, organ transplants, and diagnosing various medical conditions.

We will examine the microscopic structure of blood, identify different cell types, and learn about the significance of ABO and Rh blood groups and determine consequences of inappropriate blood transfusions. Additionally, we will determine hematocrit levels, gaining insight into red blood cell concentration and its clinical implications.

Learning Objectives

- Demonstrate skills preparing a blood smear slide.
- Identify and characterize each type of formed element in a human blood smear, including RBCs, platelets, and the five types of white blood cells (neutrophils, lymphocytes, monocytes, eosinophils, and basophils).
- Perform ABO and Rh blood typing on simulated (artificial) blood samples, applying theoretical knowledge to practical situations.
- Define and measure hematocrit of blood samples and discuss the significance of values that fall outside the normal range, highlighting potential health implications.

5.1: Background Information

5.2: Activity 1

5.3: Activity 2

5.4: Activity 3

5.5: Activity 4

5.6: Activity 5

5.7: Activity 6

5.8: Activity 7

5.9: Glossary

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5.1: Background Information

Overview

Blood is the liquid connective tissue that is pumped throughout the body by the heart and enables the transport of substances and heat around the body. It is transported through tubular structures called blood vessels. Blood constitutes ~8% of adult body weight. Adult males typically contain an average of 5 to 6 liters of blood; adult females typically contain an average 4–5 liters of blood. A hematocrit test is an important clinical tool for quickly looking at the composition of whole blood. Hematocrit is a key blood test that measures the percentage of your blood made up by red blood cells (RBCs). This value is crucial because RBCs are responsible for carrying oxygen throughout your body, directly impacting your overall health and energy levels. A blood sample is spun in a centrifuge, separating it into layers. The proportion of the layer made up by RBCs is the hematocrit.

- Normal hematocrit range is typically about 40 to 54% for men and 36 to 48% for women, but these values can vary slightly by age and altitude.
- Low hematocrit suggests anemia, blood loss, or nutritional deficiencies. Symptoms can include fatigue, shortness of breath, and pale skin.
- High hematocrit can be due to dehydration, living at high altitude, or conditions like polycythemia vera (where too many red blood cells are produced). It can increase the risk of stroke or heart attack.

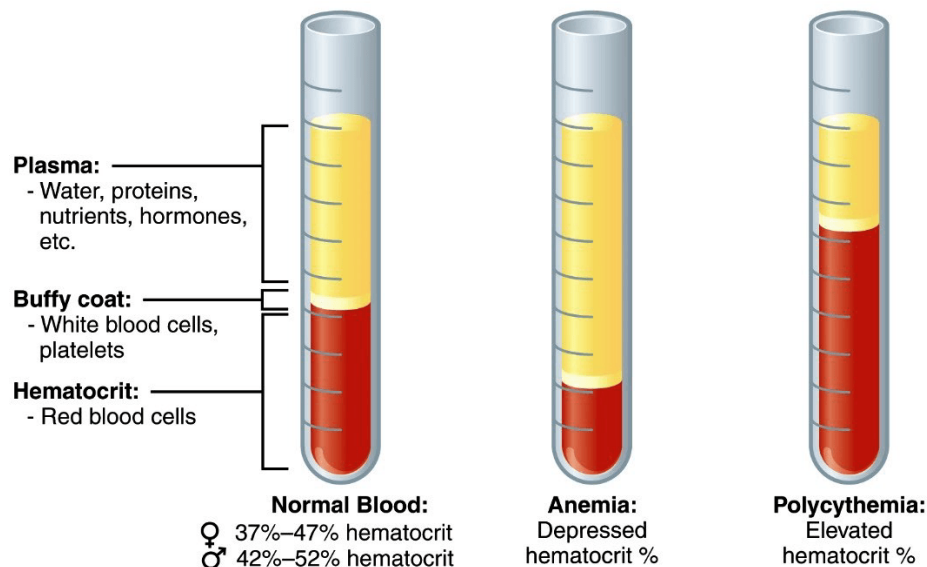


Figure 5.1.1: Composition of Blood. The cellular elements of blood include a vast number of erythrocytes and comparatively fewer leukocytes and platelets. Plasma is the fluid in which the formed elements are suspended. A sample of blood spun in a centrifuge reveals that plasma is the lightest component. It floats at the top of the tube separated from the heaviest elements, the erythrocytes, by a buffy coat of leukocytes and platelets. Hematocrit is the percentage of the total sample that is comprised of erythrocytes. Depressed and elevated hematocrit levels are shown for comparison. (CC BY 4.0; via [An Overview of Blood](#)).

Figure 5.1.1 shows three test tubes of centrifuged blood separated into layers. Each tube has:

- Plasma at the top (listed as water, proteins, nutrients, hormones, etc.).
- A thin middle layer labeled buffy coat, which contains white blood cells and platelets.
- A bottom layer labeled hematocrit, which contains red blood cells.

The first tube is labeled Normal blood and shows typical hematocrit ranges: 37%–47% and 42%–52%. The second tube is labeled Anemia and shows a depressed hematocrit percentage, meaning the red blood cell layer is smaller than normal. The third tube is labeled Polycythemia and shows an elevated hematocrit percentage, meaning the red blood cell layer is larger than normal.

Blood is viscous and somewhat sticky to the touch. Viscosity is a measure of a fluid's thickness or resistance to flow and is influenced by the presence of the plasma proteins and formed elements within the blood. The same principle applies to blood,

which is approximately five times more viscous than water. The viscosity of blood has a dramatic impact on blood pressure and flow. The plasma component of blood without the coagulation factors is called the serum. Serum is similar to the fluid surrounding the cells in other tissues, and contains precise concentrations of important ions like calcium and sodium necessary for cellular functions. Other components in the serum include proteins that assist with maintaining pH and water balance while giving viscosity to the blood. The serum also contains antibodies, specialized proteins that are important for defense against viruses and bacteria. Lipids, including cholesterol, are also transported in the serum, along with various other substances including nutrients, hormones, metabolic waste, plus external substances, such as, drugs, viruses, and bacteria.

Most common Blood Tests

- Complete Blood Count (CBC) - A CBC report will include a "reference range" and patient's results. The following are expected complete blood count results for adults. The blood is measured in cells per liter (cells/L) or grams per deciliter (grams/dL). Abnormal results can indicate a number of conditions, including:
 - Dehydration: Abnormal levels of RBCs, hemoglobin, or hematocrit can indicate dehydration.
 - Anemia: A low hemoglobin level is called anemia.
 - Infection: A high white blood cell count can indicate an infection.
 - Autoimmune disorder: A low white blood cell count can indicate an autoimmune disorder.
- Prothrombin Time (PT) test is useful for checking for bleeding problems and monitoring treatments that prevent blood clots. Prothrombin is a protein produced by the liver and is one of the key clotting factors. For someone not on blood thinners, a normal PT is between 11 to 13.5 seconds.
- Basic Metabolic Panel (BMP) test measures creatinine (a byproduct of kidney function), glucose (a key source of energy), electrolytes (Potassium, Sodium, Calcium). It also measures Blood Urea Nitrogen (BUN) which is another by product of kidney function.
- Lipid Panel is a group of tests used to evaluate cardiac risk. The test measures:
 - Total cholesterol: The combination of LDL-C, VLDL-C, and HDL-C. Low-density lipoprotein (LDL) cholesterol which is also known as "bad cholesterol". Very low-density lipoprotein (VLDL) cholesterol and high-density lipoprotein (HDL) cholesterol which is also known as "good cholesterol".
 - Triglycerides are a type of fat from food.
- Blood glucose tests can help diagnose diabetes, pre-diabetes, and gestational diabetes. There are several types of blood glucose tests, including:
 - Hemoglobin A1C test measures average blood sugar levels over the past 2 to 3 months.
 - Fasting blood sugar test measures blood sugar after an overnight fast.
- Blood enzyme tests may be used to check for heart attack include troponin and creatine kinase (CK) tests. Blood levels of troponin go up when a person has muscle damage, including damage to the heart muscle.

Blood Cells/Formed Elements

- A. Red Blood Cells (Erythrocytes) - Red blood cells (RBCs) are the most common formed element in blood. Despite the name, this is not a cell at all, although it's derived from true cells. The RBC is the mature stage of development of a cell line in which the nucleus (present in earlier forms) has been lost. Structurally RBCs are pretty uninteresting, they're merely bags of hemoglobin, the oxygen transport material. They usually take on the shape of a bi-concave disc, and have no internal organelles. While not every RBC will be perfect, any significant number of cells that are different in shape or size may indicate the presence of disease. Some examples of conditions that can affect red blood cells (anemia, sickle cell anemia, thalassemia, leukemia).
 - Lack a nucleus (anucleate); they also contain a very few organelles.
 - Small, flexible cells shaped like biconcave flattened discs with depressed centers on both sides; they look like miniature doughnuts when viewed with a microscope.
 - There are normally about 5 million cells per cubic millimeter of blood; major factor contributing to blood viscosity.
 - Erythrocytes contain the oxygen carrying protein, hemoglobin (about 5.4 million cells per microliter of blood). Clinically, normal blood contains 12 to 18 grams of hemoglobin per 100 milliliters (ml); the hemoglobin content is slightly higher in men (13 to 18 g/dl) than in women (12 to 16 g/dl). The life span of erythrocytes is limited: about 90 to 120 days.
- B. Platelets normal range is 150,000 to 400,000 platelets/mL blood. Platelets are tiny, disc-shaped cell fragments about 2 to 4 microns in diameter. They play a crucial role in stopping bleeding and supporting wound healing. When a blood vessel is injured, platelets move to the site, stick together, and form a plug to seal the break. This process is called hemostasis. Platelets are fragments of a very large cell bone marrow cell called a megakaryocytes.
- C. White Blood Cells (WBCs) are also called leukocytes, are the body's primary defenders against infection, disease, and foreign invaders. They make up only about 1% of blood but have a profound impact on immune system and overall health. All WBCs

are produced in the bone marrow and released into the bloodstream and lymphatic system. WBCs are divided into two main groups based on cytoplasmic appearance:

a. Granulocytes (contain visible granules in the cytoplasm)

- Granulocytes Neutrophils are multi-lobed nucleus (2 to 5 lobes), cytoplasm of neutrophils stains a pale pink/purple, granules are very fine, larger than red blood cells (12 to 14 μm). These cells are phagocytic for foreign cells during the acute inflammatory response. Acute infections (appendicitis, smallpox or rheumatic fever) shows increase. If the count is considerably less, it may be due to a viral infection (influenza and hepatitis).
- Granulocyte - Eosinophils (2-4% of all leukocytes) are bilobed nucleus, their cytoplasmic granules are strongly eosinophilic, staining a bright orange-pink color large reddish-orange granules in cytoplasm (with special stains). They are 10 to 14 microns in size. Combat parasites, modulate allergic responses, and help control inflammation. Eosinopenia (lower than normal number) may occur when the body is severely stressed.
- Granulocyte - Basophils (0.5 to 1% of all leukocytes) are with large blue-black round granules in the cytoplasm that mask the bilobed nucleus.
The dark granules are the most easily identifiable characteristic of this cell. Basophils release heparin, histamine and serotonin during hypersensitivity (allergic) reactions to stimulate inflammation. Abnormally high count may indicate hemolytic anemia. Basophils are not phagocytic.

b. Agranulocytes (lack visible granules; have azurophilic granules)

- Agranulocyte - Lymphocytes (25 to 35% of all leukocytes) can appear either small or large. Lymphocytes can be identified in smears by their very high ratio of nucleus to cytoplasm. The small lymphocyte (5 to 10 microns) is about the same size as an erythrocyte and contains a dark nucleus with a thin rim of surrounding cytoplasm. Small lymphocytes are inactive. Large lymphocytes (10 to 18 microns) contain more cytoplasm than small lymphocytes, and the cytoplasm remains basophilic. Large lymphocytes are active cells. Central to adaptive immunity. When the number of these cells exceeds the normal amount, one would suspect infectious mononucleosis or a chronic infection.
- Agranulocyte - Monocytes (3 to 8% of all leucocytes) nucleus is indented or kidney shaped and surrounded by foamy cytoplasm. Their large size is the most easily identifiable characteristic. When stimulated they enlarge and differentiate into wandering macrophages that clean up cellular debris and microbes following infection. Use memory aids: Try "Never Let Monkeys Eat Bananas" for order of abundance: Neutrophils, Lymphocytes, Monocytes, Eosinophils, Basophils.

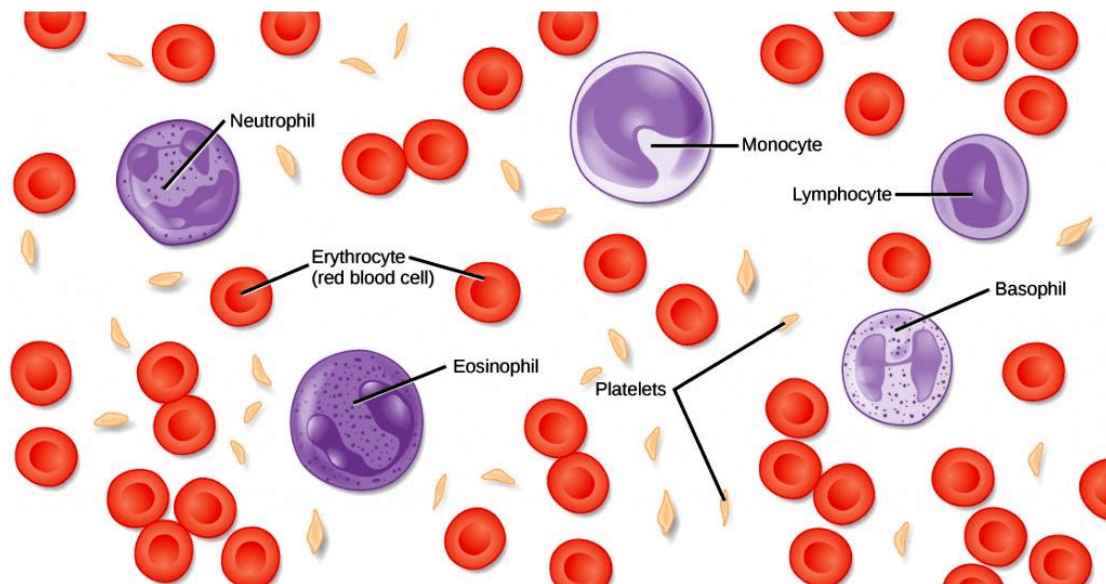
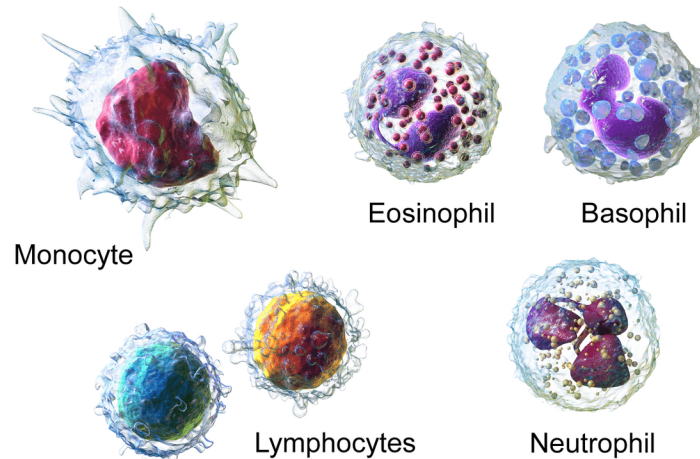


Figure 5.1.2: The cells and cellular components of human blood are shown. Erythrocytes (red blood cells) deliver oxygen to the cells and remove carbon dioxide. White blood cells—including neutrophils, monocytes, lymphocytes, eosinophils, and basophils—are involved in the immune response. Platelets form clots that prevent blood loss after injury. (CC BY-NC 4.0; Sarah Malmquist and Kristina Prescott via Human Biology).

Figure 5.1.2 shows the major cellular components of human blood. Erythrocytes (red blood cells) are shown as biconcave discs and function to deliver oxygen to tissues and remove carbon dioxide. Several types of white blood cells are labeled: neutrophils, monocytes, lymphocytes, eosinophils, and basophils. These cell types support immune responses that help protect the body from

infection. Platelets are shown as small cell fragments involved in clot formation to reduce blood loss after injury.



White Blood Cells

Figure 5.1.3: Idealized Representations of the Five Types of Leukocytes grouped into two basic categories granulocytes and agranulocytes based on whether they have specific granules (tiny packets of chemicals) in their cytoplasm. Sizes in this drawing are not to scale. (CC BY 3.0; via Human Biology).

Figure 5.1.3 presents a labeled set of five different white blood cell types. The image shows that white blood cells are not one single kind of cell, but a group of different cell categories. The five labeled cell types shown are:

1. **Monocyte**
The monocyte is shown as a single, large cell with an irregular outer edge. Inside the cell is a large central region (the nucleus area), which takes up a substantial portion of the cell. The monocyte is presented as one distinct example to represent this category of white blood cell.
2. **Eosinophil**
The eosinophil is shown as a round cell with many small internal granule-like dots throughout the cell. The center contains a prominent nucleus region that appears divided into multiple connected sections. The label “Eosinophil” identifies this cell type.
3. **Basophil**
The basophil is shown as a round cell with many internal dot-like granules. A large nucleus region is visible near the center. The label “Basophil” identifies this cell type.
4. **Lymphocytes**
The lymphocyte example is shown as a round cell with a large central nucleus area and a thinner surrounding edge of cell material. The label reads “Lymphocytes,” indicating this represents the lymphocyte category of white blood cells.
5. **Neutrophil**
The neutrophil is shown as a round cell with many small internal granules and a nucleus that appears separated into several lobes (multiple rounded sections connected together). The label “Neutrophil” identifies this cell type.

Antigens, Antibodies, and Transfusion Reactions

Antigens (agglutinogens) are substances that the body does not recognize as belonging to the “self” and that therefore trigger a defensive response from the leukocytes of the immune system. With antibodies referred to as isoantibodies or agglutinins. In this lab, we will use the more common terms antigens and antibodies.

Antigens are generally large proteins, but may include other classes of organic molecules, including carbohydrates, lipids, and nucleic acids. Following an infusion of incompatible blood, erythrocytes with foreign antigens appear in the bloodstream and trigger an immune response. Proteins called antibodies (immunoglobulins), which are produced by certain B lymphocytes

- Because the arms of the Y-shaped antibodies attach randomly to more than one nonself erythrocyte surface, they form clumps of erythrocytes. This process is called agglutination.
- The clumps of erythrocytes block small blood vessels throughout the body, depriving tissues of oxygen and nutrients.
- As the erythrocyte clumps are degraded, in a process called hemolysis, their hemoglobin is released into the bloodstream. This hemoglobin travels to the kidneys, which are responsible for filtration of the blood. However, the load of hemoglobin released can easily overwhelm the kidney's capacity to clear it, and the patient can quickly develop kidney failure.

The ABO Blood Group

Although the ABO blood group name consists of three letters, ABO blood typing designates the presence or absence of just two antigens, A and B. Both are glycoproteins. People whose erythrocytes have A antigens on their erythrocyte membrane surfaces are designated blood type A, and those whose erythrocytes have B antigens are blood type B. People can also have both A and B antigens on their erythrocytes, in which case they are blood type AB. People with neither A nor B antigens are designated blood type O. ABO blood types are genetically determined.

If agglutinogens are present very early in life, the immune system recognizes those agglutinogens as “self” and will not generate an immune response to them. As a result, the body does not generate antibodies to any A and B antigens present on its own blood cells. However, the immune system does produce antibodies to any A and B blood antigens not present on the organism's own cells. Type A blood has the A antigen on its red blood cells and anti-B antibodies in the plasma. Type B blood has the B antigen on its red blood cells and A antibodies in the plasma. Type AB blood has both A and B antigens on the red blood cells and no antibodies in the plasma. Finally, type O blood has neither A nor B antigens on the red blood cells and both A and B antibodies in the plasma. These antibodies are present even if the person has not had any foreign blood introduced into their body. It is hypothesized that the antibodies are present because of the similarity between the A and B blood antigens and other antigens present in the environment. If two antigens are similar enough, the antibodies generated to one antigen will also recognize the other.

- Type A: Has A antigens on RBCs and anti-B antibodies in the plasma.
- Type B: Has B antigens on RBCs and anti-A antibodies in the plasma.
- Type AB: Has both A and B antigens on RBCs and no anti-A or anti-B antibodies. This is the universal recipient.
- Type O: Has no A or B antigens on RBCs and has both anti-A and anti-B antibodies. This is the universal donor.

The Rh Blood Groups

Another important agglutinin found on the surface of blood cells is the Rh factor (Rhesus factor, also called D Factor). The Rh agglutinin is actually a whole group of closely related antigens. Blood containing an Rh agglutinin is said to be Rh positive (Rh+); blood lacking the antigen is said to be Rh negative (Rh-). Unlike the case for the ABO antigens, the production of Rh antibody requires prior exposure to the antigen, such as would occur in an Rh- pregnant woman carrying a fetus that was Rh+. A point of confusion that often occurs is in naming blood types. Each of the eight types in the ABO-Rh system has two parts: 1 or 2 letters and a positive or negative sign. The letter(s) indicate whether A or B agglutinogens are present on the surface of the red blood cells; the + or - sign indicates whether Rh factor is present (+) or absent (-) on the surface of the red blood cells.

- Rh-positive (Rh+): Has the Rh antigen on RBCs.
- Rh-negative (Rh-): Lacks the Rh antigen.

5.2: Activity 1

Making a Peripheral Blood Smear

Supplies needed for preparing a blood smear

- 2 glass slides
- Blood sample

A properly prepared blood smear is essential in ensuring an accurate, reliable assessment of blood cell morphology. Although most automated blood analyzers can make a proper blood smear, the manual wedge method is still a common smear preparation technique performed in laboratories today. A small drop of EDTA-anticoagulated blood or capillary blood is placed on a clean microscope slide and spread across the slide creating a thin smear. Once the blood smear dries it can be stained using a common Wright stain. A well-made and suitably stained blood smear allows the laboratory technologist to accurately assess the cellular morphology.

Safety Considerations

All specimens received in the lab must be regarded as potentially infectious so follow safe practices. For detailed guidance, refer to the **California Occupational Safety and Health Administration (Cal/OSHA)** regulations on blood borne pathogens. These regulations outline procedures for handling potentially infectious materials, using protective equipment, and maintaining a safe work environment.

You can access the full regulation here: [Cal/OSHA Title 8, Section 5193 – Bloodborne Pathogens](#)

- Place the specimen glass slide on a flat surface and hold it with the index finger and the thumb of the left hand (for Right-handed peoples). Now, Place a smooth, clean edge of the spreader slide on the specimen slide at an angle about 30° – 45° .
- Move the spreader slide toward the drop of blood until the contact is made with the drop of the blood at the specific angle. Then move the spreader slide smoothly and rapidly forward over the specimen slide, drawing the blood behind it into a thin film that should be tongue-shaped.
- Allow the blood smear to air-dry completely. Do not blow air on the slide from any source in an effort to enhance drying, it may distort the smear.

Acceptability Criteria

1. The smear is smooth, with no ripples due to the jerky movement.
2. Holes do not appear in the blood smear.
3. Extends at least two-thirds of the slide.
4. The smear is spread across (side to side) both sides of the slide to the edge.
5. Rainbow sheen at the end of the slide. (feathered edge and monolayer)
6. Smear begins 0.5 inches from the base of the slide or 4mm from the frosted edge.

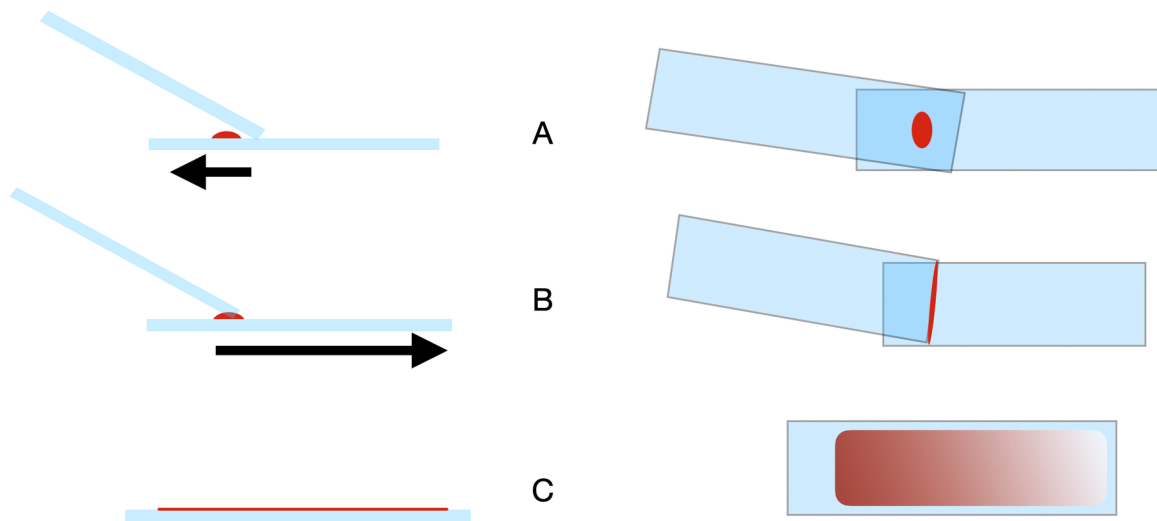


Figure 5.2.1: Preparing a blood smear. (CC BY-SA 4.0; Sheri Miraglia via Identification of [White Blood Cells](#)).

Figure 5.2.1 represents a step-by-step illustration of preparing a blood smear.

1. Step A - drop of blood is placed on the first slide, while a second slide is held at an angle in front of the drop, ready for application. The second slide is pulled back until the blood wicks along its edge by capillary action.
2. Step B - the second slide is then pushed forward smoothly to the end of the first slide, spreading the blood evenly.
3. Step C - the final result shows a thin, even layer of blood spread across the surface of the slide, ready for microscopic examination.

5.3: Activity 2

WBC Morphology - Image-Based Identification

Objective

Build skill in recognizing white blood cell types by their visual (photomicrographs) features, then use that skill to make and interpret a basic WBC differential. This skill is central to understanding immune responses and diagnosing many blood disorders. You'll see how distinct nuclear shapes, cytoplasmic colors, and the presence or absence of granules help distinguish each cell type (neutrophils, lymphocytes, monocytes, eosinophils, and basophils) using feature-based criteria. Modern techniques, including both manual examination and machine-learning tools, enhance accuracy and speed in WBC identification.

Instructions

Examine instructor-provided images (Figure 5.3.1) of stained peripheral blood smears; identify WBCs using defined morphological cues; justify each ID with at least two distinctive features.

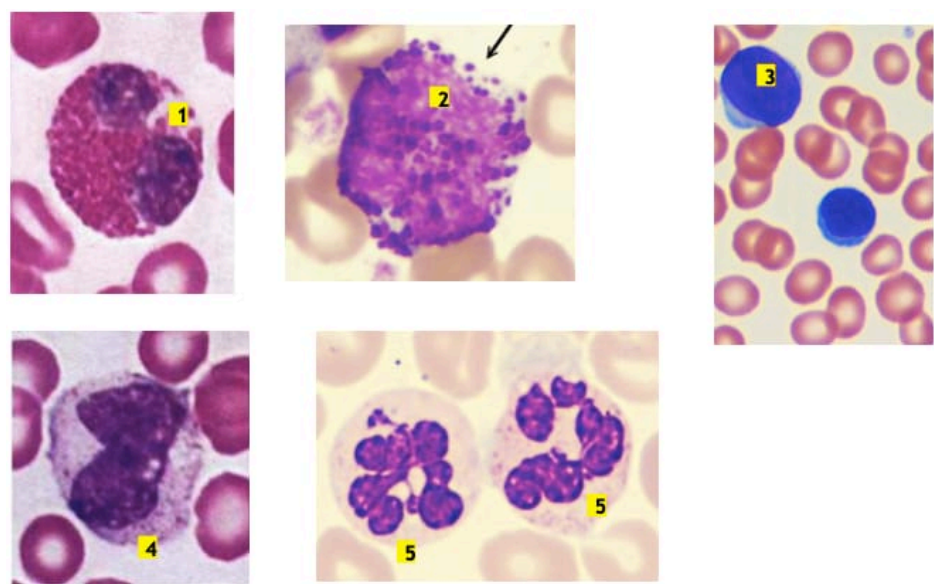


Figure 5.3.1: Labeled microscopic images of blood cells showing granules, lobed nuclei, and staining differences for identification. (CC BY-SA 4.0; via [Lecocyte](#)).

Figure 5.3.1 displays five microscopic images of blood formed elements labeled by numbers. Each image highlights different white blood cell types.

Table 5.3.1: Identification of white blood cells with at least two distinctive features per cell.

Number	White Blood Cell Identified	At least two

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5.4: Activity 3

Identification of WBC - A Microscopic Adventure

Prioritizing nuclear features, granules, and cytoplasm to distinguish neutrophils, lymphocytes (including reactive forms), monocytes, eosinophils, and basophils. Rapid triage and decision-making - shifts in WBC types help distinguish likely causes (e.g., neutrophilia with toxic changes in bacterial infection; eosinophilia in allergy/parasite; atypical lymphocytes in certain viral illnesses; blasts suggesting acute leukemia).

Objective

Build skill in recognizing WBC types from stained peripheral blood smears using feature-based criteria.

Instructions

There will be three stations numbered A, B and C with blood smear slides ready for view at 1000 times magnification (oil immersion lens). Use only the fine focus to carefully observe to identify the WBC.

1. Familiarize yourself with the microscope's components, focusing on the oil immersion lens for optimal 1000 times magnification.
2. The microscope is focusing a particular WBC. Your job is to rotate between microscope stations and identify each.

Table 5.4.1: White blood cell identification at microscope stations using 1000 times magnification.

Station	Identification
Station A White blood cell (1000 times)	
Station B White blood cell (1000 times)	
Station C White blood cell (1000 times)	

5.5: Activity 4

Creating a 'Theme' and 'Slogan' for Blood Donation Drive

Blood donation is essential for patient care, with someone in the U.S. needing blood every two seconds. Despite this constant demand, only about 3% of eligible Americans donate blood each year, while approximately 62% are eligible. Each donation can save up to **three lives**, supporting surgeries, cancer treatments, chronic illness management, trauma care, and conditions like sickle cell disease, which disproportionately affects certain ethnic groups.

The 2025 World Blood Donor Day campaign theme is "Give blood, give hope: together we save lives." This theme emphasizes the life-changing impact blood donors have on recipients and highlights the power of community and solidarity in saving lives.

Instructions

Time allocation: 10 minutes to create; 1 minute to present per group.

Note

Tips

- Use strong verbs: give, help, save, join.
 - Use warm, local words: campus, community, together, here.
 - Make it sing: rhythm, rhyme, or repeat a sound can help.
-
- If you are the Campaign Manager for a blood donation drive for your college, what will be your 'Theme' and 'Slogan'? Be creative, keep it simple use small words, make it Roll Off the Tongue!
 - Brainstorm in groups of 3–5 to create a theme and slogan for a blood donation campaign, fostering awareness about the importance of blood donation and its impact on health and community.
 - Theme: 2–5 words that set the big idea. Example: Every Type Counts.
 - Slogan: 3–7 words that roll off the tongue. Example: Be the type to help.
 - Each group will present their theme and slogan to the class orally or writing on the whiteboard.

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5.6: Activity 5

Blood Grouping: Unveiling the Mystery of Blood Types

A blood typing test shows which antigens are on a person's red blood cells. More than 50 different RBC surface antigens have been identified. These antigens can be carbohydrates or proteins and are organized into named systems such as ABO, Rh, Kell, Duffy, Kidd, and Lewis. The ABO and Rh groups are the most clinically important because mismatches are most likely to cause dangerous transfusion reactions.

When blood from one person is mixed with plasma from another person with an incompatible blood type, the blood cells will agglutinate, or clump together. Blood type is determined by the presence or absence of A and/or B antigens on the surface of red blood cells. These antigens will react with antibodies in the plasma of an incompatible blood type. Agglutination can be dangerous if someone receives a blood transfusion of an incompatible blood type. Blood vessels can become obstructed and damaged, restricting blood flow to the body's organs. This is why it is important to determine blood types before a blood transfusion.

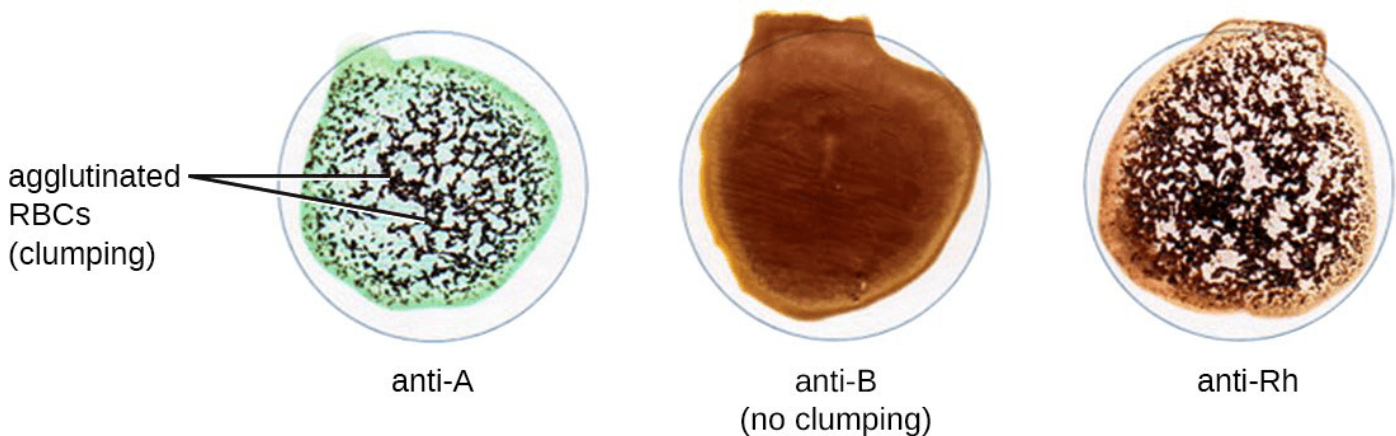


Figure 5.6.1: Blood typing by agglutination reaction. Red blood cells clump (agglutinate) when mixed with antibodies that recognize antigens present on the cell surface. Agglutination occurs with anti-A and anti-Rh antibodies, but not with anti-B antibodies, indicating an A $\diamond$ blood type. (CC BY 4.0; via [Agglutination Assays](#)).

Figure 5.6.1 displays a commercially produced 'bedside' blood typing card designed for quick identification of both recipient and donor blood types before transfusion. The card features three reaction sites or wells: one coated with anti-A antibody, one with anti-B antibody, and one with anti-Rh antibody. Agglutination (clumping) of red blood cells at a specific site indicates the presence of corresponding blood antigens; for instance, in this example, agglutination in the anti-A and anti-Rh wells signifies the presence of A and Rh antigens, identifying the blood type as A-positive.

Conceptualizing Agglutination

Before using the synthetic blood samples for ABO and Rh blood typing, it will be useful to understand the following to have a clear vision of agglutination reactions and interpretation of results.

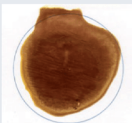
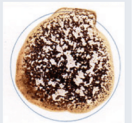
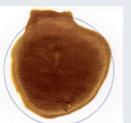
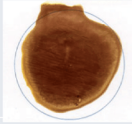
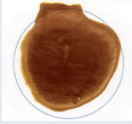
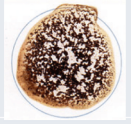
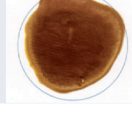
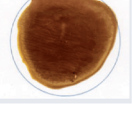
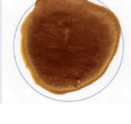
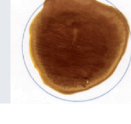
	Blood Sample	Anti-A	Anti-B	Anti-Rh
Individual A				
Individual B				
Individual C				
Individual D				

Figure 5.6.1: Comparison of agglutination reactions in blood samples from four individuals when mixed with anti-A, anti-B, and anti-Rh antibodies, illustrating how antibody reactions are used to determine blood type. (CC BY-SA 4.0; Harmony Folse via [Unknown Blood Types](#)).

Figure 5.6.1 illustration depicts the results of ABO and Rh blood typing, featuring several wells labeled Anti-A, Anti-B, and Anti-Rh, each containing drops of blood mixed with specific antibodies. When agglutination (visible clumping) occurs in a well, it indicates a reaction between the blood and the corresponding antibody. For instance, clumping in the Anti-A well signifies the presence of A antigens, while clumping in the Anti-B well indicates B antigens. Additionally, clumping in the Anti-Rh well confirms that the blood is Rh-positive, whereas the absence of clumping indicates Rh-negative status.

Determining Blood Type with Simulated Blood

Simulated blood for ABO and Rh blood group laboratory use is a safe, non-biological alternative that mimics the antigen-antibody reactions of real blood typing. These kits use chemical solutions or synthetic liquids that, when mixed with simulated anti-A, anti-B, and anti-Rh serums, create a visible clumping or agglutination to determine blood type. This allows for hands-on practice in a classroom or lab setting without the risks associated with using actual blood.

Materials

- The kit including
 - 4 simulated blood samples, each representing a different ABO/Rh type.
 - one vial of simulated antibody A serum (also called Anti-A serum). This is a blue liquid.
 - one vial of simulated antibody B serum (also called Anti-B serum). This is a yellow liquid.
 - one vial of simulated antibody Rh serum (also called Anti-Rh serum). This is a clear liquid.
- Blood typing plates (with three wells)
- Mixing sticks or toothpicks (one per sample)
- Disposable gloves and protective eyewear
- Paper towel to work on

Procedure

For each blood sample:

1. Label the wells on the blood typing tray for each blood sample and each antiserum - anti-A (contains antibodies against A antigen), anti-B (contains antibodies against B antigen), anti-Rh (anti-D) serum (contains antibodies against the Rh antigen).
2. Place a drop of blood sample A in each of the three depressions (wells) of testing tray.
3. Place a drop of the antiserum that is associated with each depression. For example anti-A antiserum (containing anti-A antibodies) goes into the depression marked A. In that depression, you will be testing to see if the anti-A antibodies

agglutinate RBCs with A antigens.

4. Do the same for anti-B and anti-Rh sera into each of their depressions in the tray.
5. Gently stir the combination of the blood and antiserum in each depression with toothpick for 30 seconds. Do not mix toothpicks across depressions. Discard each mixing stick after a single use to avoid contamination of your samples.
6. Carefully examine the thin films of liquid mixture left behind. If a film remains uniform in appearance, there is no agglutination. If the sample appears granular, agglutination has occurred. Determine the blood type of the sample using the chart below. Answer yes or no as to whether agglutination occurred in each sample. A positive agglutination reaction indicates the blood type.
7. Repeat the same procedure with other three simulated blood samples.
8. Record observations and the results (ABO and Rh type) in the Data Table.

Table 5.6.1: ABO and Rh Blood Typing Data

Sample	Agglutination when mixed with anti-A serum? (yes or no)	Agglutination when mixed with anti-B serum? (yes or no)	Agglutination when mixed with anti-Rh serum? (yes or no)	ABO and Rh Blood Type
A	Agglutinated? Yes or No	Agglutinated? Yes or No	Agglutinated? Yes or No	
B	Agglutinated? Yes or No	Agglutinated? Yes or No	Agglutinated? Yes or No	
C	Agglutinated? Yes or No	Agglutinated? Yes or No	Agglutinated? Yes or No	
D	Agglutinated? Yes or No	Agglutinated? Yes or No	Agglutinated? Yes or No	

Note

Key points to remember:

- This test models how real blood typing is done before transfusions to ensure compatibility and prevent reactions.
- Agglutination indicates the presence of the matching antigen.
- Both ABO and Rh types must be checked for safe transfusion.

Clean up

1. Clean the blood typing plate by rinsing off the liquids. Then, use soap and water. Make sure there is no red residue left on the plate. Dry the plate.
2. Return the antiserum bottles, blood sample bottles in the kit.
3. Wipe down your work area with 10% bleach or ethanol spray.

Critical Thinking Exit Question

Bianca Del Rio is a person with B+ blood, who needs a blood transfusion. There are 4 possible donors who may give packed RBCs or whole blood. Donor 1 is A+. Donor 2 is AB+. Donor 3 is B-. Donor 4 is O-. Which of the four donors can donate whole blood to Bianca?

5.7: Activity 6

Reflection of the Blood Typing Lab Activities

1. Connecting Concepts and Mechanisms - "Explain the biological reasoning behind universal donors (O-) and universal recipients (AB+). What specific components of the blood (antigens and antibodies) are involved, and why do certain combinations cause agglutination (clumping)?"
2. "What was the most challenging part of the lab procedure or the underlying concepts, and what strategies did you use to overcome it? If you could do the activity again, what would you do differently to ensure greater accuracy, and what new questions about blood composition or function would you like to explore?"
3. What is something new you learn in blood typing activity?"
4. "What was a specific observation or result that led to your 'aha' moment, and how did you interpret it?"

5.8: Activity 7

Determining Packed Cell Volume (PCV)

Packed Cell Volume (PCV), also known as hematocrit, is a crucial laboratory test that measures the percentage of red blood cells (RBCs) in a given volume of blood. Understanding PCV is essential for diagnosing various health conditions, including anemia, dehydration, and polycythemia. This lab activity allows students to learn the significance of hematocrit values and how to accurately determine them using a centrifuge.

Material required

1. Anticoagulated Blood samples (numbered)
2. Micro-hematocrit centrifuge
3. Micro-hematocrit reader
4. Sealing Wax (Clay Sealant)
5. Hematocrit tubes or capillary tubes
6. Safety goggles and gloves

Safety Considerations - Follow safety protocol for using a centrifuge. All specimens received in the lab must be regarded as potentially infectious so follow safe practices. Refer to regulations and safety precautions.

Procedure

1. Touch the red circle end of heparinized capillary tube to the drop, hold the tube in a horizontal position and allow the blood to enter the tube until it is $\frac{3}{4}$ full.
2. Place finger over the "non-blood" end of the tube and push the opposite end into a clay sealant 3 to 4 times.
3. Place the sealed hematocrit tubes into the centrifuge, ensuring they are balanced (place a tube opposite to each other). Take note of the slot you placed your capillary tube.
4. Set the centrifuge to the appropriate speed and time (typically around 10,000 RPM for 5 minutes, but refer to your instructor's guidelines).
5. Start the centrifuge and wait for it to complete the cycle.
6. After centrifugation, carefully remove the tubes from the centrifuge.
7. After centrifuge three layers will be produced:
 - Red Blood Cells are packed in the bottom
 - The Buffy Coat (WBC + Platelets) in the middle
 - The yellowish plasma on the top
8. The hematocrit (packed cell volume, PCV) is determined by measuring the length of the packed red blood cell (RBC) column and dividing it by the total height of the blood sample column (RBCs, buffy coat, and plasma) using a ruler or hematocrit reader. DO NOT INCLUDE THE CLAY PLUG!
 - This ratio is multiplied by 100 to express the hematocrit as a percentage.
 - Formula : $\text{Hematocrit} = \frac{\text{Length of packed RBCs}}{\text{Total length of blood sample}} \times 100 \%$
9. Record hematocrit value of your sample. Wipe down your work area with 10% bleach or ethanol spray.

Post Lab Discussion

1. Discuss the significance of the obtained PCV values and what they might indicate about the individual's health.
2. Compare results with classmates and analyze any variations.
3. What is the hematocrit value of a healthy male living at sea level in Boston compared to a healthy male living at one mile elevation in Denver?

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Key Term and Definitions

- **Allogeneic:** refers to blood, stem cells, bone marrow, or other tissue that is transferred from one person to another.
- **Anemia:** a blood condition in which a person either does not have enough red blood cells or has red blood cells that do not function properly.
- **Antibody:** a protein found in the blood that recognizes and binds to other substances. Helpful antibodies neutralize or destroy viruses and bacteria. Auto-antibodies may attack a person's own red blood cells or platelets, causing disease.
- **Anticoagulant:** a drug that prevents blood clots from forming.
- **Antigen:** a marker protein on cells of the body or foreign substances, such as a virus or bacteria.
- **Artery:** a muscular vessel that carries oxygen- and nutrient-rich blood under high pressure from the heart to other parts of the body.
- **Autologous:** refers to blood or other tissue derived from a person's own body.
- **B lymphocyte:** a type of white blood cell (also known as a B cell) that produces antibodies.
- **Basophil:** a type of normal white blood cell that may increase with bone marrow damage, parasitic infections, or allergic reactions.
- **Benign:** refers to a non-cancerous disease that does not spread throughout the body.
- **Bleeding disorder:** the clinical problem that results when the blood does not clot properly.
- **Blood:** the specialized fluid in your body that carries oxygen, nutrients, defensive cells, and antibodies, and forms clots in response to injury.
- **Blood banking:** the process of collecting, separating, and storing blood products.
- **Blood cancer:** a hematologic malignancy affecting blood, bone marrow, or lymph nodes, often due to uncontrolled growth of abnormal blood cells.
- **Blood smear/film:** a glass slide used to examine blood cells under a microscope for appearance and count.
- **Blood transfusion:** a procedure in which blood from a donor is transferred to another person.
- **Bone marrow:** the soft, spongy tissue inside bones where blood cells are produced.
- **Bone marrow transplantation:** the transfer of healthy bone marrow cells into a person with defective or damaged marrow.
- **Capillaries:** the smallest blood vessels, connecting arteries to veins.
- **Chronic:** refers to a slowly progressing disease.
- **Circulatory system:** the heart and blood vessels that transport blood throughout the body.
- **Clot:** a clump of platelets and proteins that forms at injury sites to prevent bleeding; may also block vessels (thrombosis).
- **Coagulation:** the process by which blood clots.
- **Complete blood count (CBC):** a test that measures types and numbers of blood cells to help diagnose conditions like anemia or infection.
- **Cord blood stem cells:** cells from the umbilical cord with the ability to self-renew and develop into other cell types; used in transplants.
- **Eosinophil:** a white blood cell that mediates allergic reactions and defends against parasites and bacteria.
- **Erythrocyte:** also called a red blood cell; carries hemoglobin and transports oxygen.
- **Erythropoietin:** a hormone from the kidneys that regulates red blood cell production.
- **Fibrin:** a threadlike protein that supports clot formation and tissue repair.
- **Granulocyte:** a white blood cell type that includes neutrophils, eosinophils, and basophils.
- **Hematocrit:** the percentage of blood volume made up of red blood cells (Hct).
- **Hematologist:** a physician specializing in blood disorders.
- **Hematology:** the study of blood and blood-forming tissues.
- **Hematopoiesis:** the process of producing new blood cells.
- **Hematopoietic stem cell:** a cell that can become any type of blood cell (HSC).
- **Hemoglobin:** a protein in red blood cells that carries oxygen (HGB, Hb, or Hg).
- **Hemoglobinopathy:** a disease caused by abnormal hemoglobin structure.
- **Hemophilia:** an inherited bleeding disorder due to a lack of clotting factors.
- **Immune system:** the network of cells and organs that protect the body from infection.
- **Intravenous:** into a vein.
- **Iron:** a mineral essential for body functions and oxygen transport via hemoglobin.
- **Leukemia:** a cancer of blood and bone marrow caused by abnormal white blood cells.
- **Leukocyte:** a white blood cell (WBC) that protects against infection; includes five types.
- **Lymph node:** small organs that filter foreign particles and support immune function.
- **Lymphocyte:** a white blood cell involved in immune response; includes T and B cells.

- **Lymphocytic:** refers to diseases involving abnormal lymphocyte growth.
- **Lymphoma:** a blood cancer from abnormal lymphocytes that impair immune function.
- **Malignant:** refers to cancerous diseases that may spread to other body parts.
- **Monocyte:** a white blood cell that ingests bacteria and foreign particles.
- **Neutropenia:** a low count of infection-fighting granulocytes.
- **Neutrophil:** the most common white blood cell, essential for fighting infection.
- **Peripheral blood:** blood circulating through vessels and the heart.
- **Peripheral blood stem cells:** rare cells in peripheral blood used in stem cell transplants.
- **Phlebotomy:** the removal of blood from a vein.
- **Plasma:** the liquid part of blood that transports cells, nutrients, waste, and hormones.
- **Plasma cell:** a white blood cell that produces antibodies.
- **Platelet:** a cell fragment (thrombocyte) involved in blood clotting.
- **Platelet count:** part of the complete blood count, a blood test used to evaluate bleeding and clotting disorders.
- **Red blood cell:** the most common blood cell; it carries the protein hemoglobin, which transports oxygen from the lungs to the rest of the body; red blood cells are also known as erythrocytes or RBC.
- **Sickle cell anemia:** a congenital inherited blood disorder characterized by a different type of hemoglobin that causes red blood cells to become rigid and sickle-shaped.
- **Stem cell:** a cell that has the unique property of self-renewal as well as the ability to develop into other types of specialized cells, such as blood cells.
- **T lymphocyte:** a type of white blood cell (also known as a T cell) that helps protect the body against infection and cancer; some T cells can also release substances to attract other white blood cells and can regulate the activity of other immune cells.
- **Thalassemia:** an inherited congenital blood disorder that results in the decreased production of hemoglobin and red blood cells.
- **Thrombectomy:** the surgical removal of a blood clot.
- **Thrombocyte:** a small cell fragment (also known as a platelet) involved in the blood's clotting process.
- **Thrombosis:** excess clotting, which may block veins or arteries.
- **Thrombus:** a clump of platelets and blood proteins (also known as a clot) that form a plug at the site of an injured blood vessel to prevent excessive bleeding.
- **Transferrin:** a protein that attaches to iron in the bloodstream and delivers it to the liver.
- **Vein:** a vessel that carries blood low in oxygen away from the body's organs and back to the heart.
- **White blood cell:** a type of blood cell (also known as a leukocyte) that is primarily responsible for protecting the body from infection; there are five major types of white blood cells (basophils, eosinophils, lymphocytes, monocytes, and neutrophils), each with special properties and functions.
- **White blood cell count (WBC):** a blood test that measures the number of white blood cells to help detect problems in the body's immune system.

6: EXPLORING THE MAMMALIAN HEART- A HANDS-ON ANATOMY LAB

Introduction

In this lab, we will be learning about the location, anatomy and functions of the heart. If one assumes an average rate of contraction of 75 beats per minute, a human heart would contract approximately 108,000 times in one day, more than 39 million times in one year, and nearly 3 billion times during a 75-year lifespan. Each of the major pumping chambers of the heart ejects approximately 70 mL blood per contraction in a resting adult. This would be equal to 5.25 liters of fluid per minute and approximately 14,000 liters per day. Over one year, that would equal 10,000,000 liters or 2.6 million gallons of blood sent through roughly 60,000 miles of vessels. In order to understand how that happens, In fact, the heart does more physical work than any other muscle over a lifetime.

Learning Objectives

- Describe the location and position of the heart within the body cavity.
- Identify the external and internal anatomy of the heart, including the four chambers and 4 valves, in models, figures and relate parts to respective location and functions.
- Emphasize on the role of valves in preventing back-flow and ensuring unidirectional blood flow.
- Safely perform a dissection of a mammalian heart, identifying external and internal structures such as the septum, valves, and chordae tendineae and the differences between atrial and ventricular walls and discuss their functional significance.
- Recognize the major blood vessels connected to the heart, such as the aorta, pulmonary trunk, pulmonary arteries, pulmonary veins and coronary vessels to trace the path of blood flow through the heart using the dissected heart and laboratory models.
- Relate observations from the dissection to human cardiovascular health and medical practices.
- Differentiate between the pulmonary and systemic circulation and trace a drop of blood in a cardiac cycle.
- Identify and Relate electrocardiogram (ECG) peaks to the electrical activity, systole/diastole of the heart chambers, and the “lub” and “dub” sounds of the heart beat.

6.1: Background Information

6.2: Activity 1

6.3: Activity 2

6.4: Activity 3

6.5: Activity 4

6.6: Activity 5

6.7: Activity 6

6.8: Glossary

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6.1: Background Information

Introduction

Heart disease is the number one cause of death in the U.S. Racial and ethnic disparities observed in heart disease deaths also shows a disproportionately higher number of deaths due to heart disease are in Black, non-Hispanic persons. Some risk factors such as obesity, hypertension, diabetes, and high cholesterol that contribute to heart disease deaths are disproportionately higher in African American communities. Both biological factors and non-biological societal issues contribute to these disparities. As (future) health practitioners, it is very important to be aware of the risks facing your patients and advise them for heart-healthy lifestyles.

Note

Caring and good choices can lower risk. The CDC spotlight report [Racial and Ethnic Disparities in Heart Disease](#) highlights racial and ethnic disparities in heart disease, focusing on differences in death rates, prevalence, and risk factors across U.S. populations.

The cardiovascular system is composed of the heart and the blood vessels. The main function of this body system is to distribute materials throughout the body, including oxygen and energy-rich nutrients. The heart is the muscular pump of the cardiovascular system and the blood vessels are a delivery system. To understand how the heart functions, it is necessary to also study the large blood vessels that deliver blood directly into the heart and carry blood immediately out of the heart. In the cardiovascular system, there are two major categories of large vessels: arteries and veins. Arteries ("a" for "away") carry blood away from the heart. Veins carry blood toward the heart.

When considering blood flow, the amount of oxygen in the blood is of great importance. Oxygen, acquired from the lungs, is transported in the blood and used by body cells to conduct cellular respiration, a metabolic process that makes the body's main energy molecule: ATP. When showing blood flow in anatomical diagrams, vessels that are colored blue carry oxygen-poor blood and vessels that are colored red carry oxygen-rich blood. Most of the time, arteries are shown as red in anatomical diagrams because they usually carry oxygen-rich blood (exceptions: the pulmonary trunk and the pulmonary arteries that carry oxygen-poor blood from the heart to the lungs). Most of the time, veins are shown as blue in anatomical diagrams because they usually carry oxygen-poor blood (exception: the pulmonary veins that carry oxygen-rich blood from the lungs to the heart).

Circulation Through the Heart and Body

The human heart consists of four chambers: The left side and the right side each have one atrium and one ventricle. Each of the upper chambers, the right atrium (plural = atria) and the left atrium, act as receiving chambers and the combination of gravity and atrial contraction move blood into the lower chambers, the right ventricle and the left ventricle. The ventricles serve as the primary pumping chambers of the heart, propelling blood to the lungs or to the rest of the body.

There are two distinct but linked circuits in the human circulation called the pulmonary and systemic circuits. Although both circuits transport blood and everything it carries, we can initially view the circuits from the point of view of gases. The pulmonary circuit transports blood to and from the lungs, where it picks up oxygen and delivers carbon dioxide for exhalation. The systemic circuit transports oxygenated blood to virtually all of the tissues of the body and returns relatively deoxygenated blood and carbon dioxide to the heart to be sent back to the pulmonary circulation. These two circulations function simultaneously and thus the heart functions as a dual pump. The right ventricle pumps deoxygenated blood into the pulmonary trunk, which leads toward the lungs and bifurcates into the left and right pulmonary arteries. Arteries carry blood away from the heart. These vessels in turn branch many times before reaching the pulmonary capillaries, where gas exchange occurs, carbon dioxide diffuses out of the blood and oxygen diffuses into the blood.

The pulmonary trunk arteries and their branches are the only arteries in the post-natal body that carry relatively deoxygenated blood. Highly oxygenated blood returning from the pulmonary capillaries in the lungs passes through a series of vessels that join together to form the pulmonary veins—the only post-natal veins in the body that carry highly oxygenated blood. Veins carry blood toward the heart. The pulmonary veins conduct blood into the left atrium, which pumps the blood into the left ventricle, which

in turn pumps oxygenated blood into the aorta and on to the many branches of the systemic circuit. Eventually, these vessels will lead to the systemic capillaries, where exchange with the tissue fluid and cells of the body occurs. In this case, oxygen and nutrients out of the systemic capillaries to be used by the cells in their metabolic processes, and carbon dioxide and waste products diffuse into the blood.

The blood exiting the systemic capillaries is lower in oxygen concentration than when it entered. The capillaries will ultimately unite to form venules, joining to form ever-larger veins, eventually flowing into the two major systemic veins, the superior vena cava and the inferior vena cava, which return blood to the right atrium. The blood in the superior and inferior venae cavae flows into the right atrium, which pumps blood into the right ventricle. This process of blood circulation continues as long as the individual remains alive. Understanding the flow of blood through the pulmonary and systemic circuits is critical to all health professions.

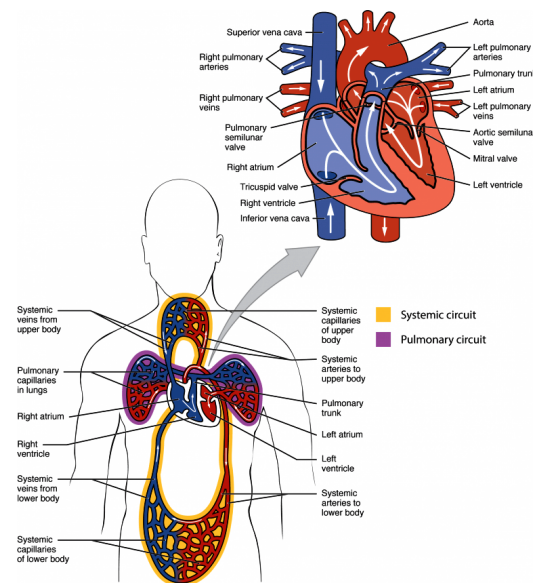


Figure 6.1.1: Diagram of the human circulatory system highlighting systemic and pulmonary circuits with labeled heart anatomy. (CC BY-SA 4.0; via [Anatomy & Physiology 2e](#)).

Figure 6.1.1 provides a visual representation of how blood moves through the pulmonary circuit (between the heart and lungs) and the systemic circuit (between the heart and the rest of the body), which was explained earlier. The diagram includes a close-up of the heart and a whole-body circulation overview showing where pulmonary and systemic blood vessels and capillaries are located.

The heart close-up labels these major features:

- Superior vena cava and inferior vena cava (large veins bringing blood into the heart)
- Right atrium and right ventricle (right-side chambers)
- Tricuspid valve (between right atrium and right ventricle)
- Pulmonary semilunar valve (outflow valve from the right ventricle)
- Pulmonary trunk, right pulmonary arteries, and left pulmonary arteries (vessels carrying blood from the heart toward the lungs)
- Right pulmonary veins and left pulmonary veins (vessels returning blood from the lungs to the heart)
- Left atrium and left ventricle (left-side chambers)
- Mitral valve (between left atrium and left ventricle)
- Aortic semilunar valve (outflow valve from the left ventricle)
- Aorta (large artery carrying blood from the heart to the body)

The body overview shows how blood travels within the systemic and pulmonary circuits. In the pulmonary circuit, oxygen-poor blood travels from the right atrium in the heart to the lungs, moving through the pulmonary capillaries, then returning as oxygen-rich blood to the left atrium in the heart.

The systemic circuit shows oxygen-rich blood pumped from the left ventricle in the heart, moving via systemic arteries to the lower body to systemic capillaries and through the body's tissues, then returning as oxygen-poor blood through the systemic veins from the lower body to the right ventricle in the heart.

Location, Size, and Shape of the Heart

The heart is a cone shaped muscular organ resides within the pericardial sac and is located in the mediastinal space within the thoracic cavity, between the lungs, and behind the sternum. The base of the heart is located at the level of the third costal cartilage and the apex, or inferior tip, is just to the left of the sternum between the fourth and fifth ribs. The heart is surrounded by a double layered membrane called the pericardium, which protects and lubricates the heart. The pericardium is attached to the mediastinum and ligaments in the spinal column and diaphragm.

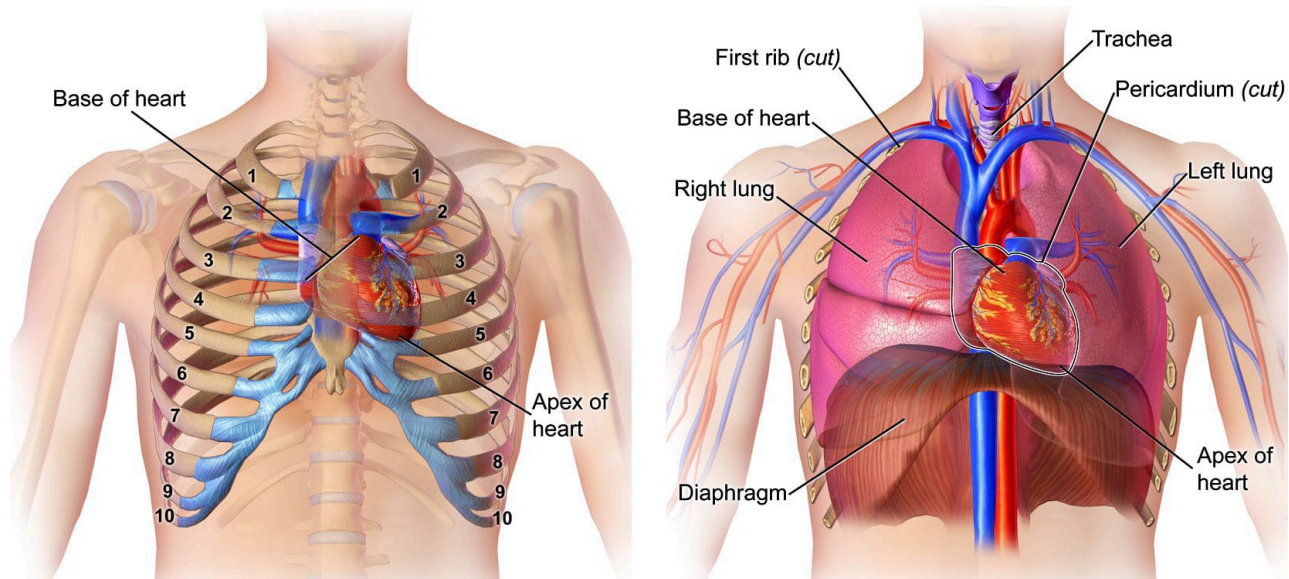


Figure 6.1.2: Internal anterior view showcasing the heart's location, size, and shape within the thoracic cavity. The diagram illustrates the heart's position relative to several key anatomical structures. The heart is nestled between the ribs, protected by the rib cage, sits under and slightly to the left of the breastbone (sternum), between the lungs. The trachea, or windpipe, is situated posterior to the heart. The diaphragm, a crucial muscle for breathing, forms the floor for the thoracic cavity. (CC BY-NC-SA 4.0; Rosanna Hartline via Location, Size and Shape of the Heart).

Figure 6.1.2 contains two anatomical diagrams of the chest that show the location and orientation of the heart within the thorax and how it relates to nearby structures. In the left panel, the heart is shown slightly to the left of the midline, within the rib cage. The ribs are numbered from one to ten, beginning in the cervical region. The base of the heart - the broader portion - lies at an angle, spanning ribs 3 to 2. The apex - the pointed tip - lies between ribs 4 and 5. The right panel is described in the figure caption. The major vessels carrying blood away from the heart are the aorta and the pulmonary trunk, which splits into the right and left pulmonary arteries. The aorta has different regions:

- ascending aorta
- aortic arch
- descending aorta

The descending aorta is shown in the figures as being cut, but would continue to descend along the posterior aspect of the heart through the thoracic and abdominal cavities. The right and left pulmonary arteries travel to the right and left lungs, respectively.

The major vessels carrying blood away from the heart are the aorta and the pulmonary trunk which splits into the right and left pulmonary arteries. The aorta has different regions (ascending aorta, aortic arch, and descending aorta). The descending aorta is shown in the figures as being cut, but would continue to descend along the posterior aspect of the heart through the thoracic and abdominal cavities. The right and left pulmonary arteries travel to the right and left lungs, respectively.

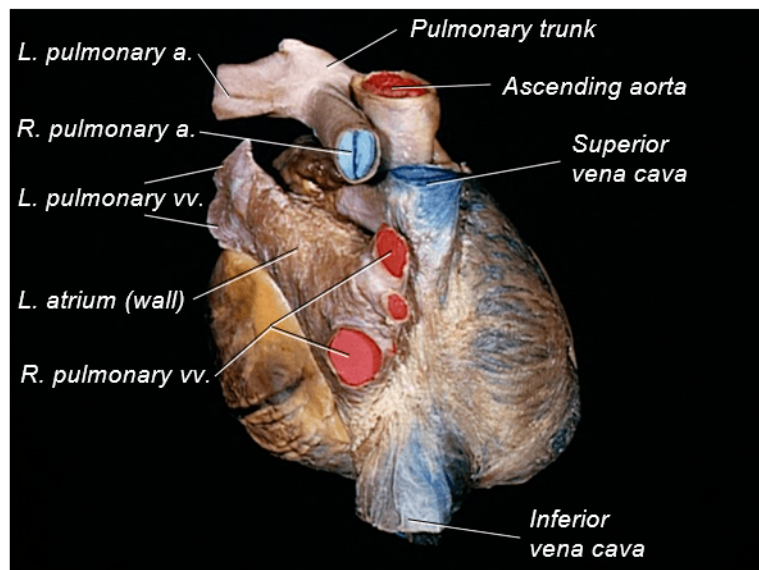


Figure 6.1.3: External anatomy of the lateral view of the right side of a heart with blood vessels (ascending aorta, pulmonary trunk, right and left pulmonary arteries, right and left pulmonary veins, left atrium wall, and inferior vena cava) colored to indicate the oxygenation of blood passing through these vessels. (CC BY-NC-SA 4.0; Rosaline Hartline via [Vessels of the Heart](#)).

Figure 6.1.3 shows an anatomical view of a heart specimen against a dark background. Multiple labels point to major blood vessels connected to the heart and to part of the left atrium. The purpose of the image is to identify the names and positions of these vessels as they enter or leave the heart.

The diagram labels the following structures:

- Pulmonary trunk: a large vessel leaving the heart that leads toward the pulmonary arteries.
- Ascending aorta: a large vessel leaving the heart that carries blood to the systemic circulation.
- Superior vena cava: a large vein entering the heart from the upper body region.
- Inferior vena cava: a large vein entering the heart from the lower body region.
- Left pulmonary artery (L. pulmonary a.): labeled as a branch associated with the pulmonary trunk.
- Right pulmonary artery (R. pulmonary a.): labeled as another branch associated with the pulmonary trunk.
- Left pulmonary veins (L. pulmonary vv.): labeled as vessels returning to the heart from the left lung side.
- Right pulmonary veins (R. pulmonary vv.): labeled as vessels returning to the heart from the right lung side.
- Left atrium (wall): labeled as the wall portion of the left atrium near where pulmonary veins connect.

Surface Features of the Heart

The heart is composed of four hollow chambers: two atria and two ventricles. The thin walled right and left atria are the two superior chambers. While both atria are visible from the anterior, the majority of the left atrium is seen on the posterior aspect. Each atrium has a superficial flap like extension called an auricle because its shape resembles the external ear of a human. You may also hear them referred to as atrial appendages. The auricles can increase the atrial capacity at times of exertion by filling with blood and, thus, relieving high atrial pressure. The two ventricles are inferior to the atria and they form the largest portion of the heart. Their walls are significantly thicker than those of the atria as a large amount of muscle mass is needed to push the blood into the arteries. The right ventricle makes up the right side and much of the anterior portion of the heart, while the left ventricle makes up the left side and much of the posterior portion of the heart.

Also prominent along the superficial surfaces of the heart is a series of fat-filled grooves, each of which is known as a sulcus (plural = sulci), containing major coronary blood vessels. The deepest is the coronary sulcus, which encircles the heart between the atria and ventricles. Located between the left and right ventricles are two shallower sulci: 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.

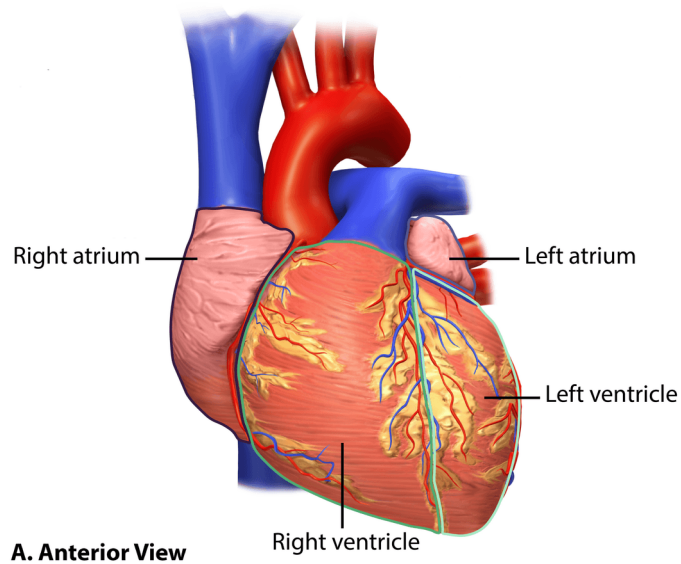


Figure 6.1.4: Anterior view of the human heart showing labeled atria and ventricles with color-coded vessels.(CC BY-NC-SA 4.0; via [Heart Anatomy](#)).

Figure 6.1.4 shows an anatomical diagram of the heart in an anterior (front) view. Labels identify the four chambers and major surface vessels.

- The right atrium is labeled on the upper left side of the image and receives blood returning from the body.
- The left atrium is labeled on the upper right side and receives oxygen-rich blood returning from the lungs.
- The right ventricle is labeled below the right atrium in the lower center-left area and pumps blood toward the lungs.
- The left ventricle is labeled on the lower right side and pumps oxygen-rich blood to the rest of the body.
- Blood vessels on the surface represent the coronary arteries and veins, which supply the heart muscle. A large vessel at the top is labeled as the aorta, which carries blood away from the heart.

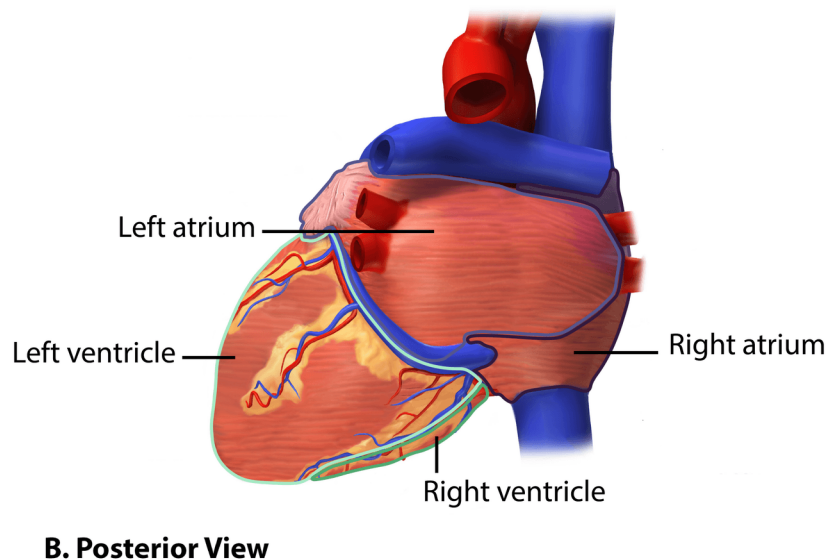


Figure 6.1.5: Posterior view of the human heart showing labeled atria and ventricles. (CC BY-NC-SA 4.0; via [Heart Anatomy](#)).

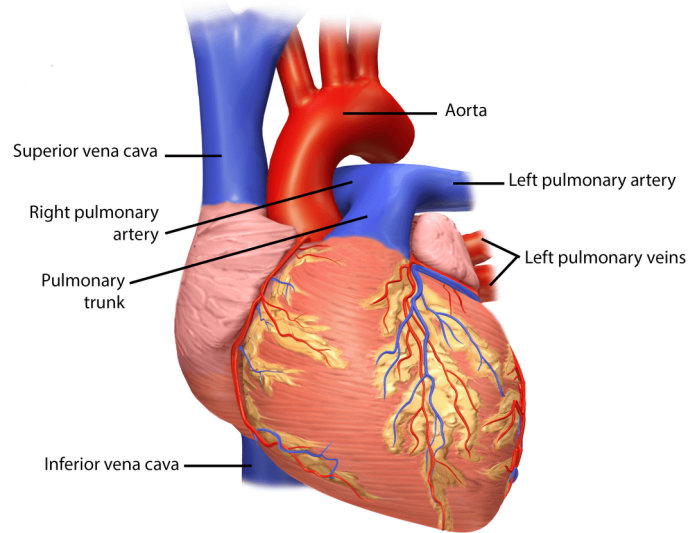
Figure 6.1.5 shows a diagram of the human heart in a posterior (back) view, meaning the heart is seen from behind. Labels identify the four chambers and surface blood vessels.

- The left atrium is labeled near the upper left of the image and receives oxygen-rich blood from the lungs.
- The right atrium is labeled on the right side and receives oxygen-poor blood returning from the body.
- The left ventricle is labeled on the lower left portion of the heart and pumps oxygen-rich blood to the body.

- The right ventricle is labeled near the lower center, below the right atrium, and pumps blood to the lungs.
- Blood vessels on the heart's surface represent coronary arteries and coronary veins, which supply the heart muscle. Large veins connected at the top and bottom represent major vessels returning blood to the heart.

Vessels of the Heart

The heart is divided into 4 chambers: two superior atria (receiving chambers) and two inferiorly positioned ventricles (discharging chambers). At least one blood vessel attaches to each of the chambers. The major vessels carrying blood toward the heart are the superior vena cava (vena=vein), inferior vena cava, left pulmonary veins, and right pulmonary veins. The superior vena cava and inferior vena cava carry blood to the heart from the superior and inferior regions of the body, respectively. The right and left pulmonary veins carry blood back to the heart from the right and left lungs, respectively. Coronary arteries are found along the surface of the heart. These arteries provide nutrients to the heart tissue.

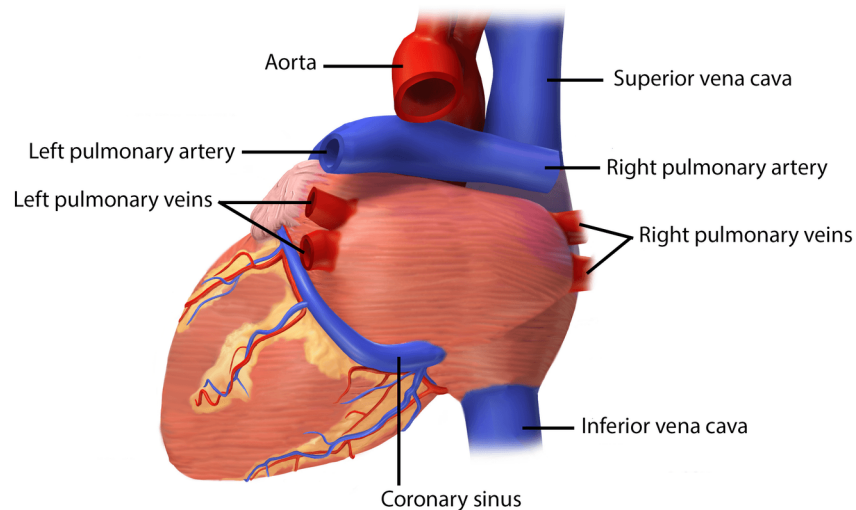


A. Anterior View

Figure 6.1.6: Posterior view of the human heart with labeled major blood vessels including the aorta, vena cava, pulmonary arteries and veins, and coronary sinus. (CC BY-NC-SA 4.0; via [Heart Anatomy](#)).

Figure 6.1.6 is a labeled anterior (front) view of the heart showing major blood vessels connected to the heart and several surface vessels. The purpose of the diagram is to identify the names and relative positions of the large vessels that carry blood to and from the heart and lungs. Labeled vessels and where they appear in the diagram:

- Aorta: A large vessel labeled near the top of the heart. It arches upward from the heart and is shown as the main outflow vessel to the body.
- Superior vena cava: A large vein labeled on the upper left side of the image, shown entering the heart from above.
- Inferior vena cava: A large vein labeled on the lower left side of the image, shown entering the heart from below.
- Pulmonary trunk: A large vessel labeled on the left side of the heart near the top; it emerges from the heart and leads toward the pulmonary arteries.
- Right pulmonary artery: Labeled on the left side of the image; it branches from the pulmonary trunk and travels toward the right lung side.
- Left pulmonary artery: Labeled on the right side of the image; it branches from the pulmonary trunk and travels toward the left lung side.
- Left pulmonary veins: Labeled on the right side of the image; multiple veins are shown returning toward the heart from the left lung side.



B. Posterior View

Figure 6.1.7: Posterior view of the human heart with labeled major blood vessels including the aorta, vena cava, pulmonary arteries and veins, and coronary sinus. (CC BY-NC-SA 4.0; via [Heart Anatomy](#)).

Figure 6.1.7 shows a labeled posterior (back) view of the heart. The purpose of the diagram is to identify major vessels connected to the heart as seen from behind, including vessels that carry blood between the heart and lungs and the large veins returning blood to the heart. Labeled structures in the diagram:

- Aorta: Labeled near the top of the image as a large vessel leaving the heart.
- Superior vena cava: Labeled on the upper right side as a large vein entering the heart from above.
- Inferior vena cava: Labeled on the lower right side as a large vein entering the heart from below.
- Left pulmonary artery: Labeled on the left side near the top; a branch carrying blood from the heart toward the left lung side.
- Right pulmonary artery: Labeled on the right side near the top; a branch carrying blood from the heart toward the right lung side.
- Left pulmonary veins: Labeled on the left side; multiple veins returning blood from the left lung side to the heart.
- Right pulmonary veins: Labeled on the right side; multiple veins returning blood from the right lung side to the heart.
- Coronary sinus: Labeled near the lower middle portion of the heart surface; a large venous channel that collects blood from veins of the heart wall and returns it to the heart.

Layers of the Heart Muscle

The heart is located in the pericardial cavity formed by the serous membranes of the pericardium. There are two layers of serous membranes (parietal and visceral) with the outer layer being the parietal pericardium which attaches the heart to the mediastinum and has fibrous tissue so the heart does not over-expand. The inner visceral layer is also called the epicardium and it lines the surface of the heart. Between these two membranes is a space, the pericardial cavity, containing a small amount of fluid to reduce friction as the heart moves. Both layers have mesothelium which produces serous fluid. The heart wall is composed of three layers (from outside to inside):

1. Epicardium - the same tissue as the visceral pericardium.
2. Myocardium - makes up most of heart wall, composed of cardiac muscle tissue which is made of uninucleated cardiac muscle cells.
3. Endocardium - a thin layer of endothelial tissue that lines the heart chambers.

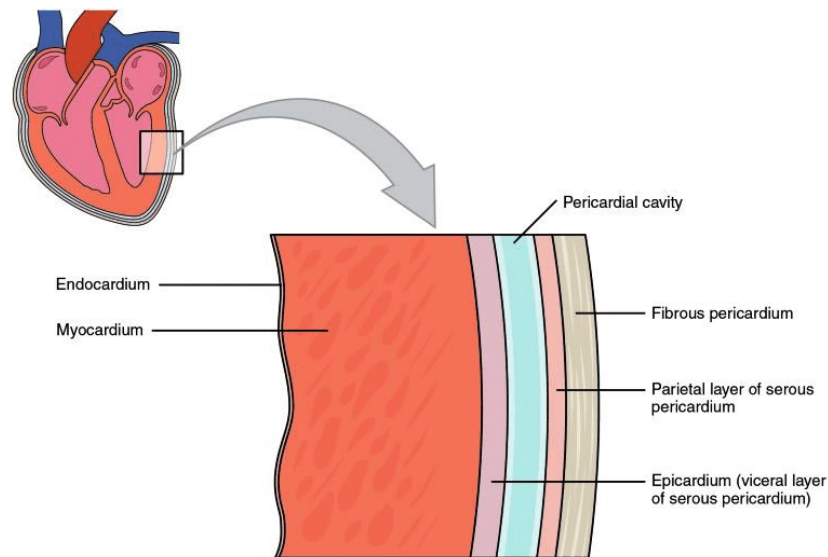


Figure 6.1.8: Pericardial Membranes and Layers of the Heart Wall: The pericardial membrane that surrounds the heart consists of three layers (fibrous pericardium, parietal layer of serous pericardium and visceral layer of serous pericardium aka epicardium) and the pericardial cavity. The heart wall also consists of three layers (endocardium, myocardium, epicardium). (CC BY-NC-SA 4.0; via [Anatomy & Physiology](#)).

Figure 6.1.8 is a simplified anatomical diagram that explains the layered structure of the heart wall and the pericardium (the surrounding sac). A small heart icon in the upper left includes a boxed region, and an arrow points from that box to a magnified cross-sectional view. Reading the magnified cross-section from left (heart interior side) to right (outer covering side), the diagram labels:

1. Endocardium
 - The thin inner lining of the heart wall.
2. Myocardium
 - The thick muscular middle layer of the heart wall.
3. Epicardium (visceral layer of serous pericardium)
 - The outer surface layer of the heart wall; it is also identified as the visceral layer of the serous pericardium.
4. Pericardial cavity
 - A thin fluid-filled space between the visceral and parietal serous pericardium layers. The diagram highlights this as a distinct “gap” or space.
5. Parietal layer of serous pericardium
 - The serous membrane layer that lines the inside of the fibrous pericardium.
6. Fibrous pericardium
 - The tough, outermost protective layer surrounding the heart.

Internal Anatomy of the Heart

The heart is divided into four chambers: right atrium, right ventricle, left atrium, and left ventricle. The atria are the two superior chambers of the heart and the ventricles are the two inferior chambers of the heart. The right side of the heart and the left side of the heart are isolated from each other. The right and left sides are separated by septa. Between the right and left atria is tissue called the interatrial septum and between right and left ventricles is tissue called the interventricular septum.

Normally in an adult heart, the interatrial septum bears an oval-shaped depression known as the fossa ovalis, a remnant of an opening in the fetal heart known as the foramen ovale. The foramen ovale allowed blood in the fetal heart to pass directly from the right atrium to the left atrium, allowing some blood to bypass the pulmonary circuit. Within seconds after birth, a flap of tissue that previously acted as a valve closes the foramen ovale and establishes the typical cardiac circulation pattern. Between the two ventricles is a second septum known as the interventricular septum. Unlike the interatrial septum, the interventricular septum is normally intact after its formation during fetal development. It is substantially thicker than the interatrial septum, since the ventricles generate far greater pressure when they contract.

The septum between the atria and ventricles is known as the atrioventricular septum. It is marked by the presence of 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. The valves between the atria and ventricles are known generically as atrioventricular valves. Each flap of an atrioventricular valve is attached to strong strands of connective tissue, the chordae tendineae, literally “tendinous cords,” or sometimes more poetically referred to as “heart strings”. There are several chordae tendineae associated with each of the valve flaps that are composed of approximately 80 percent collagenous fibers with the remainder consisting of elastic fibers and endothelium. They connect each of the flaps to a papillary muscle. The valves at the openings that lead to the pulmonary trunk and aorta are known generically as semilunar valves. The semilunar valves are both comprised of three small flaps of endothelium reinforced with dense connective tissue.

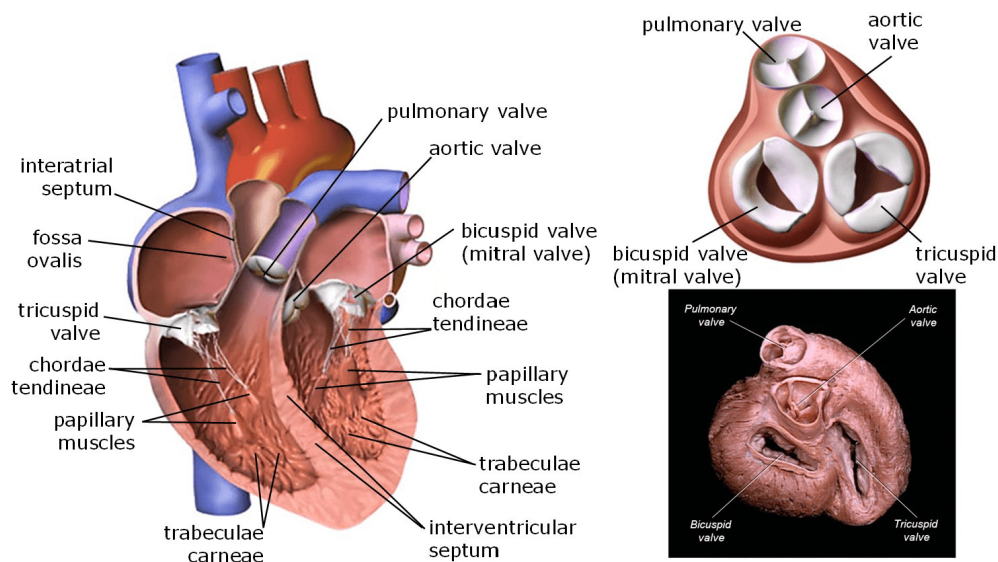


Figure 6.1.9: Internal structures of the heart in coronal section. (Left) Anterior view of the internal heart (interatrial septum, fossa ovalis, tricuspid valve, chordae tendineae, papillary muscles, trabeculae carneae, interventricular septum, bicuspid valve, aortic valve and pulmonary valve) and (right) superior view of the valves of the heart with the atria removed. (CC BY-NC-SA 4.0; Rosanna Hartline via [Internal Structures of the Heart](#)).

Figure 6.1.9 is a multi-panel instructional figure about the valves of the heart and related internal structures. It includes:

1. A large cutaway diagram of the heart with labels
2. A simplified top view showing the four valves together
3. A photo of a heart specimen showing the valves.

Panel 1 (left) - Cutaway heart diagram with labeled internal structures

- The main panel shows a cutaway view of the heart interior with many labels pointing to structures in the atria and ventricles. Labeled items include:

Atrial landmarks

- Interatrial septum: the wall separating the right and left atria.
- Fossa ovalis: a feature labeled on the interatrial septum.

Atrioventricular (AV) valves (between atria and ventricles)

- Tricuspid valve: labeled on the right side AV opening.
- Bicuspid valve (mitral valve): labeled on the left side AV opening.

Semilunar valves (outflow valves from the ventricles)

- Pulmonary valve: labeled at the ventricular outflow leading toward the pulmonary artery.
- Aortic valve: labeled at the ventricular outflow leading toward the aorta.

Supporting valve structures inside the ventricles

- Chordae tendineae: labeled as cord-like structures attached to the AV valves.
- Papillary muscles: labeled as muscle projections in the ventricles that anchor the chordae tendineae.
- Trabeculae carneae: labeled as muscular ridges lining the ventricular walls.
- Interventricular septum: labeled as the wall separating the right and left ventricles.

Panel 2 (upper right): Simplified view of the four valves together

This panel shows a top-down style view of the valve openings and labels all four:

- Pulmonary valve
- Aortic valve
- Bicuspid (mitral) valve
- Tricuspid valve

Panel 3 (lower right): Photo of a heart specimen with valve labels

This panel is a photograph of a heart specimen with labels pointing to:

- Pulmonary valve
- Aortic valve
- Bicuspid (mitral) valve
- Tricuspid valve

Table 6.1.1: Mapping the Journey: Heart Chambers and Valves Guiding Blood Flow Through the Cardiovascular Highway

Heart Chamber	Location	Blood flowing into this chamber	Blood flowing out of this chamber	Associated valves
left atrium	superior left side of the heart	from pulmonary veins; O ₂ -rich blood	to the left ventricle	mitral valve (aka left atrioventricular valve; aka bicuspid valve) drains blood from the left atrium when it is open during ventricular diastole.
left ventricle	inferior left side of the heart	from left atrium; O ₂ -rich blood	to the aorta	blood moves into this chamber through the mitral valve (aka left atrioventricular valve; aka bicuspid valve) during ventricular diastole; blood moves out of this chamber through the aortic valve during ventricular systole.
right atrium	superior right side of the heart	from superior vena cava and inferior vena cava; O ₂ -poor blood	to the right ventricle	tricuspid valve (aka right atrioventricular valve) drains blood from the right atrium when it is open during ventricular diastole.

Heart Chamber	Location	Blood flowing into this chamber	Blood flowing out of this chamber	Associated valves
right ventricle	inferior right side of the heart	from right atrium; O ₂ -poor blood to the pulmonary trunk	to the pulmonary trunk	blood moves into this chamber through the tricuspid valve (aka right atrioventricular valve) during ventricular diastole; blood moves out of this chamber through the pulmonary valve during ventricular systole.

6.2: Activity 1

External Anatomy of Heart

Build a 3D mental map of the heart's orientation and surface features to support understanding of blood flow, coronary circulation, and clinical landmarks.

- What you will focus on
 - Orientation: apex vs base; anterior (sternocostal) vs posterior (diaphragmatic) surfaces; right vs left sides in situ.
 - Great vessels: aorta (and arch), pulmonary trunk and arteries, superior/inferior vena cava, pulmonary veins.
 - Surface landmarks: right and left auricles, coronary (atrioventricular) sulcus, anterior and posterior interventricular sulci.
 - Coronary circulation: right and left coronary arteries (including LAD/anterior interventricular and circumflex branches), coronary veins (great, middle) and coronary sinus.
 - External clues to internal structures: where AV and semilunar valves lie relative to surface grooves; where chamber borders project to the surface.
- Why it matters (clinical connections)
 - Localizing myocardial infarctions by artery territory (e.g., LAD on anterior interventricular sulcus).
 - Placing ECG leads and valve auscultation points using external landmarks.

Work with your group to identify key surface features (numbered) using the laboratory models and fill in the Table 6.2.1.

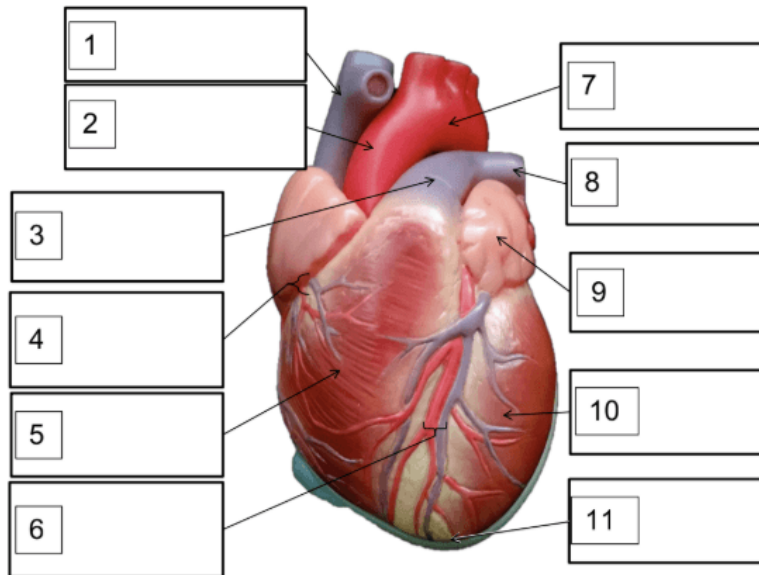


Figure 6.2.1: Labeled diagram of the human heart showing major vessels and chambers with numbered markers. (Public Domain ; via Lakshmi Kanta Sengupta).

Figure 6.2.1 shows a detailed anterior view of the human heart with eleven numbered labels pointing to major anatomical structures, including vessels and chambers. The labels are placeholders for names like aorta, vena cava, pulmonary arteries, and veins.

Table 6.2.1: Identification of major anatomical structures in the anterior view of the human heart.

Number	Identification
	Apex of the heart
	Ascending aorta
	Auricle

Number	Identification
	Aortic arch
	Left ventricle
	Anterior interventricular sulcus
	Pulmonary trunk
	Left pulmonary artery
	Superior vena cava
	Right ventricle
	Coronary sulcus

6.3: Activity 2

Internal Heart Anatomy in Coronal Section

- Purpose: Build a clear 3D understanding of the blood vessels, heart's chambers, valves, and septa using laboratory models using consistent landmarks to tell right from left, atria from ventricles, and AV from semilunar valves. This will link structures to their function in blood flow or valve mechanics.
- Why it matters: Accurate recognition of internal anatomy underpins understanding of blood flow, valve function, imaging (echo/CT/MRI), and common pathologies (valve disease, septal defects, hypertrophy)

Materials

- Anatomical heart models (dissectible, with removable walls) – enough for small groups
- Torso models or circulatory system posters (optional, for overall orientation)
- Large laminated diagrams of the heart and great vessels for reference

These supplies will support hands-on identification of:

- Right vs left side of the heart (using consistent external landmarks)
- Atria vs ventricles
- AV (tricuspid, mitral) vs semilunar (pulmonary, aortic) valves
- Major vessels (vena cavae, pulmonary trunk/arteries/veins, aorta) and septa, linked directly to the direction of blood flow and valve mechanics.

Instructions

1. Identify internal heart features indicated by numbers (1 to 14) in Figure 6.3.1.
2. Use a systematic approach focusing on the four chambers, associated major vessels, septa, and valves, while keeping the heart's orientation (apex pointing down and to the left) in mind.
3. Add functions to the structures identified and fill in the Table 6.3.1.

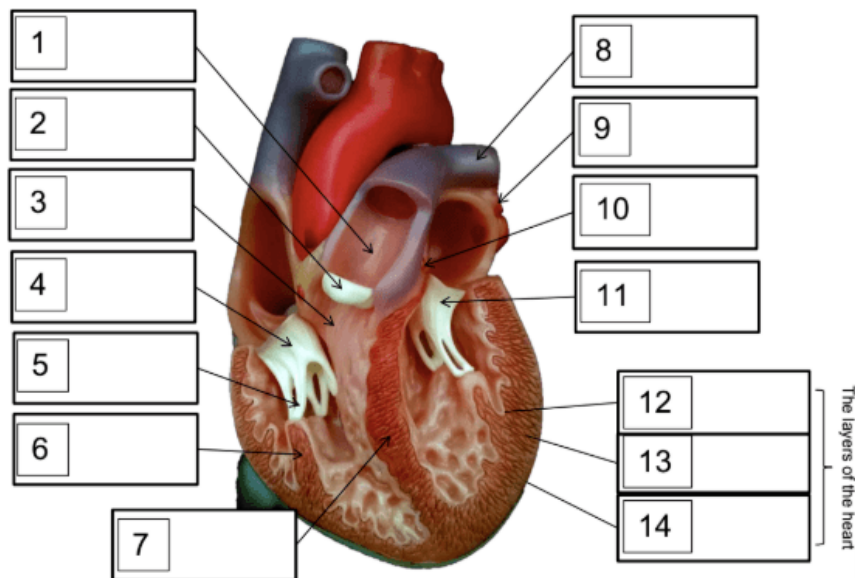


Figure 6.3.1: Detailed anatomical diagram of the human heart with numbered labels for identification. (Public Domain; via Lakshmikanta Sengupta).

Figure 6.3.1 shows an anatomical diagram of the human heart. It includes arrows pointing to specific internal structures, each labeled with a number from 1 to 14. These numbers correspond to different components such as major blood vessels, heart chambers, layers of the heart muscle, and other features like chordae tendineae, intended for identification.

Table 6.3.1: Identification and functions of key anatomical structures in the human heart.

Number	Identification	Function
	Left pulmonary artery	
	Left pulmonary vein	large valveless vessels that carry oxygen-rich blood from the lungs to the left atrium of the heart. These veins are unique in that, unlike other veins of the body which transport deoxygenated blood, the pulmonary veins carry oxygenated blood.
	Interventricular septum	
	Mitral (Bicuspid) valve	
	Tricuspid valve	
	Pulmonary semilunar valve	
	Chordae tendineae	
	Papillary muscle	
	Endocardium	
	Left coronary artery	
	Conus arteriosus (infundibulum of the right ventricle)	
	Myocardium	
	Pulmonary trunk	
	Epicardium	

6.4: Activity 3

Identifying Major Blood Vessels

The heart has its own blood vessels that supply the heart muscle with blood. The coronary arteries branch from the aorta and surround the outer surface of the heart like a crown. They diverge into capillaries where the heart muscle is supplied with oxygen before converging again into the coronary sinus to take the deoxygenated blood back to the right atrium to ensure that the blood is re-oxygenated through the pulmonary circuit. The heart muscle will die without a steady supply of blood.

- Build a clear map of the heart's inflow and outflow vessels and the coronary circulation that supplies the heart muscle itself.
- Strengthen 3D orientation skills by using external landmarks on a model to identify vessels labeled A–K.

Pick up the Heart model with vessels to work in group to identify the structures labeled with letters A to K

- Systemic/pulmonary great vessels: aorta (ascending/arch), superior vena cava (SVC), inferior vena cava (IVC)
- Coronary circulation: right coronary artery (RCA), left coronary artery (LCA) and branches such as LAD, left circumflex artery, diagonal branch, right marginal artery, great cardiac vein, left marginal artery

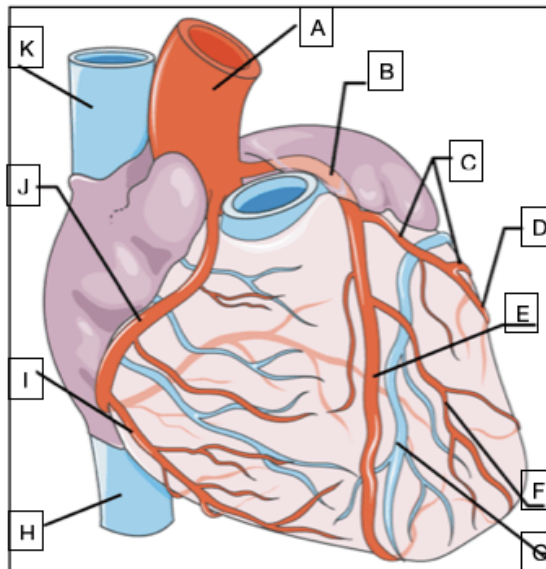


Figure 6.4.1: Detailed anterior view of the human heart showing labeled Systemic/pulmonary great vessels: aorta (ascending/arch), superior vena cava (SVC), inferior vena cava (IVC) and Coronary circulation: right coronary artery (RCA), left coronary artery (LCA) and branches such as LAD, left circumflex artery, diagonal branch, right marginal artery, great cardiac vein, left marginal artery. (Public Domain; via Lakshmikanta Sengupta).

Table 6.4.1: Identification of blood vessels labeled A to K in the heart diagram.

Letter	Identification of blood vessels
A	
B	
C	
D	
E	
F	
G	

Letter	Identification of blood vessels
H	
I	
J	
K	

6.5: Activity 4

Anatomy of the Heart Conduction System

A fully developed adult heart maintains the capability of generating its own electrical impulse, triggered by the fastest cells, as part of the cardiac conduction system. Build a concrete understanding of the cardiac conduction pathway.

What You Need to Do

Build a concrete understanding of the cardiac conduction pathway.

- Trace the normal depolarization sequence: SA node → atria → AV node delay → His bundle → right/left bundle branches → Purkinje fibers → ventricles.
- Identify SA node, AV node, bundle of His, right/left bundle branches, and Purkinje network on a heart model and relate them to chamber anatomy.

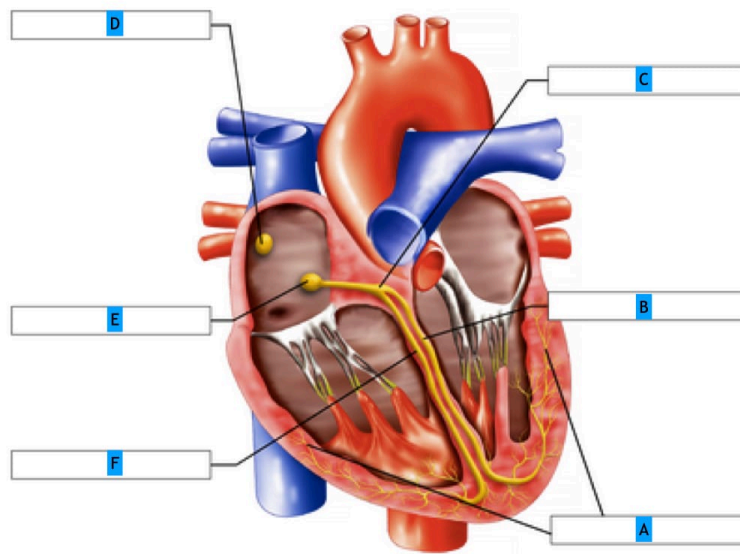


Figure 6.5.1: Detailed anatomical diagram of the human heart showing labeled internal structures and major vessels. (Public Domain; via Lakshmikanta Sengupta).

Figure 6.5.1 is an anatomical diagram of the human heart. It displays internal structures including chambers, valves, and major blood vessels, with labels pointing to each part for identification.

Table 6.5.1: Key Components of the Cardiac Conduction System and Their Associated Labels

Letter	Component	Letter	Component
	Bundle of His (AV Bundle)		SA Node
	AV Node		AV Node
	Purkinje fibers		Right and Left Bundle Branches

Map the Path and Explain the AV Pause

Trace the normal pathway of that electrical signal, from the SA node through the Purkinje fibers. In your own words (2–3 sentences), answer on your worksheet:

- What is the AV pause (AV nodal delay)?
- Why is it important for normal heart function?

This will help you connect conduction to the timing of atrial and ventricular contraction and to ECG waveforms.

Critical Thinking Prompt

A patient has damage to the Bundle of His. Which chambers might still contract together normally, and which may become uncoordinated? Briefly explain.

6.6: Activity 5

Sheep Heart Dissection

Sheep heart anatomy is very similar to human heart. Therefore we will dissect sheep heart to deepen 3D understanding of cardiac anatomy that models and images alone can't provide—relating external grooves to internal chambers and valves, wall thickness (LV vs RV) and coronary pathways.

Safety

- Wear closed-toe shoes that cover the entire foot.
- Wear safety goggles.
- Do not eat, drink, or chew gum during the lab
- Be mindful that scalpels and scissors are sharp. Handle them with care and be aware of their location at all times.
- Wash hands thoroughly with soap and water before and after the dissection.
- Be aware of the location of the nearest eyewash station.

Materials

- Apron (disposable)
- Preserved sheep heart
- Dissection tray
- Gloves (disposable latex or nitrile gloves)
- Safety goggles
- Scalpel
- Probe
- Pins
- Scissors
- Tweezers

Instructions

Obtain a sheep heart. Rinse it thoroughly in water.

Note

A thorough sheep heart dissection begins with an external examination to identify major blood vessels and orient the specimen before making any cuts. This prepares you for the internal anatomy, which reveals the four chambers, valves, and key structures that regulate blood flow.

External Anatomy

1. Initial Observation: Before beginning the dissection, carefully observe the external features of the heart. Note its overall size, shape (somewhat conical), and color. The outer covering of the heart, the pericardium may not be present in the specimen. If it is there, remove it. Carefully pull the visceral pericardium (epicardium) away from the myocardium.
2. Orient the heart - Locate the apex, the pointed end, and position it facing down. The ventral (front) surface is identified by a diagonal line of blood vessels, the interventricular sulcus, that runs from the base toward the apex.
3. Examine the external surface of the heart. Notice the accumulation of adipose tissue. This adipose usually accumulates along the boundaries of the heart chambers and along the coronary arteries. Remove as much adipose as possible.

4. Distinguish left and right - Place the heart in your hands so that the ventral side faces you and the apex points to the left. On one side you will see a diagonal line called the interventricular sulcus that has the left anterior interventricular artery and the vein. The half that includes the apex of the heart is the left side. The left side of the heart is stronger because it has to pump blood to the whole body. The right side only pumps blood to the lungs

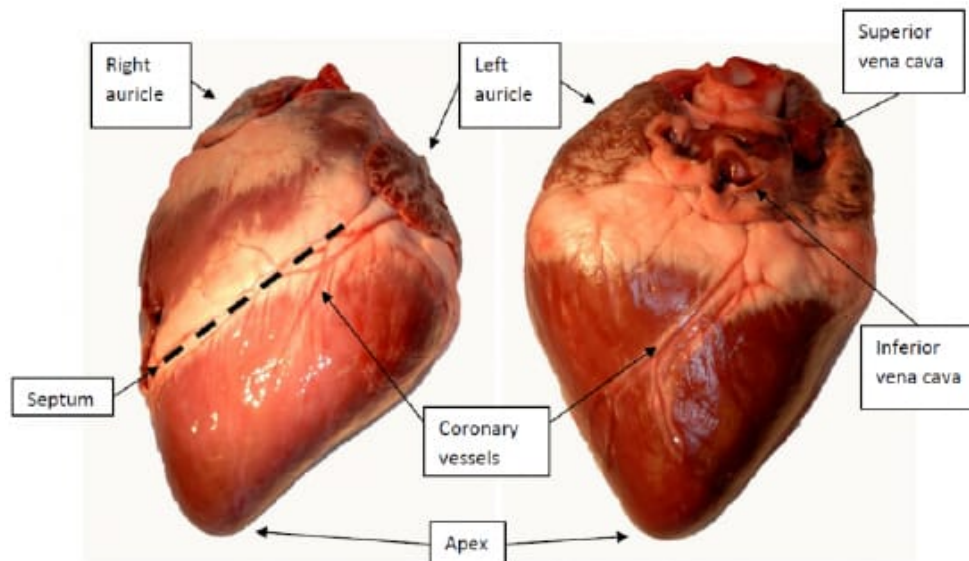


Figure 6.6.1: Two views of the heart showing labeled anatomical features: auricles, septum, coronary vessels, apex, and venae cavae. (CC BY-NC-SA 4.0; Sheryl Shook via [Heart Dissection](#)).

Figure 6.6.1 displays two views of a human heart with labeled anatomical features. The left view highlights the right auricle and septum, while the right view highlights the left auricle. Both views include labels for coronary vessels and the apex. The superior vena cava is labeled at the top of the right view, and the inferior vena cava is labeled below it.

5. Locate the small, ear-shaped muscular pouches - the auricles, that extend from their respective atria (the heart's upper chambers). Their primary function is to act as reservoirs, expanding the capacity of the atria and helping regulate blood flow into the ventricles
6. Find the large opening at the top of the heart next to the right auricle. This is the superior vena cava (SVC) which brings O₂ poor blood from the top half of the body to the right atrium (the atria are the top chambers in the heart). Place a blunt probe in this vessel, you may also use your finger to feel the inside of the right atrium.
7. A little down and to the left of the superior vena cava there is another blood vessel opening (sometimes the two openings are merged). Insert your probe into this; it should also lead into the right atrium. This is the inferior vena cava [IVC], which brings O₂ poor blood from the lower body tissues.
8. Locate another opening on the backside of the heart on the left side. This is the pulmonary vein that brings oxygen rich blood from the lungs into the left atrium.
9. Sticking straight up from the center of the heart is the largest blood vessel you will see. This is the aorta, which takes O₂ rich blood from the left ventricle to the rest of the body. The aorta starts as ascending aorta, then branches into brachiocephalic trunk, left coronary artery and left subclavian artery. If you do not see the arteries that branch out of the aorta in your sheep heart specimen, look at them in the models.

There is another large blood vessel - the pulmonary trunk that exits the right ventricle and branches into pulmonary arteries which takes blood from the right ventricle to the lungs. Note the position of the aorta and its relation to the pulmonary trunk/pulmonary arteries.

Internal Anatomy

5. Open the right side: Use a scalpel to make an incision in the superior vena cava. Continue the cut down through the wall of

the right atrium and right ventricle toward the apex. Pull the two sides apart to view the inside.

6. Open the left side: Insert your scalpel into the left auricle near the base of the aorta. Make an incision down through the wall of the left atrium and left ventricle toward the apex. As you open the left side, notice that the muscle wall is much thicker than the right.
7. Notice that the heart is made up of three layers: the epicardium (which is the same as the visceral pericardium), the myocardium (literally "heart muscle"), and the endocardium ("inside the heart"). Locate the side with the thickest myocardial wall. This will orient you to the left side of the heart.

Key internal structures

1. Examine the Chambers - Observe the four chambers: the right and left atria (upper chambers) and the right and left ventricles (lower chambers). "Vent" referring to something coming out of the space, which is blood in this case.
 - Right atrium receives O₂- poor (deoxygenated) blood from the body (SVC, IVC and coronary sinus).
 - Right ventricle pumps O₂- poor (deoxygenated) blood to the lungs via the pulmonary trunk.
 - Left atrium receives O₂- rich (oxygenated) blood from the lungs via pulmonary veins.
 - Left Ventricle pumps O₂- poor (oxygenated blood) to the rest of the body via the aorta.
2. Locate the Atrioventricular Valves - These valves allow blood to enter the ventricles (discharging chambers) from the atria (receiving chambers) while prevents back flow during ventricular contraction. Examine the valves separating the atria and ventricles:
 - Tricuspid Valve (right AV valve) - Note its three cusps,
 - Mitral (Bicuspid) Valve (left AV valve) - Note its two cusps.
3. Locate the Semilunar Valves
To find the semilunar valves, make an incision into the large arteries exiting the ventricles. The pulmonary valve is located at the base of the pulmonary artery leaving the right ventricle, and the aortic valve is at the base of the aorta leaving the left ventricle.
 - Make an incision along the length of the pulmonary trunk/artery, which is a large vessel exiting the top of the right ventricle. Inside the pulmonary artery, near its connection to the right ventricle, look for three small, pocket-like flaps. This is the pulmonary semilunar valve. This valve prevents blood from flowing back into the right ventricle.
 - Make an incision along the length of the aorta, the other large vessel exiting the top of the heart from the left ventricle. Inside the aorta, where it connects to the left ventricle, look for another set of three small, membranous pockets. This is the aortic semilunar valve. It prevents blood from flowing back into the left ventricle.
4. Coronary arteries - The two main coronary arteries branch off from the aorta just above the aortic valve. Start by probing the coronary artery entrance. By gripping the heart with the forceps next to the entrance of the artery, you may straighten out the closest part of the artery, which makes it easier to cut. Cut the coronary arteries starting from the aorta and proceeding along one or more branches as far as their size permit. Use the forceps to visualize the opened the artery.

Heart Dissection Image Atlas

The image atlas is a visual guide to the external and internal anatomy of the heart. Using labeled photographs or illustrations of real specimens, this resource is to help students orient the heart, identify major surface features (such as the apex, auricles, sulci, and great vessels), and locate deeper structures like the heart valves, septa, and coronary arteries as they proceed with dissection.

By following images that correspond to each dissection cut or anatomical region, students can compare their specimen directly to high-quality references, reducing confusion and ensuring accurate identification. This resource is especially valuable for visualizing relationships between structures and for clarifying features that may be difficult to distinguish in preserved tissue.

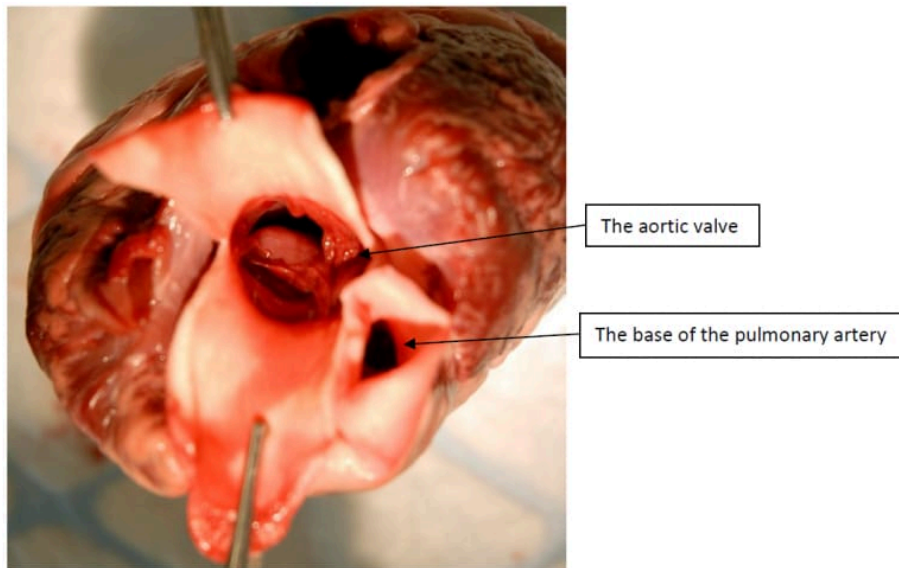


Figure 6.6.2: Superior view of a dissected heart showing the base of the ascending aorta with the aortic valve and the adjacent base of the pulmonary trunk indicating the pulmonary semilunar valve. Note the close anterior position of the pulmonary root relative to the aortic root.. (CC BY-NC-SA 4.0; Sheryl Shook via [Heart Dissection](#)).

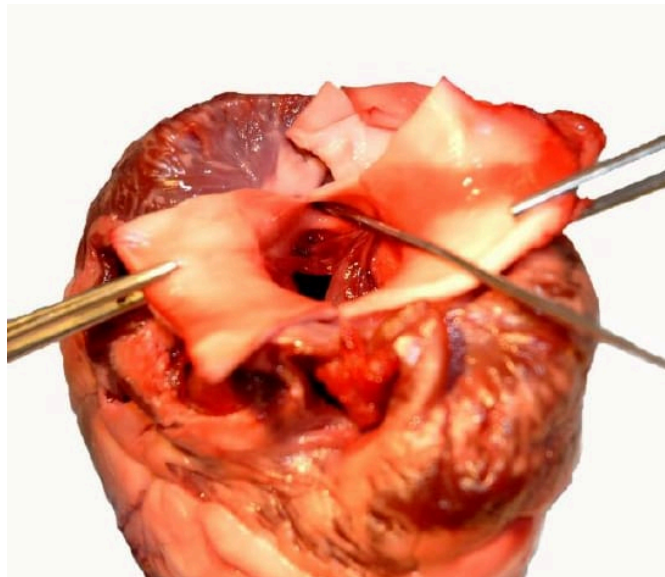


Figure 6.6.3: Probe entering the left coronary ostium in the left aortic sinus (just above the aortic valve cusps), marking the origin of the left coronary artery from the aortic root. From here it typically bifurcates into the anterior interventricular (LAD) and circumflex branches. (CC BY-NC-SA 4.0; Sheryl Shook via [Heart Dissection](#)).

Figure 6.6.3 Two surgical clamps retract heart valve leaflets, exposing the pale, translucent cusps within deep reddish-brown cardiac tissue—a close-up dissection view consistent with a semilunar valve, likely from a dissection or surgical demonstration.

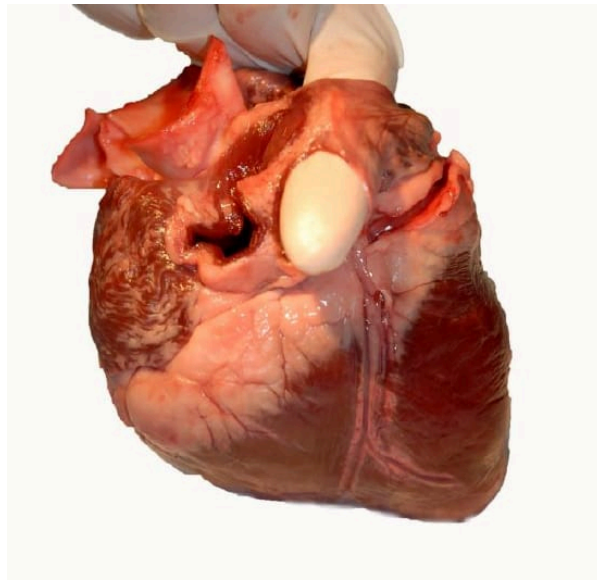


Figure 6.6.4: A gloved hand holds a dissected heart with index finger passing through the two entrances of the vena cavae.. (CC BY-NC-SA 4.0; Sheryl Shook via [Heart Dissection](#)).

Figure 6.6.4 Shows gloved hand holding a dissected heart with the index finger passing through the right atrium from the superior vena cava to the inferior vena cava, demonstrating the two caval openings and venous inflow into the heart.

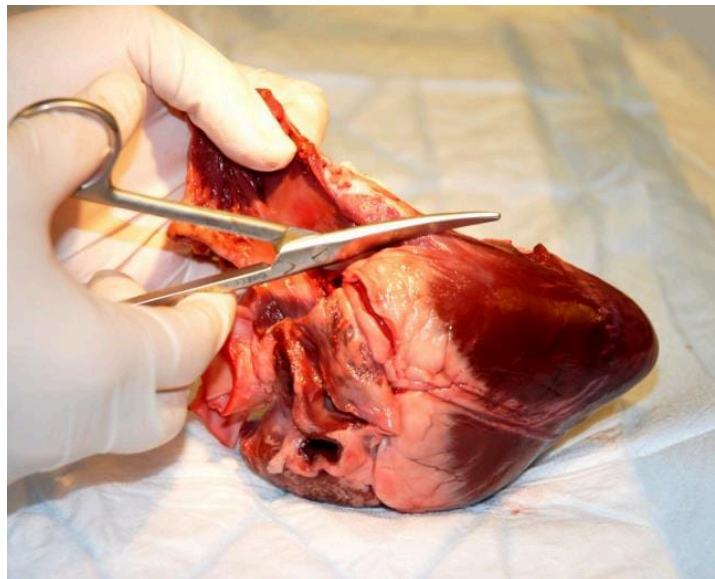


Figure 6.6.5: Cutting open the right ventricle. (CC BY-NC-SA 4.0; Sheryl Shook via [Heart Dissection](#)).

Figure 6.6.5 represents a gloved hand holds a pair of surgical scissors, using them to make an incision into a dark red, somewhat conical organ that resembles a heart. The organ rests on a light-colored surface, possibly a surgical drape. The scissors are metallic and sharp, positioned to cut through the tissue of the organ. The image captures a moment of anatomical dissection or preparation.

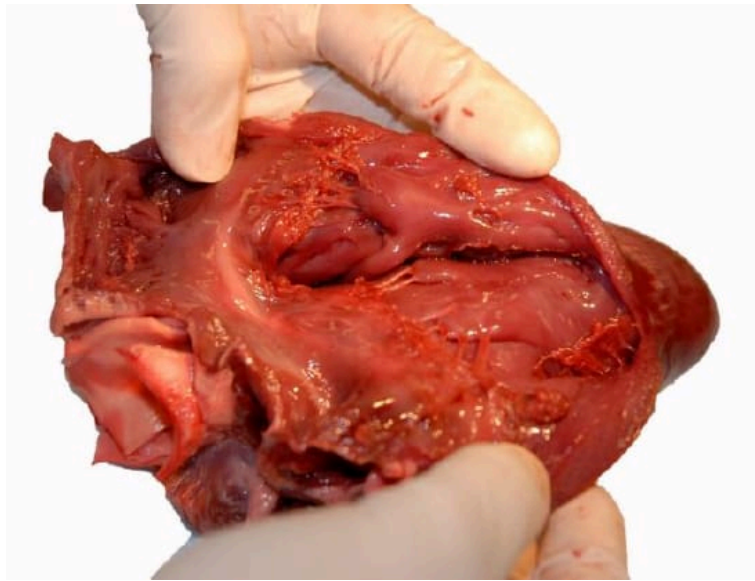


Figure 6.6.6: Inside of the right ventricle. (CC BY-NC-SA 4.0; Sheryl Shook via [Heart Dissection](#)).

Figure 6.6.6 depicts a gloved hand holds open a dissected organ, likely a heart, revealing its internal chambers and structures. The organ tissue is a deep, rich red, with various muscle folds and smoother lining visible inside. The dissection exposes the intricate internal anatomy, characteristic of a biological specimen prepared for study or demonstration.

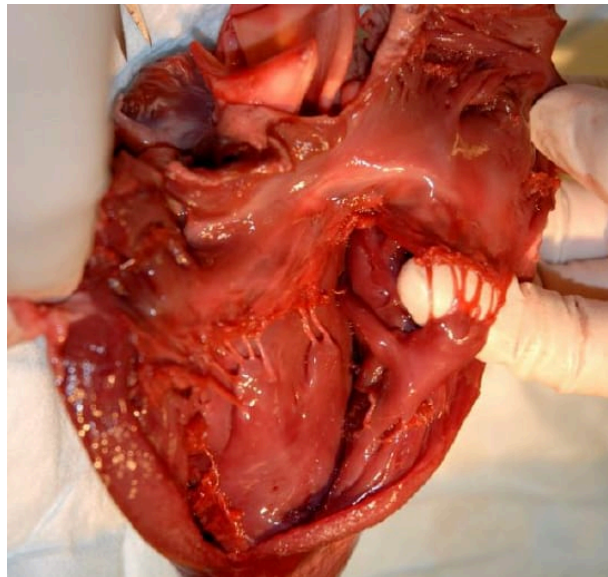


Figure 6.6.7: One of the cusps of the tricuspid valve, held up by a finger. Note the papillary muscle and chordae tendineae. (CC BY-NC-SA 4.0; Sheryl Shook via [Heart Dissection](#)).

Figure 6.6.7 illustrates a pair of gloved hands gently holds open a dissected organ, likely a heart, to reveal its intricate internal anatomy. The deep red muscular tissue is visible, along with smoother, paler areas of valves and chamber linings. A prominent, irregularly shaped white mass is noticeable within one of the chambers, contrasting sharply with the surrounding red tissue. This mass appears somewhat firm and textured, suggesting a possible abnormality or foreign object within the organ. The image is a close-up, providing a clear view of the internal structures and the distinctive white mass.

Cut open the left atrium and ventricle through the entrance for the pulmonary vein into the left atrium. Cut along the left side of the heart. The valve between the left atrium and ventricle has two cusps and is termed the bicuspid or mitral valve. Examine the endocardium and the mitral valve. Identify the entrance to the aorta and probe it from the inside of the left ventricle. Compare the right and left ventricles with regard to their respective sizes and the thickness of the myocardium. Finally, palpate the muscle wall between the right and left ventricles (interventricular septum). Here run the right and left bundle branches, part of the electrical conduction system of the heart.

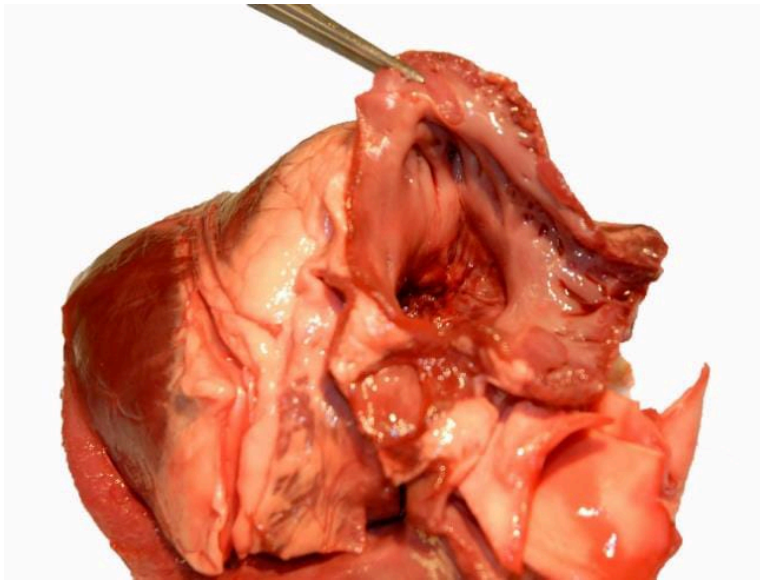


Figure 6.6.8: A close-up view of a dissected heart, revealing the internal chambers and structures. (CC BY-NC-SA 4.0; Sheryl Shook via [Heart Dissection](#)).

Figure 6.6.8 represents a dissecting tool, resembling a pair of forceps or tweezers, holds open a section of what appears to be a heart. The deep reddish-brown tissue of the organ is exposed, revealing internal structures like valves and chamber walls. The delicate, paler pinkish-white leaflets of a valve are visible, held apart by the tool. The image provides a close-up, anatomical view of the organ's interior, likely for educational or medical purposes.

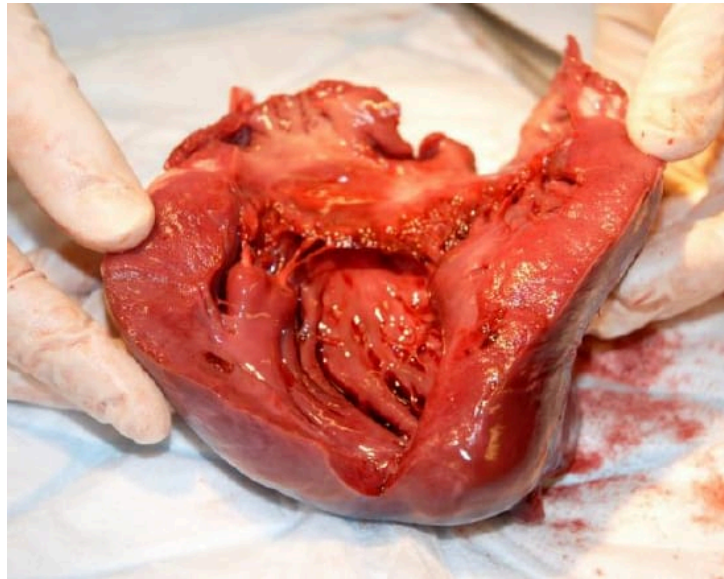


Figure 6.6.9: Left ventricle. (CC BY-NC-SA 4.0; Sheryl Shook via [Heart Dissection](#)).

Figure 6.6.9 represents a pair of gloved hands holds open a dissected organ, likely a heart, split longitudinally to expose its internal chambers and structures. The rich, deep red of the muscular tissue is prominent, with various ridges and smoother surfaces of the internal walls visible. A dark, slightly viscous fluid, possibly blood, is pooled in some areas. The organ rests on a light-colored surface, possibly a surgical drape, which has some reddish stains. The image provides a detailed view of the heart's interior anatomy after dissection.

6.7: Activity 6

Heart Dissection Documentation

1. Carefully photograph your dissected heart specimen from various angles.
2. Compile your photographs or illustrations into a single document. Insert this document as an attachment for submission.
3. Make sure all labels are clear and legible in the images.

Key structures that need to be labeled on the dissected sheep heart

- Bicuspid valve
- Tricuspid valve
- Interventricular septum
- Left ventricle, Right ventricle
- Right auricle, Left auricle
- Chordae tendineae
- Left myocardium
- Right myocardium
- Pulmonary trunk
- Aorta
- Papillary muscles

Clean up

- Specimen Disposal - Gather all sheep heart tissue, fat, place them in a designated biohazard bin.
- Tray Cleaning - Clean and rinse dissection trays; dry with paper towels. Return trays to the cart.
- Discard paper towel in the regular trash can.
- Tool Cleaning - Rinse all dissection tools (scalpels, scissors, probes, tweezers) thoroughly with water to remove tissue and fat, then wash with soap or disinfectant.
- Return tools to storage tray.
- Surface Decontamination - Wipe down work surfaces, benches, and sinks with a disinfectant solution or approved sanitizing wipes.
- Personal Clean-Up
 - Remove gloves by turning them inside out; dispose of them in the approved waste bag.
 - Remove aprons and goggles; clean reusable items as directed.
 - Thoroughly wash your hands with soap and water after finishing all clean-up steps

Heart Dissection: Post-Lab Peer Dialogue

1. How can you tell which side of the heart is the anterior surface and which side is the posterior surface?
2. Which chambers are the pumping chambers of the heart?
3. From where in the body does the blood entering the superior vena cava come? Inferior vena cava?
4. How do the walls of the atria compare with the walls of the ventricles and why are they different?
5. What is the purpose of heart valves?
6. What are the names of the blood vessels that carry blood away from the heart, and those that carry blood toward the heart?
7. Which artery is the largest and why?
8. What is the purpose of the coronary artery and what results if there is blockage in this vessel?
9. Can an artery carry deoxygenated blood? Please explain.
10. In what ways did the hands-on experience enhance your understanding of the heart compared to theoretical learning?

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Key Terms and Definitions

- **Anastomosis:** (plural = anastomoses) area where vessels unite to allow blood to circulate even if there may be partial blockage in another branch.
- **Anterior cardiac veins:** vessels that parallel the small cardiac arteries and drain the anterior surface of the right ventricle; bypass the coronary sinus and drain directly into the right atrium.
- **Anterior interventricular artery:** (also, left anterior descending artery or LAD) major branch of the left coronary artery that follows the anterior interventricular sulcus.
- **Anterior interventricular sulcus:** sulcus located between the left and right ventricles on the anterior surface of the heart.
- **Aortic valve:** (also, aortic semilunar valve) valve located at the base of the aorta.
- **Artificial pacemaker:** medical device that transmits electrical signals to the heart to ensure that it contracts and pumps blood to the body.
- **Atrioventricular (AV) node:** cluster of myocardial cells located in the inferior portion of the right atrium within the atrioventricular septum; receives the impulse from the SA node, pauses, and then transmits it into specialized conducting cells within the interventricular septum.
- **Atrioventricular bundle:** (also, bundle of His) group of specialized myocardial conductile cells that transmit the impulse from the AV node through the interventricular septum; form the left and right atrioventricular bundle branches.
- **Atrioventricular bundle branches:** (also, left or right bundle branches) specialized myocardial conductile cells that arise from the bifurcation of the atrioventricular bundle and pass through the interventricular septum; lead to the Purkinje fibers and also to the right papillary muscle via the moderator band.
- **Atrioventricular septum:** cardiac septum located between the atria and ventricles; atrioventricular valves are located here.
- **Atrioventricular valves:** one-way valves located between the atria and ventricles; the valve on the right is called the tricuspid valve, and the one on the left is the mitral or bicuspid valve.
- **Atrium:** (plural = atria) upper or receiving chamber of the heart that pumps blood into the lower chambers just prior to their contraction; the right atrium receives blood from the systemic circuit that flows into the right ventricle; the left atrium receives blood from the pulmonary circuit that flows into the left ventricle.
- **Auricle:** extension of an atrium visible on the superior surface of the heart.
- **Bundle of His:** (also, atrioventricular bundle) group of specialized myocardial conductile cells that transmit the impulse from the AV node through the interventricular septum; form the left and right atrioventricular bundle branches.
- **Cardiac cycle:** period of time between the onset of atrial contraction (atrial systole) and ventricular relaxation (ventricular diastole).
- **Cardiac notch:** depression in the medial surface of the superior lobe of the left lung where the apex of the heart is located.
- **Cardiac skeleton:** (also, skeleton of the heart) reinforced connective tissue located within the atrioventricular septum; includes four rings that surround the openings between the atria and ventricles, and the openings to the pulmonary trunk and aorta; the point of attachment for the heart valves.
- **Cardiomyocyte:** muscle cell of the heart.
- **Chordae tendineae:** string-like extensions of tough connective tissue that extend from the flaps of the atrioventricular valves to the papillary muscles.
- **Circumflex artery:** branch of the left coronary artery that follows coronary sulcus.
- **Coronary arteries:** branches of the ascending aorta that supply blood to the heart; the left coronary artery feeds the left side of the heart, the left atrium and ventricle, and the interventricular septum; the right coronary artery feeds the right atrium, portions of both ventricles, and the heart conduction system.
- **Coronary sinus:** large, thin-walled vein on the posterior surface of the heart that lies within the atrioventricular sulcus and drains the heart myocardium directly into the right atrium.
- **Coronary sulcus:** sulcus that marks the boundary between the atria and ventricles.
- **Coronary veins:** vessels that drain the heart and generally parallel the large surface arteries.
- **Electrocardiogram (ECG):** surface recording of the electrical activity of the heart that can be used for diagnosis of irregular heart function; also abbreviated as EKG.
- **Endocardium:** innermost layer of the heart lining the heart chambers and heart valves; composed of endothelium reinforced with a thin layer of connective tissue that binds to the myocardium.
- **Epicardium:** innermost layer of the serous pericardium and the outermost layer of the heart wall.
- **Foramen ovale:** opening in the fetal heart that allows blood to flow directly from the right atrium to the left atrium, bypassing the fetal pulmonary circuit.
- **Fossa ovalis:** oval-shaped depression in the interatrial septum that marks the former location of the foramen ovale.
- **Great cardiac vein:** vessel that follows the interventricular sulcus on the anterior surface of the heart and flows along the

coronary sulcus into the coronary sinus on the posterior surface; parallels the anterior interventricular artery and drains the areas supplied by this vessel.

- **Heart rate (HR):** number of times the heart contracts (beats) per minute.
- **Hypertrophic cardiomyopathy:** pathological enlargement of the heart, generally for no known reason.
- **Inferior vena cava:** large systemic vein that returns blood to the heart from the inferior portion of the body.
- **Interatrial septum:** cardiac septum located between the two atria; contains the fossa ovalis after birth.
- **Intercalated disc:** physical junction between adjacent cardiac muscle cells; consisting of desmosomes, specialized linking proteoglycans, and gap junctions that allow passage of ions between the two cells.
- **Internodal pathways:** specialized conductile cells within the atria that transmit the impulse from the SA node throughout the myocardial cells of the atrium and to the AV node.
- **Interventricular septum:** cardiac septum located between the two ventricles.
- **Left atrioventricular valve:** (also, mitral valve or bicuspid valve) valve located between the left atrium and ventricle; consists of two flaps of tissue.
- **Marginal arteries:** branches of the right coronary artery that supply blood to the superficial portions of the right ventricle.
- **Middle cardiac vein:** vessel that parallels and drains the areas supplied by the posterior interventricular artery; drains into the great cardiac vein.
- **Mitral valve:** (also, left atrioventricular valve or bicuspid valve) valve located between the left atrium and ventricle; consists of two flaps of tissue.
- **Moderator band:** band of myocardium covered by endocardium that arises from the inferior portion of the interventricular septum in the right ventricle and crosses to the anterior papillary muscle; contains conductile fibers that carry electrical signals followed by contraction of the heart.
- **Myocardial conducting cells:** specialized cells that transmit electrical impulses throughout the heart and trigger contraction by the myocardial contractile cells.
- **Myocardial contractile cells:** bulk of the cardiac muscle cells in the atria and ventricles that conduct impulses and contract to propel blood.
- **Myocardium:** thickest layer of the heart composed of cardiac muscle cells built upon a framework of primarily collagenous fibers and blood vessels that supply it and the nervous fibers that help to regulate it.
- **P wave:** component of the electrocardiogram that represents the depolarization of the atria.
- **Pacemaker:** cluster of specialized myocardial cells known as the SA node that initiates the sinus rhythm.
- **Papillary muscle:** extension of the myocardium in the ventricles to which the chordae tendineae attach.
- **Pectinate muscles:** muscular ridges seen on the anterior surface of the right atrium.
- **Pericardial cavity:** cavity surrounding the heart filled with a lubricating serous fluid that reduces friction as the heart contracts.
- **Pericardial sac:** (also, pericardium) membrane that separates the heart from other mediastinal structures; consists of two distinct, fused sublayers: the fibrous pericardium and the parietal pericardium.
- **Pericardium:** (also, pericardial sac) membrane that separates the heart from other mediastinal structures; consists of two distinct, fused sublayers: the fibrous pericardium and the parietal pericardium.
- **Posterior cardiac vein:** vessel that parallels and drains the areas supplied by the marginal artery branch of the circumflex artery; drains into the great cardiac vein.
- **Posterior interventricular artery:** (also, posterior descending artery) branch of the right coronary artery that runs along the posterior portion of the interventricular sulcus toward the apex of the heart and gives rise to branches that supply the interventricular septum and portions of both ventricles.
- **Posterior interventricular sulcus:** sulcus located between the left and right ventricles on the posterior surface of the heart.
- **Pulmonary arteries:** left and right branches of the pulmonary trunk that carry deoxygenated blood from the heart to each of the lungs.
- **Pulmonary capillaries:** capillaries surrounding the alveoli of the lungs where gas exchange occurs: carbon dioxide exits the blood and oxygen enters.
- **Pulmonary circuit:** blood flow to and from the lungs.
- **Pulmonary trunk:** large arterial vessel that carries blood ejected from the right ventricle; divides into the left and right pulmonary arteries.
- **Pulmonary valve:** (also, pulmonary semilunar valve, the pulmonic valve, or the right semilunar valve) valve at the base of the pulmonary trunk that prevents backflow of blood into the right ventricle; consists of three flaps.
- **Pulmonary veins:** veins that carry highly oxygenated blood into the left atrium, which pumps the blood into the left ventricle, which in turn pumps oxygenated blood into the aorta and to the many branches of the systemic circuit.
- **Purkinje fibers:** specialized myocardial conduction fibers that arise from the bundle branches and spread the impulse to the myocardial contraction fibers of the ventricles.
- **QRS complex:** component of the electrocardiogram that represents the depolarization of the ventricles and includes, as a component, the repolarization of the atria.

- **Right atrioventricular valve:** (also, tricuspid valve) valve located between the right atrium and ventricle; consists of three flaps of tissue.
- **Semilunar valves:** valves located at the base of the pulmonary trunk and at the base of the aorta.
- **Septum:** (plural = septa) walls or partitions that divide the heart into chambers.
- **Sinoatrial (SA) node:** known as the pacemaker, a specialized clump of myocardial conducting cells located in the superior portion of the right atrium that has the highest inherent rate of depolarization that then spreads throughout the heart.
- **Sinus rhythm:** normal contractile pattern of the heart.
- **Small cardiac vein:** parallels the right coronary artery and drains blood from the posterior surfaces of the right atrium and ventricle; drains into the coronary sinus, middle cardiac vein, or right atrium.
- **Sulcus:** (plural = sulci) fat-filled groove visible on the surface of the heart; coronary vessels are also located in these areas.
- **Superior vena cava:** large systemic vein that returns blood to the heart from the superior portion of the body.
- **Systemic circuit:** blood flow to and from virtually all of the tissues of the body.
- **Systole:** period of time when the heart muscle is contracting.
- **T wave:** component of the electrocardiogram that represents the repolarization of the ventricles.
- **Trabeculae carneae:** ridges of muscle covered by endocardium located in the ventricles.
- **Tricuspid valve:** term used most often in clinical settings for the right atrioventricular valve.
- **Valve:** in the cardiovascular system, a specialized structure located within the heart or vessels that ensures one-way flow of blood.
- **Ventricle:** one of the primary pumping chambers of the heart located in the lower portion of the heart; the left ventricle is the major pumping chamber on the lower left side of the heart that ejects blood into the systemic circuit via the aorta and receives blood from the left atrium; the right ventricle is the major pumping chamber on the lower right side of the heart that ejects blood into the pulmonary circuit via the pulmonary trunk and receives blood from the right atrium.

7: BLOOD VESSELS, BLOOD PRESSURE AND ECG (ELECTROCARDIOGRAM)

Introduction

In this lab, you will explore the fascinating dynamics of the cardiovascular system, focusing on blood vessels, blood pressure, and the electrocardiogram (ECG). Understanding how these components work together is crucial for grasping how the heart functions and how it maintains blood circulation throughout the body. You will learn about the different types of blood vessels—arteries, veins, and capillaries—and their roles in transporting blood. We will also measure blood pressure using a sphygmomanometer, allowing you to observe the effects of various factors on blood flow and pressure. Additionally, you will analyze ECG readings, which provide valuable insights into the electrical activity of the heart.

Learning Objectives

- Identify the major arteries and veins of the body using a torso or other lab model.
- Locate the auscultation areas for the heart to determine the pulse/heart rate.
- Use a stethoscope to listen to the heart sounds at the auscultation areas.
- Measure the apical pulse, radial pulse and carotid pulse. Understand the concept of pulse deficit.
- Measure blood pressure and pulse rate at rest, during exercise, and during the recovery period after exercise.
- Calculate the pulse pressure and mean arterial pressure (MAP).
- Perform ECG and analyze the results by identifying the components of the ECG to heart activities.

7.1: Background Information

7.2: Activity 1

7.3: Activity 2

7.4: Activity 3

7.5: Activity 4

7.6: Activity 5

7.7: Activity 6

7.8: Activity 7

7.9: Activity 8

7.10: Activity 9

7.11: Activity 10

7.12: Activity 11

7.13: Activity 12

7.14: Glossary

7.1: Background Information

Structure and Function of Blood Vessels

Blood pumped by the heart flows through a series of vessels known as arteries, arterioles, capillaries, venules, and veins before returning to the heart. Arteries transport blood away from the heart and branch into smaller vessels, forming arterioles. Arterioles distribute blood to capillary beds, the sites of exchange with the body tissues. Capillaries lead back to small vessels known as venules that flow into the larger veins and eventually back to the heart.

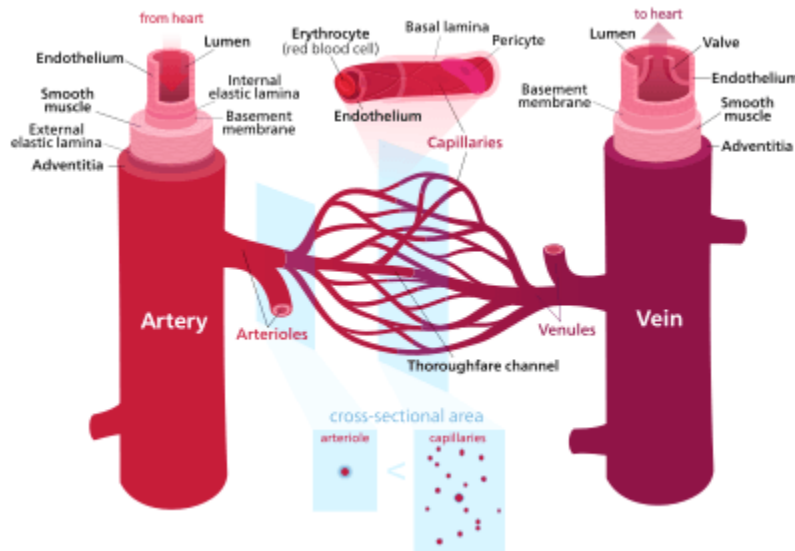


Figure 7.1.1: Diagram illustrating the structural differences between arteries, veins, and capillaries. Key components such as endothelium, smooth muscle, lumen, and adventitia are labeled. The diagram also shows the flow of blood from the heart through arteries to arterioles, capillaries, venules, and back to veins. (CC BY-NC-SA 4.0; via [Anatomy and Physiology Laboratory Manual for Nursing and Allied Health](#)).

Figure 7.1.1 compares an artery, a capillary network, and a vein, with cutaways that show their structures in detail.

Artery: Moving from the adventitia (surface of the vessel) inward, we see the external elastic lamina, then a layer of smooth muscle, followed by the basement membrane, then the internal elastic lamina and the endothelium. Finally we reach the lumen, the surface that blood moves over as it flows from the heart.

Arterioles: These are the smaller blood vessels that exit the artery. Focusing on one arteriole, we see that it maintains one slender thoroughfare channel as it branches off into multiple small capillaries that loop through the body tissues before rejoining the vessel where it nears the vein at a venule.

Capillaries: A cross section of a capillary reveal that these narrow vessels are only slightly wider than one erythrocyte (red blood cell). The endothelium is the interior surface of the capillary, and is covered by the basal lamina. A pericyte is shown on the surface of the capillary.

Venules: Blood passes through these vessels to the vein.

Vein: This vessel is thinner and has fewer layers than the artery. Moving from the adventitia (surface of the vessel) inward, we see a layer of smooth muscle, then the basement membrane and the endothelium. Finally we reach the lumen. A valve keeps blood moving toward the heart.

Small inset images show cross-sectional area comparisons, illustrating that the capillary network has a much larger total cross-sectional area than a single arteriole or venule.

Elastic arteries, such as the aorta, are the largest arteries and have thick, elastic walls that allow them to withstand and smooth

out the high pressure generated by the heart's pumping. Muscular arteries are medium-sized vessels that distribute blood to specific organs and contain more smooth muscle in their walls to help regulate blood flow. Arterioles are the smallest arterial branches that lead directly to capillaries and play a critical role in controlling blood pressure and directing blood flow to tissues. Capillaries are microscopic channels that supply blood to the tissues in a process known as perfusion; within these vessels, gases and other substances are exchanged between the blood and the surrounding cells and interstitial fluid. To allow this exchange, capillary walls are leaky, permitting substances to pass through, and the capillaries then lead into small vessels called venules.

Venules are small veins that merge to form larger veins, and a vein is defined as a blood vessel that carries blood back toward the heart. Compared to arteries, veins have thinner walls and larger, more irregular lumens; the two largest veins are the superior vena cava, which returns blood from the upper body to the right atrium, and the inferior vena cava, which returns blood from the lower body to the right atrium. Many larger veins contain valves that ensure one-way movement of blood toward the heart and prevent backflow caused by low venous blood pressure and gravity. The walls of both arteries and veins are composed of three distinct layers:

1. The tunica intima, an inner layer of smooth endothelial cells that reduces friction
2. The tunica media, especially thick in arteries, which contains smooth muscle and elastic fibers to regulate blood pressure and flow
3. The tunica externa, or adventitia, an outer connective tissue layer that provides support and anchors vessels to surrounding tissues

Together, these structures ensure efficient and adaptable blood circulation throughout the body.

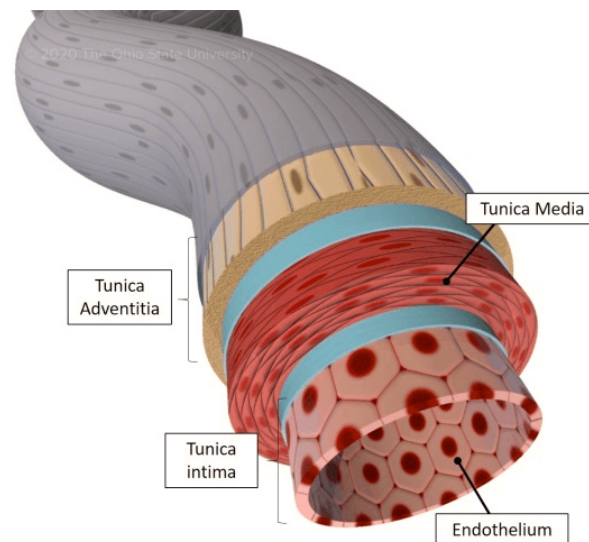


Figure 7.1.2: Artery wall structures or tunics. The vessel wall is organized from inner to outer layers as endothelium, tunica intima, tunica media, and tunica adventitia. (CC BY-NC-SA 4.0; via [Vascular Tunics](#)).

Figure 7.1.2 shows a blood vessel as a cutaway tube to illustrate the layers of the vessel wall from the inside outward. Labels identify four structures:

- Endothelium: The thin inner cell layer lining the inside of the vessel.
- Tunica intima: The innermost layer of the vessel wall, shown adjacent to the endothelium.
- Tunica media: The middle layer of the vessel wall, shown as a thicker band surrounding the tunica intima.
- Tunica adventitia: The outermost layer of the vessel wall, shown on the outside of the vessel.

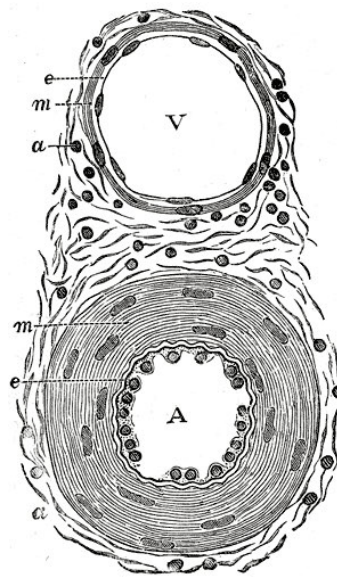


Figure 7.1.3: Detailed illustration of the cross-sectional anatomy of an artery (A) and a vein (V), highlighting the layers including the endothelium (e), muscle layer (m), and adventitia (a). (CC BY-NC-SA 4.0; via [Lab 3 - Introduction to the Cardiovascular System](#)).

Figure 7.1.3 compares veins (labeled V) and arteries (labeled A), focusing on their structural differences and similarities. Both types of blood vessels are lined with an endothelium (e), made of simple squamous epithelial tissue. The tunica media (m) in arteries is thicker and composed mainly of smooth muscle, allowing them to maintain high pressure and control blood flow through vasoconstriction and vasodilation. In contrast, veins have a thinner tunica media, reflecting their role in returning blood to the heart at lower pressure. Finally, the tunica adventitia (a), made of connective tissue, provides structural support and flexibility to both vessels, but is typically thicker in veins to accommodate their larger lumen.

The Major Arteries and Veins in the Human Body

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, you will find 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 and not paired. Names of vessels may change with location. Like a street that changes name as it passes through an intersection, 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 into the axillary region, and then becomes the brachial artery as it enters the upper arm. The next two diagrams illustrate the major arteries and veins in the human body (Figure 7.1.4, Figure 7.1.5).

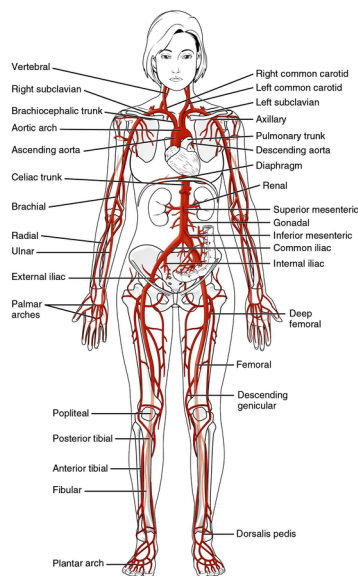


Figure 7.1.4: Systemic Arteries. The major systemic arteries shown here deliver oxygen-rich blood throughout the body. (CC BY-NC-SA 4.0; via [Cardiovascular System – Blood Vessels and Blood](#)).

Figure 7.1.4 is a full-body overview of the major systemic arteries, shown as a network of large red vessels extending from the chest into the head/neck, arms, abdomen, pelvis, and legs. Labels identify key arteries and major branches from the aorta.

Major vessels in the chest and trunk:

- Ascending aorta rises from the heart and continues into the aortic arch, then becomes the descending aorta.
- The pulmonary trunk is labeled near the heart region.
- In the abdomen, branches from the aorta are labeled celiac trunk, superior mesenteric, renal, gonadal, inferior mesenteric, and then the aorta divides into the common iliac arteries.

Head, neck, and upper limb branches:

- From the aortic arch region, the brachiocephalic trunk is labeled, along with the right common carotid and left common carotid arteries and the right subclavian and left subclavian arteries.
- Additional labeled upper-body arteries include vertebral, axillary, and brachial.
- In the forearm and hand, labeled arteries include radial, ulnar, and palmar arches.

Pelvis and lower limb branches:

- The common iliac artery branches into internal iliac and external iliac arteries.
- In the thigh, the femoral and deep femoral arteries are labeled.
- Around the knee and leg, labeled arteries include popliteal, descending genicular, anterior tibial, posterior tibial, and fibular.
- In the foot, labeled arteries include dorsalis pedis and the plantar arch.

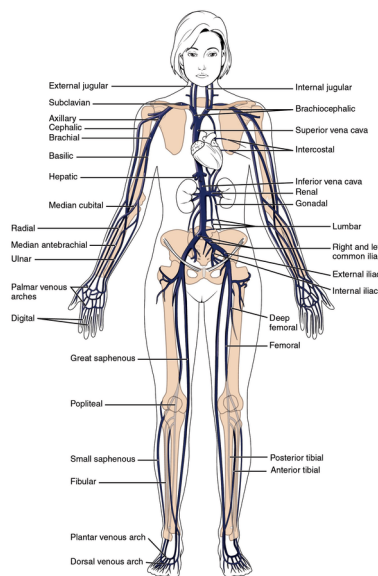


Figure 7.1.5: Major Systemic Veins of the Body. The major systemic veins of the body are shown here in an anterior view. (CC BY-NC-SA 4.0; via Cardiovascular System – Blood Vessels and Blood).

Figure 7.1.5 is a full-body overview of the major systemic veins, shown as a network of large dark vessels running from the head and limbs to the chest and abdomen. Labels identify major superficial and deep veins and emphasize how venous blood returns to the heart through the venae cavae.

Head, neck, and upper chest veins

- The neck veins are labeled external jugular and internal jugular.
- Veins near the shoulder and upper chest are labeled subclavian and brachiocephalic.
- The main large vein entering the heart region is labeled superior vena cava.
- Additional labeled veins in the chest include intercostal.

Upper limb veins

- In the upper arm region, labeled veins include axillary, cephalic, brachial, and basilic.
- Near the elbow, the connecting vein is labeled median cubital.
- In the forearm, labeled veins include radial, median antebrachial, and ulnar.
- In the hand, labeled veins include palmar venous arches and digital veins.

Abdominal and pelvic veins

- In the abdomen, labeled veins include hepatic, inferior vena cava, renal, gonadal, and lumbar.
- In the pelvis, the diagram labels the right and left common iliac veins and their branches: external iliac and internal iliac.

Lower limb veins

- In the thigh, labeled veins include femoral and deep femoral.
- Around the knee, the vein is labeled popliteal.
- In the lower leg, labeled veins include anterior tibial, posterior tibial, and fibular.
- Superficial veins of the leg are labeled great saphenous and small saphenous.
- In the foot, labeled veins include the dorsal venous arch and plantar venous arch.

Physiology of the Blood Vessels

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, since much of the oxygen carried by the arteries has been delivered to the cells. In contrast, in the pulmonary circuit, arteries carry blood low

in oxygen exclusively 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.

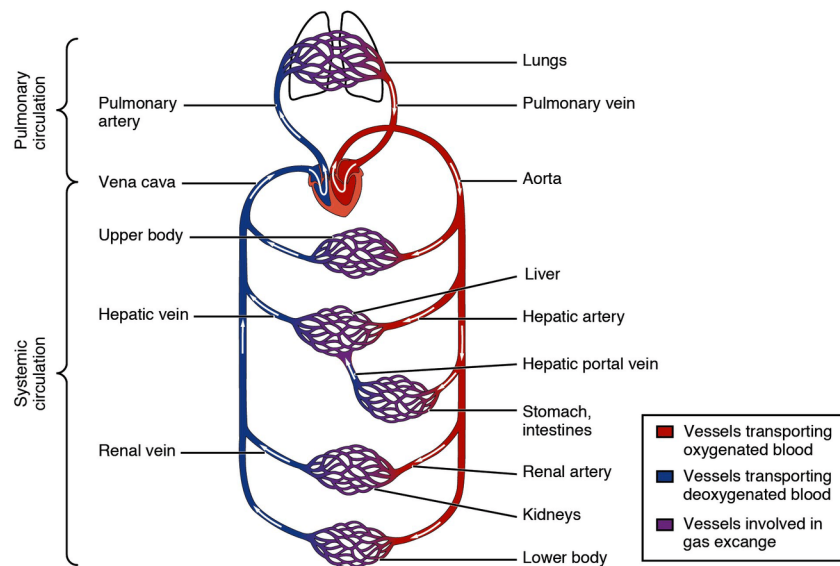


Figure 7.1.6: Cardiovascular Circulation. The pulmonary circuit moves blood from the right side of the heart to the lungs and back to the heart. The systemic circuit moves blood from the left side of the heart to the head and body and returns it to the right side of the heart to repeat the cycle. The arrows indicate the direction of blood flow, and the colors show the relative levels of oxygen concentration. (CC BY-NC-SA 4.0; via [Cardiovascular System – Blood Vessels and Blood](#)).

Figure 7.1.6 depicts the cardiovascular circulation system, highlighting two main circuits: the pulmonary circuit and the systemic circuit. The pulmonary circuit transports blood from the right side of the heart to the lungs for oxygenation and returns it to the heart. The systemic circuit carries oxygen-rich blood from the left side of the heart to the head and body, then returns deoxygenated blood back to the right side of the heart. Arrows indicate the direction of blood flow, while colors represent the relative levels of oxygen concentration in the blood.

Blood Flow, Blood Pressure and Resistance

Blood Flow

Blood flow refers to the movement of blood through a vessel, tissue, or organ, and is usually expressed in terms of volume of blood per unit of time. It is initiated by the contraction of the ventricles of the heart. Ventricular contraction ejects blood into the major arteries, resulting in flow from regions of higher pressure to regions of lower pressure, as blood encounters smaller arteries and arterioles, then capillaries, then the venules and veins of the venous system. A relatively constant flow is required by the body's tissues, so pressure and resistance are altered to maintain this consistency. A too-high flow can damage blood vessels and tissue, while flow that's too low means tissues served by the blood vessel may not receive sufficient oxygen to function.

Blood Pressure

Hydrostatic pressure is the force exerted by a fluid due to gravitational pull, usually against the wall of the container in which it is located. One form of hydrostatic pressure is blood pressure, the force exerted by blood upon the walls of the blood vessels or the chambers of the heart. Blood pressure may be measured in capillaries and veins, as well as the vessels of the pulmonary circulation; however, the term blood pressure without any specific descriptors 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 mm Hg and is usually obtained using the brachial artery of the arm. Arterial blood pressure in the larger vessels consists of several distinct components: systolic and diastolic pressures, pulse pressure, and mean arterial pressure.

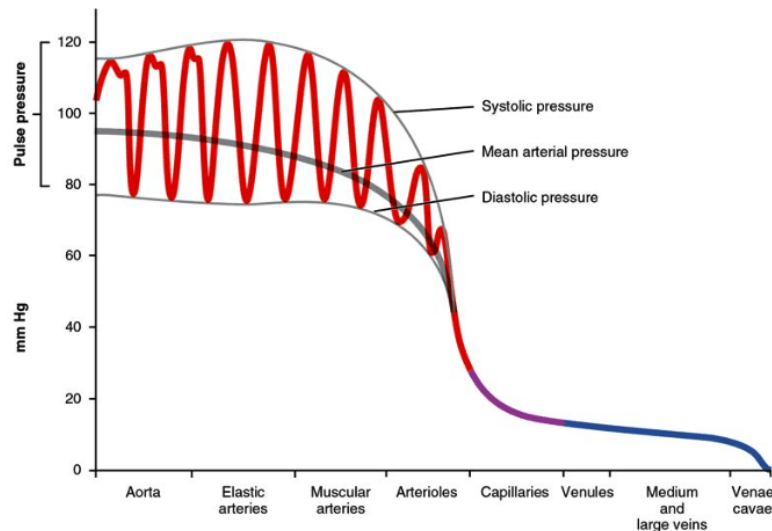


Figure 7.1.7: The graph shows the components of blood pressure throughout the blood vessels, including systolic, diastolic, mean arterial, and pulse pressures. (CC BY-NC-SA 4.0; via [Blood Flow and Blood Pressure](#)).

Figure 7.1.7 is a line graph showing how blood pressure changes across the systemic circulation, from the aorta through arteries and microvessels to the venae cavae. The vertical axis is pressure in mm Hg (ranging from about 0 to 120). The horizontal axis lists vessel types in order: aorta, elastic arteries, muscular arteries, arterioles, capillaries, venules, medium and large veins, and venae cavae.

A red, pulsating waveform represents arterial pressure pulses. The peaks of the waveform are labeled systolic pressure, and the troughs are labeled diastolic pressure. A darker central line is labeled mean arterial pressure. The graph shows that:

- In the aorta and large arteries, pressure is high and strongly pulsatile, with systolic values near the top of the scale and diastolic values lower, creating a large pulse pressure.
- As blood moves through elastic and muscular arteries, the overall pressure gradually declines and the pulsations become smaller.
- The largest drop in mean pressure occurs across the arterioles, and the pulsations decrease markedly.
- In the capillaries, pressure is much lower and essentially non-pulsatile.
- Pressure continues to fall through venules and medium/large veins, approaching very low values in the venae cavae near the end of the graph.

Systolic and Diastolic Pressures

When systemic arterial blood pressure is measured, it is recorded as a ratio of two numbers (e.g., 120/80 is a normal adult blood pressure), expressed as systolic pressure over diastolic pressure. The systolic pressure is the higher value (typically around 120 mm Hg) and reflects the arterial pressure resulting from the ejection of blood during ventricular contraction, or systole. The diastolic pressure is the lower value (usually about 80 mm Hg) and represents the arterial pressure of blood during ventricular relaxation, or diastole.

Pulse Pressure, as shown in Figure 7.1.7, the difference between the systolic pressure and the diastolic pressure is the pulse pressure. It is calculated using the formula: $\text{Pulse Pressure} = \text{Systolic Blood Pressure (SBP)} - \text{Diastolic Blood Pressure (DBP)}$

For example, if a person's blood pressure is recorded as 120/80 mm Hg, the pulse pressure would be: $\text{Pulse Pressure} = 120 \text{ mm Hg (SBP)} - 80 \text{ mm Hg (DBP)} = 40 \text{ mm Hg}$

A wider pulse pressure (generally considered to be greater than 40 mmHg) can indicate increased stiffness of the arteries or other cardiovascular issues, while a narrow pulse pressure may be a sign of reduced stroke volume or heart problems.

Mean Arterial Pressure

Mean arterial pressure (MAP) represents the “average” pressure of blood in the arteries, that is, the average force driving blood into vessels that serve the tissues. MAP is a key measure of blood flow and organ perfusion, calculated using both systolic and diastolic blood pressure values. The most common formula is:

$$MAP = \frac{\text{Systolic Blood Pressure (SBP)} + 2 \times \text{Diastolic Blood Pressure (DBP)}}{3}$$

This formula weights diastolic pressure more heavily because the heart spends more time in diastole during the cardiac cycle. For example, with a blood pressure of 120/80 mm Hg: $MAP = [120 + (2 \times 80)] \div 3 = [120 + 160] \div 3 = 280 \div 3 \approx 93 \text{ mm Hg}$

A MAP of at least 60 mm Hg is needed for adequate organ perfusion, with normal values typically between 70 and 100 mm Hg.

Pulse

Pulse refers to the rhythmic expansion and contraction of the arteries as blood is pumped through them by the heart. It is a vital sign that reflects the heart's function and overall cardiovascular health. The pulse can be palpated manually at various points in the body, most commonly at the wrist (radial pulse) and neck (carotid pulse) or measured electronically.

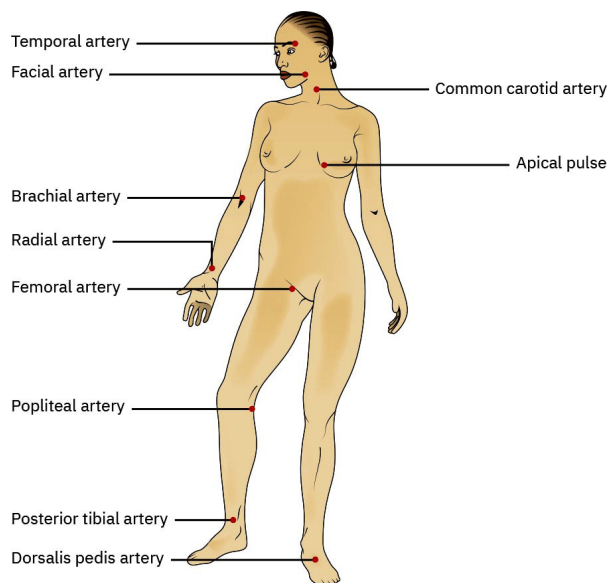


Figure 7.1.8: A patient's pulse is most readily measured at the radial artery but can be measured at any of the pulse points shown. (CC BY 4.0; via [How to Perform Vital Signs](#)).

Figure 7.1.8 explains that the pulse can be most easily measured at the radial artery, located at the wrist, but it can also be assessed at various pulse points shown in the image. These points include the carotid artery in the neck, the brachial artery in the arm, the femoral artery in the groin, and others, allowing for flexibility in pulse measurement depending on the situation.

Figure 7.1.8 - The pulse is most readily measured at the radial artery, but can be measured at any of the pulse points shown.

- Temporal Pulse: Located at the temple, just in front of the ear.
- Carotid Pulse: Found on either side of the neck, alongside the trachea.
- Apical Pulse: Located at the fifth intercostal space at the left mid-clavicular line on the chest; this is the point of maximum impulse over the heart.
- Brachial Pulse: Situated on the inner aspect of the elbow, along the brachial artery.
- Radial Pulse: Found at the wrist, on the thumb side.
- Femoral Pulse: Located in the groin, where the femoral artery passes.
- Popliteal Pulse: Felt at the back of the knee.
- Posterior Tibial Pulse: Found behind the medial malleolus (inner ankle bone).
- Dorsalis Pedis Pulse: Located on the top of the foot, near the center.

A typical resting pulse rate for adults ranges from 60 to 100 beats per minute (bpm). Factors such as age, fitness level, and overall health can influence this rate. To measure your pulse, lightly press on an artery with your fingers (not your thumb) and count the beats for 30 seconds, then multiply by 2 to get the beats per minute.

Resistance

Resistance to flow must be overcome to push blood through the circulatory system. If resistance increases, either pressure must increase to maintain flow, or flow rate must reduce to maintain pressure. Numerous factors can alter resistance, but the three most important are vessel length, vessel radius, and blood viscosity. With increasing length, increasing viscosity, and decreasing radius, resistance is increased. The arterioles and capillary networks are the main regions of the circulatory system that generate resistance, due to the small caliber of their lumen. Arterioles in particular are able to rapidly alter resistance by altering their radius through vasodilation or vasoconstriction. The resistance offered by peripheral circulation is known as systemic vascular resistance (SVR), while the resistance offered by the vasculature of the lungs is known as pulmonary vascular resistance (PVR).

Measurement of Blood Pressure

Blood pressure measurement is a fundamental clinical skill that provides vital information about cardiovascular health. The most common method in laboratory and clinical settings is the noninvasive, intermittent cuff-based technique using a sphygmomanometer and stethoscope, known as the auscultatory method. In this approach, a blood pressure cuff is wrapped snugly around the upper arm at heart level and inflated to temporarily stop blood flow in the brachial artery. As the cuff is gradually deflated, a stethoscope is used to listen for Korotkoff sounds—the first appearance of these sounds marks the systolic pressure (occurs when the ventricles contract and eject blood into arteries), while their disappearance indicates the diastolic pressure (occurs when the ventricles relax and fill with blood from the atria). The average blood pressure of healthy young adults (about 20 yrs old) is 120 / 80 mm Hg.

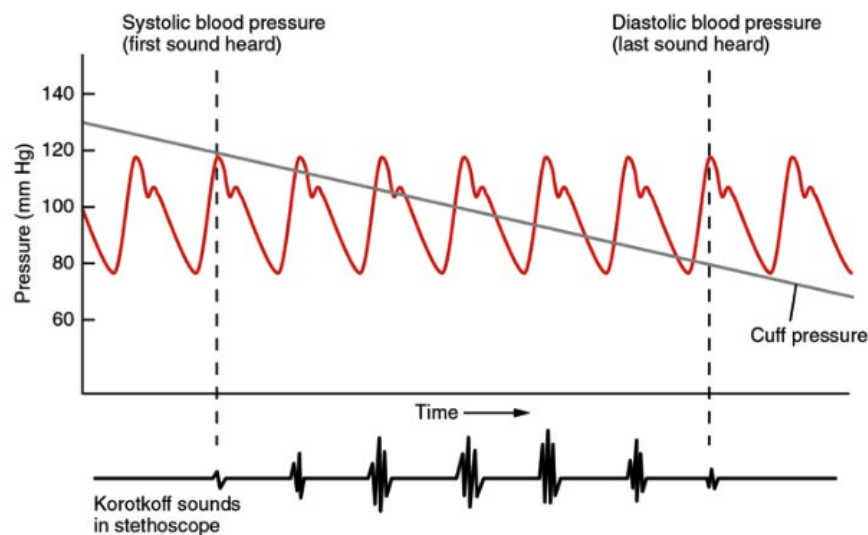


Figure 7.1.9: When pressure in a sphygmomanometer cuff is released, a clinician can hear the Korotkoff sounds. In this graph, a blood pressure tracing is aligned to a measurement of systolic and diastolic pressures. (CC BY-NC-SA 4.0; J. Gordon Betts; Kelly A. Young; James A. Wise; Eddie Johnson; Brandon Poe; Dean H. Kruse; Oksana Korol; Jody E. Johnson; Mark Womble; and Peter DeSaix via [Blood Flow and Blood Pressure](#)).

Figure 7.1.9 explains how systolic and diastolic blood pressure are determined during a manual blood pressure measurement using a cuff and a stethoscope.

Axes and lines

- The vertical axis is pressure (mm Hg).
- The horizontal axis is time.
- A red wavy line represents the arterial pressure pulse over time (repeating peaks and troughs).

- A gray sloped line labeled cuff pressure shows cuff pressure gradually decreasing as the cuff deflates.

Key labeled events

- A vertical dashed line on the left is labeled “Systolic blood pressure (first sound heard)”. This marks the moment when the decreasing cuff pressure first allows blood to pass intermittently through the artery, producing the first audible Korotkoff sound.
- A vertical dashed line on the right is labeled “Diastolic blood pressure (last sound heard)”. This marks the moment when cuff pressure falls below diastolic pressure and blood flow becomes smoother, so Korotkoff sounds disappear.

Korotkoff sounds

- Along the bottom of the figure is a trace labeled “Korotkoff sounds in stethoscope.”
- The sounds begin at the systolic marker (first sound), continue while cuff pressure is between systolic and diastolic pressures, and stop at the diastolic marker (last sound).

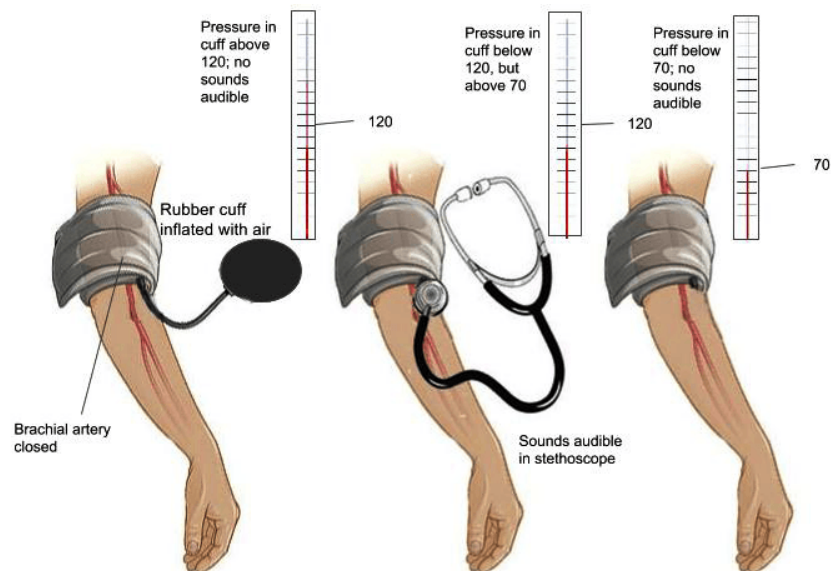


Figure 7.1.10: Illustration of blood pressure measurement technique using a sphygmomanometer and stethoscope. (CC BY-NC-SA 4.0; via [Anatomy and Physiology 2 Laboratory Manual](#)).

Figure 7.1.10 is a three-panel figure shows how cuff pressure relates to blood flow in the brachial artery and the presence or absence of Korotkoff sounds during a manual blood pressure measurement.

Panel 1 (left): cuff pressure above systolic

- A rubber blood pressure cuff is inflated around the upper arm.
- Text indicates pressure in the cuff above 120 and no sounds audible.
- The brachial artery is closed, meaning blood flow is temporarily stopped by the cuff.

Panel 2 (middle): cuff pressure between systolic and diastolic

- The cuff pressure is shown below 120 but above 70.
- A stethoscope is placed over the artery.
- Text indicates sounds audible in the stethoscope.
- This represents intermittent blood flow through the partially compressed artery, producing Korotkoff sounds.

Panel 3 (right): cuff pressure below diastolic

- The cuff pressure is shown below 70.
- Text indicates no sounds audible.
- This represents blood flowing freely through the artery without the turbulent flow that produces Korotkoff sounds.

Automated devices can also be used, which inflate and deflate the cuff electronically and provide digital readings. Another commonly used method is the oscillometric technique, which measures pressure oscillations in the cuff to estimate systolic, diastolic, and mean arterial pressures; this method is widely used in home and ambulatory monitors. Proper positioning of the arm at heart level, relaxed posture, and correct cuff size are essential for accuracy.

Electrocardiogram

An electrocardiogram (ECG), also abbreviated as EKG (K for kardiologie in German), is a diagnostic tool that records the electrical activity of the heart over a period of time. It provides essential information about heart rhythm, rate, and overall cardiac function. An ECG is typically measured by placing six electrodes across the chest, two on the arms and two on the legs. This is called a 12-lead ECG. However, due to privacy concerns, we will measure the ECG by placing electrodes only on the arms and legs (Figure 11). These impulses are then translated into waveforms displayed on a monitor or printed on paper. Analysis of the ECG reveals a detailed picture of both normal and abnormal heart function.

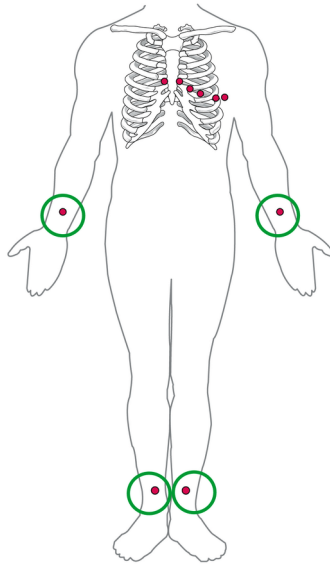


Figure 7.1.11: ECG lead placement: This figure shows the placement of the electrodes for a typical 12-lead ECG. However, we will only place electrodes on the arms and limbs for this lab. The electrodes on the arms and legs are circled in green. (CC BY 4.0; Harmony Folse via [Instructions for Recording EKG](#)).

Figure 7.1.11 shows a front view outline of a body with the rib cage drawn in the chest. Several marked points indicate common pulse or auscultation locations. The marked points appear as small dots; some are additionally highlighted with larger circles.

Chest (rib cage area)

- Multiple marked points are shown across the front of the chest over the rib cage, clustered near the center and toward the left side of the chest.

Upper limbs

- One marked point is shown on each forearm near the wrist area (left and right). These wrist points are emphasized with large circles.

Lower limbs

- Two marked points are shown near the inner ankle areas (one on each side). These ankle points are emphasized with large circles.

Instructions for Recording an ECG

1. The subject should lie flat on their back, with hands at their sides; lying on side or sitting up alters the heart's electrical axis.
2. The inner aspect of the right and left arms and right and left legs are rubbed with alcohol.
3. Place electrodes (shiny side down) firmly on the limbs.
4. Clip leads to the electrodes on the limb sites. Lead RA (right arm); lead LA (left arm); lead LL (left leg); and lead RL (right leg).
Note: lead RL to the right leg will serve as ground.
5. Turn the unit on.
6. Press "MANUAL" button to print out ECG tracings.
7. Once the ECG tracings comes out of the machine, press "STOP" button to stop the printing.
8. After the resting ECG has been recorded, remove the lead wires and the electrodes.
9. Discard the electrodes.

A normal ECG tracing is presented in Figure 7.1.12. Each tiny square, 1mm, is the passing of 0.04 seconds. Notice there are 25mm every 1 second. Segments are defined as the regions between two waves. Intervals include one segment plus one or more waves. Each wave, segment, and interval is related to electrical events associated with various stages of contraction and relaxation of the heart.

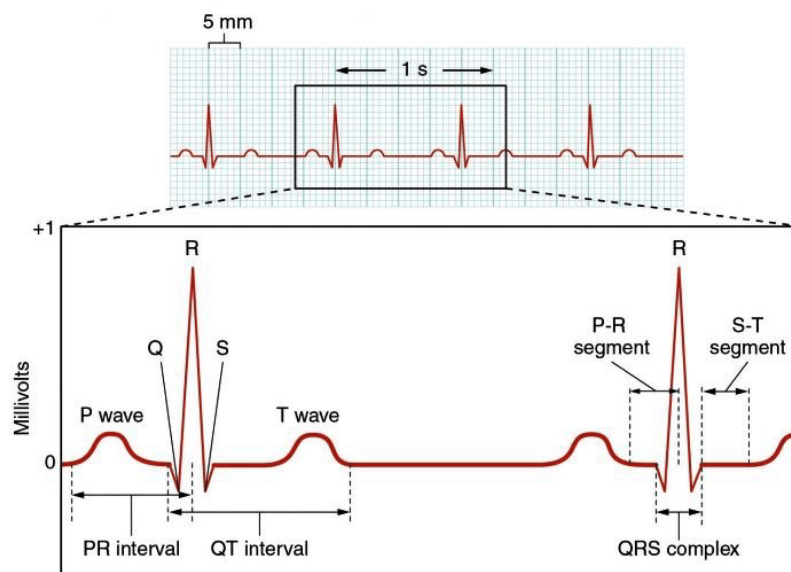


Figure 7.1.12: Labeled ECG tracing (one cardiac cycle). The diagram identifies the P wave, QRS complex, and T wave, along with the P-R segment, S-T segment, PR interval, and QT interval used to describe the timing of atrial and ventricular electrical activity. (CC BY-NC-SA 4.0; Harmony Folsie via [Introduction to Heart Electrophysiology](#)).

Figure 7.1.12 is a labeled diagram of a typical electrocardiogram (ECG/EKG) tracing showing one full cardiac cycle and the main waves, complexes, segments, and time intervals.

Overall layout

- The tracing is plotted on a grid. A scale marker indicates 5 mm and a time marker indicates 1 second.
- The vertical axis is labeled millivolts, ranging from 0 to +1.

Labeled ECG components

- P wave: A small upward deflection that occurs before the main spike.
- QRS complex: The sharp, tall complex labeled Q, R, and S:
 - Q is a small downward deflection before the main spike.
 - R is the tall upward spike.
 - S is the downward deflection after the R spike.
- T wave: A broader upward wave that follows the QRS complex.

Labeled segments

- P-R segment: The flat portion after the P wave and before the QRS complex.
- S-T segment: The flat portion after the QRS complex and before the T wave.

Labeled intervals

- PR interval: The time from the start of the P wave to the start of the QRS complex.
- QT interval: The time from the start of the QRS complex to the end of the T wave.

Using an ECG to Calculate Heart Rate

The heart rate can be calculated based on the amount of time elapsed between the “R” of the QRS complexes on the ECG, this is called the R-R interval. To calculate heart rate from the R-R interval, you need to divide 60 by the R-R interval measured in seconds. The R-R interval is the time between two consecutive “R” waves on an electrocardiogram (ECG) and represents the duration of one heart cycle.

Example:

- If your R-R interval is 1 second, your heart rate is $60/1 = 60$ bpm.
- If your R-R interval is 0.8 seconds, your heart rate is $60/0.8 = 75$ bpm.

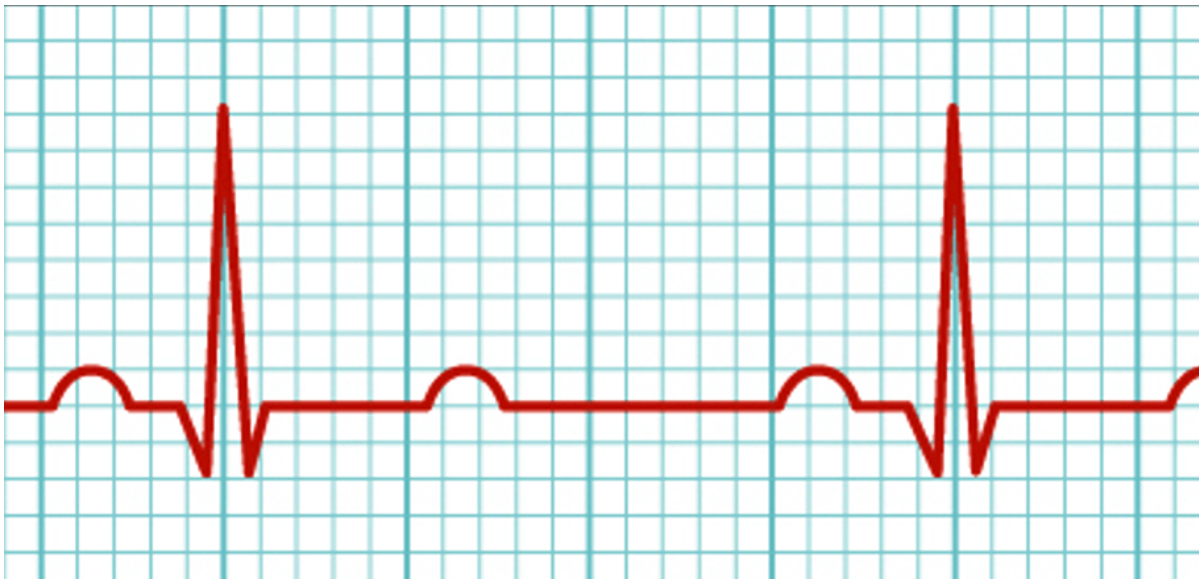


Figure 7.1.13: ECG rhythm strip: A short segment of an electrocardiogram showing repeating cardiac cycles with a small wave preceding a tall spike and a subsequent rounded wave, representing a regular heartbeat pattern. (CC BY-NC-SA 4.0; Harmony Folse via [Instructions for Recording an ECG](#)).

Figure 7.1.13 shows an electrocardiogram (ECG) tracing on grid paper. Two repeating heartbeat cycles are visible: each cycle includes a small rounded wave before a tall, narrow spike (the main complex), followed by a flat segment and then another small rounded wave. The pattern repeats across the strip, illustrating a regular rhythm.

We will use Figure 7.1.13 to practice how to measure heart rate on an ECG.

1. Locate two consecutive R waves on the ECG strip. The R wave is the peak of the QRS complex. Measure R-R interval on the ECG. In Figure 13 only one R-R interval is seen for practice purposes.
2. Counting Small Squares: Count the number of small squares between two R waves (R-R interval):
 - Number of small squares you counted (____) $\times 0.04$ seconds = ____ seconds
 - This gives you the R-R interval using small squares.
3. Counting Big Squares: Count the number of big squares between two R waves (R-R interval):
 - Number of big squares you counted (____) $\times 0.2$ seconds = ____ seconds.
 - This gives you the R-R interval using big squares.

4. Counting Both Small and Big Squares:
 - If you counted both small and big squares:
 - Number of big squares you counted () $\times 0.2$ seconds + Number of small squares you counted () $\times 0.04$ seconds = _____ seconds.
 - This total gives you the R-R interval using both small and big squares.
5. The total amount of time you found is for one heartbeat. So how many heartbeats will take place in one minute (60 seconds)? We can use the following formula to calculate heart rate (beats per minute/bpm) Heart Rate (beats per minute) = $60 / \text{R-R interval (in seconds)}$.

Another way to calculate heart rate (HR):

1. Convert the R-R interval to seconds: If the R-R interval is measured in millimeters, remember that each small square (1 mm) on an ECG usually represents 0.04 seconds.
 - For example: If the R-R interval is 17.5 mm, then $17.5 \text{ mm} \times 0.04 \text{ seconds/mm} = 0.7$ seconds.
2. Apply the formula: Heart Rate = $60 \div 0.7 \text{ seconds} = 85.7$ beats per minute (bpm).

The 6 second method:

1. Denotes a 6 second interval on ECG strip.
2. Count the number of QRS complexes or R waves occurring within the 6 seconds interval, and then multiply that number by 10.
 - For example, if there are 8 R waves in a 6 second strip, the heart rate is $(8 \times 10) = 80$ bpm.

Alternatively, you can quickly and easily calculate the heart rate from an ECG by using the following formula:

- Heart Rate (bpm) = $1500 / \text{Number of small squares in the R-R interval}$

This method is particularly useful for beginners as it provides a straightforward calculation based on the number of small squares between two R waves. It allows for rapid calculations during clinical assessments.

Example Calculation: If you count 10 small squares between two R waves, Heart Rate = $1500 \div 10 = 150$ bpm

7.2: Activity 1

Examine the Microanatomy of Blood Vessels

Materials: Compound microscope, Microscope lens paper, lens cleaning solution, Artery and Vein prepared microscope slide.

Procedures

1. Carefully place the artery slide onto the microscope stage, securing it with the stage clips. Make sure the objective and ocular lenses are clean. If not, use the lens paper and lens cleaning solution to wipe these.
2. Begin by focusing on the slide under low magnification (4 times objective lens and then 10 times objective lens). Identify the overall structure of the artery and vein. Note the relative thickness of the vessel wall.
3. Switch to higher magnification (40 times objective) to examine the details. Locate and identify the three tunics: the tunica intima (innermost layer), the tunica media (middle layer), and the tunica externa (outer layer). Note the relative thickness of each layer.
4. Create a detailed sketch of both the artery and vein, labeling the tunics and any other observable structures. Alternatively, you can take a clear photomicrograph.

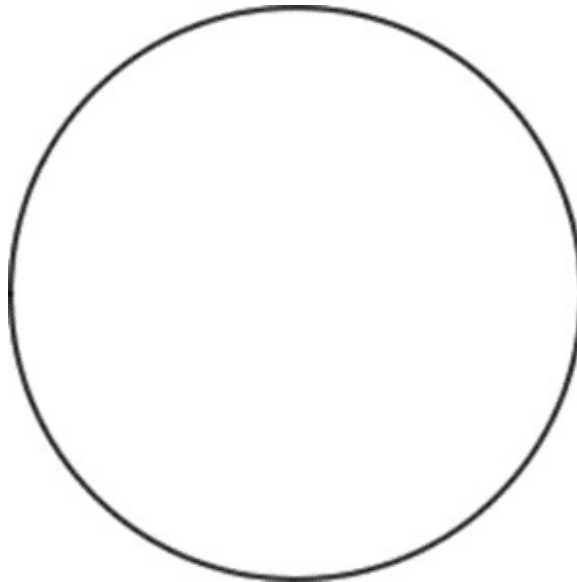


Figure 7.2.1: Space for the sketch or the microphotograph (Total magnification: 400 times).

7.3: Activity 2

Identifying Arteries: Exploring the Circulatory System

In this activity, you will use the provided key to identify the arteries indicated on the image by their corresponding numbers (1 - 25). This exercise will help reinforce your understanding of the major arteries and their locations within the circulatory system.

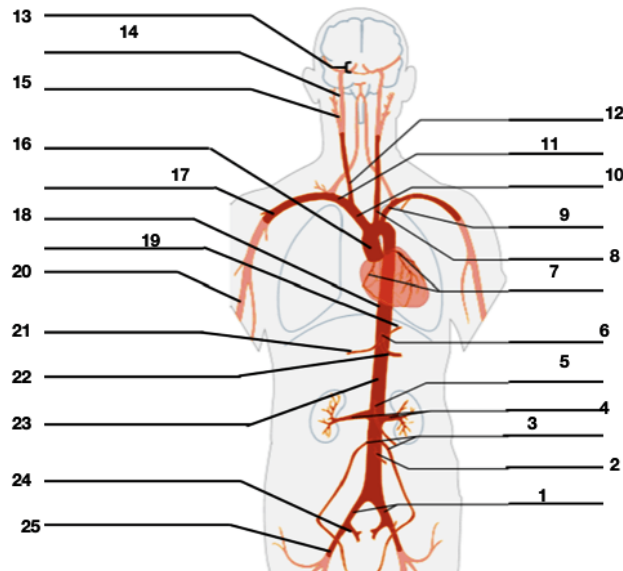


Figure 7.3.1: Human circulatory system diagram showing major arteries labeled with numbers from 1 to 25. (CC BY-NC-SA 4.0; Rosanna Hartline via Laboratory Activities and Assignment).

Figure 7.3.1 Displays 25 arteries, each labeled with numbers for easy identification. It serves as a visual guide for students to locate and name each artery within the circulatory system.

Table 7.3.1: Identify the arteries indicated by numbers in the image

Artery	Identifying Number	Artery	Identifying Number	Artery	Identifying Number
Ascending aorta		Common iliac arteries		Internal iliac artery	
Axillary artery		Descending abdominal aorta		Left gastric artery	
Brachial artery		Descending thoracic aorta		Renal arteries	
Brachiocephalic trunk		External carotid artery		Right and left Coronary arteries	
Celiac trunk		External iliac artery		Splenic artery	
Circle of Willis		Gonadal arteries		Subclavian artery (right and left)	
Common carotid artery (right and left)		Inferior mesenteric artery		Superior mesenteric artery	
Common hepatic artery		Internal carotid artery			

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7.4: Activity 3

Group Discussion: Case Studies to Prepare for Hands-On Lab Activities

This group discussion aims to help students reflect on their existing knowledge while analyzing case studies related to blood vessels and blood pressure. By revisiting what they already understand, students can build a solid foundation for deeper exploration and practical application in the lab. This collaborative setting encourages peer learning, enhances retention of concepts, and prepares students for hands-on activities.

Instructions:

1. Read Case Study 1 and Case Study 2, think about what you know that relates to the information provided in the case studies.
2. Listen to your peers and contribute your thoughts to foster a collaborative learning environment.
3. Jot down key insights and questions that arise during the discussion for reference in the lab.
4. Think about how the concepts discussed will apply to your upcoming hands-on activities.
5. Answer the questions provided at the end of case studies.

Case Study 1: Hypertension in an Adult

Background: John is a 50-year-old male with a sedentary lifestyle. His recent blood pressure readings are consistently around 150/95 mmHg. He has a family history of heart disease and is overweight.

Questions to Consider

1. What structural changes in John's arteries might contribute to his elevated blood pressure?
2. How does his lifestyle impact his blood vessel health and overall cardiovascular risk?
3. What recommendations would you make for John to manage his blood pressure effectively?

Case Study 2: Athletic Training in a Young Adult

Background: Sarah is a 24-year-old athlete who participates in long-distance running. Her resting blood pressure is measured at 110/65 mmHg. She trains regularly and follows a balanced diet.

Questions to Consider

1. How do Sarah's training and physical activity levels influence her blood vessel structure and function?
2. What is the significance of her lower blood pressure reading compared to the average adult?
3. How might her cardiovascular system adapt further with continued training?

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7.5: Activity 4

Measure Radial Pulse (Radial Artery)

To find your radial artery (the most common point from which people take pulses), hold one hand straight out, elbow bent, palm relaxed and facing up. Raise your thumb slightly skyward, as if holding an apple or a tennis ball, to create a small pocket under your thumb at the top of your wrist. Place the tips of your index and middle fingers of the other hand (don't use your thumb--it also has a pulse and could cause counting confusion) on the pocket under your thumb. Your fingers should lay across the tendon running down your arm. Adjust your fingertips until you can feel a steady beat under the skin of your wrist.

1. Count the beats for 30 seconds and multiply by 2.
2. Repeat the count thrice and record beats per minute (bpm). Record Trial 1, Trial 2, Trial 3 and calculate average. The units should be in bpm.

7.6: Activity 5

Measure Carotid Pulse (Carotid Artery)

Neck pulse points are stronger and more accessible. The carotid is located just below your jaw in the groove where your head and neck meet, on either side of your windpipe. Use your index and middle fingertips to feel around in the groove for a tangible pulsation. Hold your fingers in place for a few seconds to make sure you've got it.

1. Count the beats for 30 seconds and multiply by 2.
2. Repeat the count thrice and record beats per minute (bpm). Record Trial 1, Trial 2, Trial 3 and calculate average. The units should be in bpm.

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7.7: Activity 6

Measuring Apical Pulse

Measuring the apical pulse is an essential skill in clinical practice, particularly in assessing heart function and overall cardiovascular health. The apical pulse is taken at the apex of the heart, located at the fifth intercostal space along the left mid-clavicular line (where the heart's mitral valve is best heard). This measurement provides a direct assessment of heartbeats, making it particularly useful in patients with irregular rhythms or when peripheral pulses are difficult to palpate.

Instructions for Self-Measuring Apical Pulse

Gather Your Materials: You will need a stethoscope to accurately listen to your heartbeat. Most stethoscopes have an end piece with a flat diaphragm and a concave bell, only one of which is directly connected to the earpieces at any one time. The end piece can be turned 180° to change the working side. The bell is generally better than the diaphragm for this experiment because it reduces room noise. The earpieces should point slightly forward to match the direction of the external auditory canal. Make sure that the earpiece is properly positioned, and that the bell of the stethoscope is active.

1. Find a comfortable position, sit or lie down in a quiet space where you can focus without distractions.
2. Locate Your Apical Pulse:
 - Use your left hand to find the fifth intercostal space. This is located below your left nipple.
 - Move your fingers inward until you reach the mid-clavicular line, which is an imaginary vertical line that runs down from the center of your collarbone.
3. Position the Stethoscope: Place the diaphragm of the stethoscope firmly against your chest in the area where you located your pulse. Ensure it is snug against your skin for clear sound transmission. If you can't hear anything through the diaphragm, check that it is tightly attached to the stethoscope. If it's loose, you may not hear anything. Note: Clean earpieces and diaphragm of stethoscope with alcohol swab routinely after each use.
4. Count Your Heartbeats:
 - Listen carefully for the heart sounds. You should hear the characteristic "lub-dub" sound of your heartbeat.
 - Count the number of beats you hear for 60 seconds. If you prefer, you can also count for 30 seconds and multiply by 2, but a full minute gives a more accurate reading.
 - By learning to self-measure your apical pulse, you gain insight into your heart health and develop a greater awareness of how your body functions.
5. Record Your Results: Write down your heart rate in beats per minute (bpm) and note any irregularities you might hear, such as skipped beats or unusual rhythms.

Recorded Heart Rate

Heart rate is measured in beats per minute. With heart rates:

- Normal range, at rest, is between 60 and 100, although it can vary based on factors that include fitness (conditioned athletes can have slower rates) or age (children have faster rates).
- Bradycardia is a slow heart rate, less than 60 beats per minute in most people.
- Tachycardia is a fast heart rate of more than 100 beats per minute.

7.8: Activity 7

Calculating Pulse Deficit

Pulse deficit is the difference between the apical pulse rate (measured at the heart) and the peripheral pulse rate (measured at sites like the wrist). This measurement is important because it can indicate issues with heart function, particularly in cases of arrhythmias where the heart is not effectively pumping blood to the periphery.

A pulse deficit can indicate a problem with the efficiency of your heart or cardiac function. A pulse deficit greater than 4 might indicate some physiological problem. Atrial fibrillation (Afib) is a common arrhythmia that can result in a rapid, irregular heart rate. This causes a pulse deficit, because each ventricular contraction may not be sufficiently strong to transmit an arterial pulse wave through the peripheral artery. Assessment of the radial pulse in isolation will not be an accurate reflection of the actual heart rate. Other causes for a pulse deficit include atrial flutter.

Steps to Calculate Pulse Deficit

1. Measure the Apical Pulse:
 - Use a stethoscope to listen to the heartbeats at the apex (fifth intercostal space, midclavicular line).
 - Count the heartbeats for a full 60 seconds to get the apical pulse rate (in beats per minute, bpm).
2. Measure the Peripheral Pulse:
 - At the same time (or shortly after), measure the radial pulse (at the wrist) or another peripheral pulse site.
 - Count the beats for a full 60 seconds to get the peripheral pulse rate (in bpm).
3. Calculate: Simultaneous measurement of apical and radial pulse
 - Pulse deficit is the difference between radial pulse and apical pulse.
 - Is it greater than 4?

NOTE: The measurements are for learning purpose only.

7.9: Activity 8

Manually Measuring Blood Pressure with a Sphygmomanometer and Stethoscope

Measuring blood pressure is a fundamental clinical skill that provides critical insights into an individual's cardiovascular health. Blood pressure reflects the force exerted by circulating blood on the walls of blood vessels and is expressed in millimeters of mercury (mmHg) with two values: systolic pressure (the pressure during heartbeats) and diastolic pressure (the pressure when the heart is at rest between beats).

Instructions

1. Work in pairs. Those who are to have their blood pressure measured should be seated with their sleeves rolled up.
2. Have the subject sit with their right or left arm resting on a table at the level of their heart.
3. Make sure the cuff is deflated. If there is remaining air in the cuff, open the screw valve of the pump and press the bag to release the air.
4. Palpate where the brachial artery is in the cubital fossa and wrap the cuff of the sphygmomanometer around the arm with the cuff arrow pointing at the artery.
5. Place the bell of the stethoscope under the cuff above the brachial artery.
6. Gently close the screw valve and pump the pressure in the cuff up to 160-180 mmHg.
7. Open the screw valve to allow the pressure in the cuff to drop slowly, at a rate of about 2 or 3 mmHg per second.
8. Listen for the first and last sound. Record the systolic pressure and diastolic pressure in the Results section.
9. Wait a few minutes and make sure the cuff is fully deflated. Then, take the measurements with the subject in a standing position (arms down).

Follow the steps above to measure the resting systolic and diastolic blood pressure.

- a. Record the values of Resting Systolic Pressure, use average of 3 trials.
- b. Record the values of Resting Diastolic Pressure, use average of 3 trials.

For an adult, the systolic blood pressure should be less than 120 mmHg and the diastolic blood pressure should be less than 80 mmHg. This range is considered "normal."

7.10: Activity 9

Measuring Blood Pressure With the Automatic Digital Blood Pressure Monitor

1. Work in pairs. Those who are to have their blood pressure measured should be seated with their sleeves rolled up.
2. Attach the cuff of the sphygmomanometer snugly around the upper arm.
3. Turn on the blood pressure monitor and press the “start” button. The cuff will automatically inflate to 180-200 mm Hg and then begin to deflate.
4. The blood pressure and pulse readings will be displayed on the monitor screen at the end of cuff deflation. Record the blood pressure readings.
5. Repeat two more times, recording the blood pressure and pulse after each trial. NOTE: Allow the subject to rest 30-60 seconds with the cuff deflated at the end of each trial.
6. Determine and record the average blood pressure and average pulse.
7. Trade places with your partner and repeat the procedure.
8. Turn the blood pressure monitor off.

Record the values here:

- a. Record the values of Resting Systolic Pressure, use average of 3 trials. _____
- b. Record the values of Resting Diastolic Pressure, use average of 3 trials. _____

7.11: Activity 10

Calculating Pulse Pressure and Cardiac Output

Calculating pulse pressure and cardiac output is essential for understanding cardiovascular health. Pulse pressure is the difference between systolic and diastolic blood pressure, providing insight into the state of the arteries and the heart's pumping ability. Cardiac output (CO) indicates the volume of blood the heart pumps in one minute, reflecting overall heart function. These measurements are crucial for assessing an individual's cardiovascular status and identifying potential health issues.

Instructions

Part 1: Calculating Pulse Pressure

1. Measure Blood Pressure:
 - Obtain the systolic and diastolic blood pressure readings using a sphygmomanometer.
 - Record Calculated Pulse Pressure, which is the difference between Diastolic Blood Pressure and Systolic Blood Pressure.

Part 2: Calculating Cardiac Output

2. Gather Heart Rate:
 - Measure the heart rate (HR) in beats per minute (bpm). You can use the apical pulse or radial pulse for this measurement.
 - Recorded Heart Rate (beats per minute).
 - Stroke Volume (SV): is the amount of blood pumped by the heart with each beat. You may need to estimate or obtain this value through methods such as echocardiography. A typical stroke volume is about 70 mL for a healthy adult.
 - Calculate Cardiac Output:
 - Cardiac Output (CO) = Stroke Volume (SV) x Heart Rate (HR)
 - Convert stroke volume to liters (e.g., 70 mL = 0.07 L).
3. Record Calculated Cardiac Output.

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7.12: Activity 11

Computing Mean Arterial Pressure (MAP)

The mean arterial pressure is the average pressure in the arteries over one cardiac cycle. MAP is a better indicator of blood flow to vital organs than systolic blood pressure alone. A normal MAP is typically above 65 mmHg to ensure adequate organ perfusion. A MAP below 60 mmHg can signal inadequate blood flow and a risk of organ damage.

$$MAP = \frac{\text{Systolic Blood Pressure (SBP)} + 2 \times \text{Diastolic Blood Pressure (DBP)}}{3}$$

Record Computed Mean Arterial Pressure (MAP) = _____ mm Hg

7.13: Activity 12

Exploring Cardiac Function: Understanding Electrocardiogram (ECG)

The electrocardiogram (ECG or EKG) lab is designed to provide students with a foundational understanding of the heart's electrical activity. An ECG is a crucial diagnostic tool that records the electrical impulses generated by the heart as it beats, allowing healthcare professionals to assess heart rate, rhythm, and overall cardiac health. This lab activity will guide students through the fundamental concepts of electrocardiograms, focusing on how to set up an ECG, interpret the waveforms, and analyze the heart's electrical activity.

Instructions for Recording an ECG

1. The subject should lie flat on their back, with hands at their sides; lying on side or sitting up alters the heart's electrical axis.
2. The inner aspect of the right and left arms and right and left legs are rubbed with alcohol.
3. Place electrodes (shiny side down) firmly on the limbs.
4. Clip leads to the electrodes on the limb sites. Lead RA (right arm); lead LA (left arm); lead LL (left leg); and lead RL (right leg).
Note: lead RL to the right leg will serve as ground.
5. Turn the unit on.
6. Press "MANUAL" button to print out ECG tracings.
7. Once the ECG tracings comes out of the machine, press "STOP" button to stop the printing.
8. After the resting ECG has been recorded, remove the lead wires and the electrodes.
9. Discard the electrodes.

Record Results

1. After obtaining the ECG printout, analyze the waveform components:
 - Identify the P wave, QRS complex, and T wave, noting their shapes and intervals.
2. Attach the ECG strip as part of the worksheet submission.

Key Terms and Definitions

- **Abdominal aorta** – The portion of the aorta located in the abdomen.
- **Aneurysm** – A sac-like protrusion from a blood vessel or the heart due to a weakened wall.
- **Angina (Angina Pectoris)** – Chest pain caused by restricted blood flow to the heart.
- **Angiography** – An X-ray technique using dye to visualize heart chambers and coronary arteries.
- **Angioplasty** – A nonsurgical procedure using a balloon to open narrowed arteries.
- **Anticoagulant** – A medication that prevents blood clotting; also known as a blood thinner.
- **Antihypertensive** – A medication or therapy that lowers blood pressure.
- **Aorta** – The largest artery in the body, carrying blood from the heart to the rest of the body.
- **Aortic valve** – The valve controlling blood flow from the heart into the aorta.
- **Arrhythmia** – An irregular or abnormal heartbeat.
- **Arterioles** – Small branches of arteries that regulate blood pressure by contracting.
- **Arteries** – Blood vessels that carry oxygen-rich blood away from the heart.
- **Arteriosclerosis** – Hardening and thickening of artery walls, reducing elasticity.
- **Ascending aorta** – The first section of the aorta emerging from the heart's left ventricle.
- **Atherosclerosis** – Buildup of plaque inside blood vessels, narrowing them.
- **Atrium (Right and Left)** – The heart's two upper chambers that receive blood.
- **Atrial flutter** – A fast, irregular heartbeat originating in the atria.
- **Atrial tachycardia** – A rapid heartbeat (160–200 bpm) starting in the atria.
- **Atrioventricular block** – A disruption in electrical signals between the atria and ventricles.
- **Atrioventricular (AV) node** – A group of cells that regulate electrical signals from atria to ventricles.
- **Autoregulation** – The ability of an organ to maintain constant blood flow despite pressure changes.
- **Blood clot** – A mass formed by clotting factors to stop bleeding; may cause heart attack or stroke if formed in arteries.
- **Blood Pressure (BP)** – The force of blood against vessel walls, measured in mmHg (systolic/diastolic).
- **Blue babies** – Infants with cyanosis due to low oxygen levels, often from heart defects.
- **Bradycardia** – An abnormally slow heart rate.
- **Bundle branch block** – A defect in the heart's electrical conduction system causing arrhythmia.
- **Bypass** – Surgery to reroute blood around blocked arteries.
- **Capillaries** – Tiny blood vessels that exchange oxygen, nutrients, and waste between blood and tissues.
- **Cardiac** – Pertaining to the heart.
- **Cardiac arrest** – Sudden stopping of the heartbeat, often due to electrical signal failure.
- **Cardiac output** – The volume of blood pumped by the heart per minute.
- **Cardiologist** – A doctor specializing in heart health and disease.
- **Cardiology** – The study of the heart and its functions.
- **Cardiomegaly** – An enlarged heart, often due to underlying conditions.
- **Cardiomyopathy** – Disease of the heart muscle affecting its ability to pump blood.
- **Cardiopulmonary bypass** – A machine temporarily replaces heart and lung function during surgery.
- **Cardiopulmonary resuscitation (CPR)** – Emergency procedure to maintain breathing and circulation.
- **Cardiovascular (CV)** – Relating to the heart and blood vessels.
- **Cardiovascular Disease (CVD)** – A group of conditions affecting the heart and blood vessels.
- **Carotid artery** – Major arteries in the neck supplying blood to the brain.
- **Cerebral hemorrhage** – Bleeding in the brain due to a ruptured vessel or injury.
- **Cerebral thrombosis** – A blood clot in a brain artery.
- **Cerebrovascular** – Pertaining to brain blood vessels.
- **Cerebrovascular accident (Stroke)** – Disruption of blood flow to the brain causing tissue damage.
- **Circulatory system** – The system that circulates blood through the heart and vessels.
- **Collateral circulation** – Alternate blood flow through nearby vessels when a main vessel is blocked.
- **Computed tomography (CT/CAT scan)** – Imaging technique using X-rays and computers for cross-sectional views.
- **Conduction system** – Specialized heart muscle fibers that transmit electrical impulses.
- **Congestive heart failure** – A condition where the heart can't pump effectively, causing fluid buildup.
- **Coronary arteries** – Arteries supplying blood to the heart muscle.
- **Coronary artery anomaly (CAA)** – A congenital defect in coronary artery structure.
- **Coronary artery bypass (CAB)** – Surgery to reroute blood around blocked coronary arteries.
- **Coronary artery disease (CAD)** – Narrowing of the coronary arteries due to plaque buildup, increasing heart attack risk.

- **Coronary heart disease** – Heart disease caused by atherosclerotic plaque in coronary arteries, leading to angina or heart attack.
- **Coronary occlusion** – Blockage in a coronary artery that restricts blood flow to the heart muscle.
- **Coronary thrombosis** – A blood clot in a coronary artery; also referred to as coronary occlusion.
- **Cyanosis** – Bluish skin tint caused by low oxygen levels in the blood.
- **Deep vein thrombosis (DVT)** – A blood clot in a deep vein, typically in the calf.
- **Defibrillator** – A device that restores normal heart rhythm by delivering an electric shock.
- **Diastolic blood pressure** – The lowest arterial pressure, occurring when the heart rests between beats.
- **Diuretic** – A medication that lowers blood pressure by promoting fluid loss through increased urination.
- **Doppler ultrasound** – A sound wave-based test to assess blood flow and detect valve issues.
- **Dysarthria** – A speech disorder caused by muscle control problems due to brain or nerve damage.
- **Dyspnea** – Difficulty or shortness of breath.
- **Echocardiography** – Imaging technique using sound waves to visualize heart structure and function.
- **Ejection fraction** – Percentage of blood pumped out of a filled ventricle with each heartbeat; normal is 50% or higher.
- **Electrocardiogram (ECG or EKG)** – A test recording the heart's electrical activity to assess rhythm and rate.
- **Embolus (Embolism)** – A blood clot that travels from one part of the body to another, potentially causing blockage.
- **Endocardium** – The smooth inner lining of the heart chambers.
- **Endothelium** – The inner lining of blood vessels and the heart.
- **Endocarditis** – Infection of the heart's inner lining, typically caused by bacteria.
- **Enlarged heart** – An abnormally large heart due to genetics, disease, or conditions like hypertension or obesity.
- **Epicardium** – The outer membrane covering the heart muscle.
- **Exercise stress test** – A test to evaluate heart function during physical activity, often using a treadmill and imaging tools.
- **Fibrillation** – Rapid, uncoordinated contractions of heart muscle fibers, impairing effective pumping.
- **First-degree heart block** – A delay in electrical impulses between the atria and ventricles.
- **Flutter** – Rapid, more coordinated contractions of a heart chamber, less chaotic than fibrillation.
- **Heart assist device** – A surgically implanted device that supports heart function.
- **Heart attack** – Damage or death of heart muscle due to insufficient oxygen-rich blood supply.
- **Heart block** – A disruption in the heart's electrical conduction system, affecting rhythm.
- **Heart failure** – See **Congestive heart failure**.
- **Heart-lung machine** – A device that temporarily takes over heart and lung functions during surgery.
- **Heart murmur** – An abnormal heart sound caused by turbulent blood flow, possibly indicating valve issues or structural defects.
- **Hematocrit** – Percentage of red blood cells in a given volume of whole blood.
- **High blood pressure** – Chronic elevation of blood pressure above the normal range.
- **Holter monitor** – Portable device that records heart activity continuously for 24 hours or more.
- **Hypertension** – High blood pressure.
- **Hypertrophic obstructive cardiomyopathy (HOCM)** – Thickened heart muscle that bulges into the ventricle and obstructs blood flow.
- **Hypertrophy** – Enlargement of tissues or organs due to increased workload.
- **Hyperventilation** – Rapid breathing often caused by anxiety, leading to tingling, numbness, or fainting.
- **Hypotension** – Abnormally low blood pressure.
- **Hypoxia** – Reduced oxygen levels in body tissues and organs.
- **Incompetent valve (Insufficiency)** – A valve that leaks blood backward due to improper closure.
- **Infarct** – Area of heart tissue permanently damaged due to lack of oxygen.
- **Inferior vena cava** – Large vein that returns blood from the lower body to the heart.
- **Internal mammary artery** – Chest wall artery often used for coronary artery bypass grafts.
- **Intravascular echocardiography** – Imaging technique combining echocardiography and catheterization to view inside the heart and vessels.
- **Ischemia** – Reduced blood flow to an organ due to narrowed or blocked arteries.
- **Ischemic heart disease** – Heart condition caused by narrowed coronary arteries, reducing blood supply to the heart.
- **Ischemic stroke** – Stroke caused by a blockage in a blood vessel supplying the brain.
- **Jugular veins** – Veins that return blood from the head to the heart.
- **Korotkoff sounds** – Sounds heard via stethoscope during blood pressure measurement, indicating systolic and diastolic pressures.
- **Left ventricular assist device (LVAD)** – Mechanical pump that helps the left ventricle circulate blood; used in advanced heart failure.
- **Lesion** – An injury or abnormal change in tissue; atherosclerotic lesions affect artery walls.
- **Lumen** – The hollow interior of a tubular structure, such as a blood vessel.

- **Mean Arterial Pressure (MAP)** – Average pressure in arteries during one cardiac cycle; used to assess organ perfusion.
- **Mitral stenosis** – Narrowing of the mitral valve, often due to congenital defects or rheumatic fever.
- **Mitral valve** – Valve between the left atrium and left ventricle that regulates blood flow.
- **Mitral valve prolapse** – Condition where mitral valve leaflets bulge into the atrium, allowing backflow.
- **Mitral valve regurgitation** – Incomplete closure of the mitral valve, causing blood to leak back into the left atrium.
- **mm Hg** – Millimeters of mercury; unit used to measure blood pressure.
- **Murmur** – Abnormal heart sound caused by turbulent blood flow, often due to valve defects or congenital issues.
- **Myocardial infarction (Heart attack)** – Damage or death of heart muscle due to blocked blood supply; symptoms include chest pain and low blood pressure.
- **Myocardial ischemia** – Occurs when part of the heart muscle doesn't receive enough oxygen.
- **Myocarditis** – Inflammation of the heart muscle due to infection, toxins, or diseases like rheumatic fever.
- **Myocardium** – The muscular wall of the heart responsible for pumping blood.
- **Occluded artery** – An artery blocked by plaque or a clot, impairing blood flow.
- **Open heart surgery** – Surgical procedure involving opening the chest and heart, often using a heart-lung machine.
- **Pacemaker** – An implanted device that regulates the heartbeat electronically.
- **Palpitation** – An irregular or rapid heartbeat felt in the chest.
- **Pericarditis** – Inflammation of the pericardium, increasing fluid and restricting heart function.
- **Pericardium** – The fibrous sac surrounding the heart.
- **Plaque** – Fatty deposits in artery walls, characteristic of atherosclerosis.
- **Positron emission tomography (PET)** – Imaging test showing heart muscle function and blood flow.
- **Pulmonary** – Pertaining to the lungs and respiratory system.
- **Pulmonary embolism** – A blood clot that travels to the lungs, blocking blood flow.
- **Pulmonary valve** – Valve between the right ventricle and pulmonary artery.
- **Pulmonary vein** – Vessel carrying oxygenated blood from lungs to the heart's left atrium.
- **Pulse pressure** – Difference between systolic and diastolic pressure; reflects artery health.
- **Regurgitation** – Backward flow of blood due to a faulty heart valve.
- **Rheumatic fever** – Childhood disease following strep infection; may damage heart valves.
- **Rheumatic heart disease** – Heart valve damage caused by rheumatic fever.
- **Risk factor** – A condition or behavior increasing the chance of cardiovascular disease.
- **R wave** – The peak of the QRS complex on an ECG, used to measure heart rate.
- **Second-degree heart block** – Electrical impulses are delayed or blocked between atria and ventricles.
- **Septal defect** – A hole in the wall separating heart chambers.
- **Septum** – Muscular wall dividing the left and right sides of the heart.
- **Shunt** – A passage allowing blood flow between two locations.
- **Sinus (SA) node** – The heart's natural pacemaker located in the right atrium.
- **Sphygmomanometer** – Instrument used to measure blood pressure.
- **Stent** – Expandable mesh device placed in arteries to keep them open.
- **Stenosis** – Narrowing of a blood vessel or heart valve.
- **Stethoscope** – Instrument for listening to internal body sounds.
- **Sternum** – The breastbone.
- **Stress** – Physical or emotional strain; can affect heart health.
- **Stroke** – Sudden disruption of blood flow to the brain due to clot or vessel rupture.
- **Subclavian arteries** – Major arteries supplying blood to the arms.
- **Superior vena cava** – Vein returning blood from the upper body to the heart.
- **Syncope** – Temporary loss of consciousness due to reduced brain blood flow.
- **Systolic blood pressure** – Highest arterial pressure during heart contraction.
- **Tachycardia** – Abnormally fast heart rate; may occur in episodes.
- **Tamponade (Cardiac tamponade)** – Compression of the heart due to fluid buildup in the pericardium.
- **Third-degree heart block** – Complete blockage of electrical signals between atria and ventricles.
- **Thrombolysis** – Dissolution of a blood clot.
- **Thrombosis** – Formation of a blood clot inside a vessel or heart cavity.
- **Thrombus** – A blood clot.
- **Transient ischemic attack (TIA)** – Temporary stroke-like event caused by brief blood vessel blockage.
- **Transplantation** – Replacement of a failing organ with a donor organ.
- **Tricuspid valve** – Valve between the right atrium and right ventricle.
- **Ultrasound** – Diagnostic imaging using high-frequency sound waves.
- **Valve replacement** – Surgery to replace a malfunctioning heart valve.
- **Varicose vein** – Abnormally widened vein.

- **Vascular** – Pertaining to blood vessels.
- **Vasodilators** – Medications that widen arteries.
- **Vasopressors** – Medications that raise blood pressure.
- **Veins** – Vessels that carry deoxygenated blood back to the heart.
- **Ventricle (Right and Left)** – The heart's lower chambers that pump blood.
- **Ventricular Assist Device (VAD)** – Mechanical pump aiding ventricular function in heart failure.
- **Ventricular fibrillation** – Rapid, uncoordinated ventricular contractions preventing effective blood flow.
- **Ventricular tachycardia** – Fast, abnormal heartbeat originating in the ventricles.

8: RESPIRATORY SYSTEM ANATOMY AND PHYSIOLOGY

Introduction

This respiratory anatomy and physiology lab will provide a comprehensive exploration of the system's structure and function. You will begin by identifying and labeling key structures—the nasal cavity, pharynx, larynx, trachea, bronchi, and lungs—using anatomical models and diagrams. This will be followed by an examination of the mechanics of breathing, focusing on gas exchange and the coordinated actions of the lungs and diaphragm. You will then gain hands-on experience using spirometry to measure respiratory volumes (tidal volume, vital capacity, total lung capacity). Finally, you will apply this knowledge by analyzing clinical scenarios and identifying potential respiratory disorders based on provided symptoms and physiological data. This lab integrates theory with practice, equipping you to understand both the mechanics and clinical relevance of respiratory function.

Learning Objectives

- Identify the major anatomical structures of the respiratory system, including the nasal cavity, pharynx, larynx, trachea, bronchi, and lungs, using anatomical models and diagrams.
- Articulate the primary functions of each component of the respiratory system and explain how these structures contribute to gas exchange and respiration.
- Determine the pathway and mechanism of airflow into and out of the lungs, explain how the lungs and diaphragm work together during the breathing process, and apply Boyle's Law to understand how changes in pressure and volume affect respiration.
- Demonstrate the techniques for measuring respiratory volumes and capacities, such as tidal volume, vital capacity, and total lung capacity, using spirometry.
- Apply their understanding of respiratory anatomy and physiology to clinical scenarios, identifying potential respiratory disorders based on symptoms and physiological data.

8.1: Background Information

8.2: Activity 1

8.3: Activity 2

8.4: Activity 3

8.5: Activity 4

8.6: Activity 5

8.7: Activity 6

8.8: Activity 7

8.9: Activity 8

8.10: Glossary

8.1: Background Information

Overview

Breathing is an involuntary event. How often a breath is taken and how much air is inhaled or exhaled are tightly regulated by the respiratory center in the brain. Human adults breathe about 12-20 times a minute on average and much more during physical exertion. A breath is one complete respiratory cycle that consists of one inspiration and one expiration.

With every inhalation, air fills the lungs, and with every exhalation, air rushes back out. That air is doing more than just inflating and deflating the lungs in the chest cavity. The air contains oxygen that crosses the lung tissue, enters the bloodstream, and travels to organs and tissues. Oxygen (O_2) enters the cells where it is used for metabolic reactions that produce ATP, a high-energy compound. At the same time, these reactions release carbon dioxide (CO_2) as a by-product. CO_2 exits the cells, enters the bloodstream, travels back to the lungs, and is expired out of the body during exhalation. Another key role of respiration is maintaining proper blood pH. The concentration of H^+ ions in blood is partially determined by the amount of dissolved CO_2 in the blood, so that more CO_2 results in more H^+ ion, causing the blood to have a lower pH and be more acidic.

When the blood becomes acidic, respiratory acidosis occurs, which can cause tissue damage if too severe. Acidosis can be caused by hypoventilation (too little breathing), which reduces the removal rate of carbon dioxide, causing it to build up in the bloodstream along with hydrogen. There are many symptoms of acidosis, such as headache, confusion, increased heart rate, and muscle weakness.

Respiratory alkalosis happens when the opposite effect occurs. When the blood pH becomes too high, from too few H^+ ions because of too little CO_2 , the blood will become alkaline, which is also harmful to the body. Alkalosis can happen from hyperventilation (too much breathing) which removes too much carbon dioxide from the bloodstream.

Thankfully, negative feedback mechanisms exist so that hyperventilation and hypoventilation can be corrected. These feedback mechanisms can fail in people with chronic respiratory diseases like emphysema and bronchitis, or from the side effects of certain drugs, in which acidosis and alkalosis will occur regardless.

Respiratory Organs

The organs of the respiratory system form a continuous system of passages called the respiratory tract, through which air flows into and out of the body. The respiratory tract has two major divisions: the upper respiratory tract and the lower respiratory tract. The organs in each division are shown in Figure 8.1.1. In addition to these organs, certain muscles of the thorax (the body cavity that fills the chest) are also involved in respiration by enabling breathing. Most important is a large muscle called the diaphragm, which lies below the lungs and separates the thorax from the abdomen. Smaller muscles between the ribs also play a role in breathing. You can learn more about breathing muscles in the concept of Breathing.

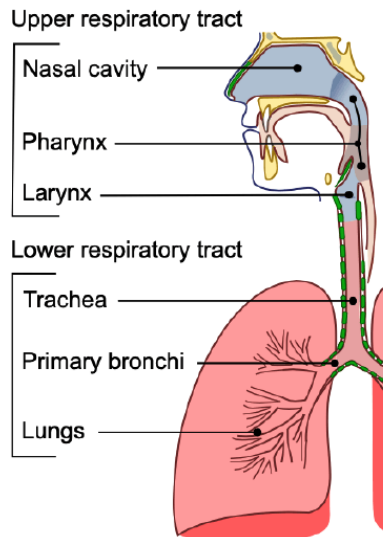


Figure 8.1.1: Diagram illustrating the human respiratory system, highlighting the components of the upper and lower tracts. The upper tract includes the nose, nasal cavity, and pharynx, which filter, warm, and moisten incoming air. The lower tract, consisting of the larynx, trachea, bronchi, and lungs, is responsible for conducting air into the lungs and facilitating gas exchange at the alveoli. (CC BY-NC 4.0; Christine Miller via Human Biology).

Figure 8.1.1 shows the respiratory system divided into two parts. The upper respiratory tract includes the nasal cavity, pharynx (throat), and larynx. In the lower respiratory tract the trachea branches into the primary bronchi and into the lungs.

Upper Respiratory Tract

All of the organs and other structures of the upper respiratory tract are involved in the conduction or the movement of air into and out of the body. Upper respiratory tract organs provide a route for air to move between the outside atmosphere and the lungs. They also clean, humidity, and warm the incoming air. However, no gas exchange occurs in these organs.

Nasal Cavity

The nasal cavity is a large, air-filled space in the skull above and behind the nose in the middle of the face. It is a continuation of the two nostrils. As inhaled air flows through the nasal cavity, it is warmed and humidified. Hairs in the nose help trap larger foreign particles in the air before they go deeper into the respiratory tract. In addition to its respiratory functions, the nasal cavity also contains chemoreceptors that are needed for the sense of smell and that contribute importantly to the sense of taste.

Pharynx

The pharynx is a tube-like structure that connects the nasal cavity and the back of the mouth to other structures lower in the throat, including the larynx. The pharynx has dual functions: both air and food (or other swallowed substances) pass through it, so it is part of both the respiratory and digestive systems. Air passes from the nasal cavity through the pharynx to the larynx (as well as in the opposite direction). Food passes from the mouth through the pharynx to the esophagus.

Larynx

The larynx, a cartilaginous structure inferior to the laryngopharynx connects the pharynx and trachea and helps to conduct air through the respiratory tract. Three large cartilage pieces—the thyroid cartilage (anterior), epiglottis (superior), and cricoid cartilage (inferior)—form the major structure of the larynx. 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 in males. The thick cricoid cartilage forms a ring, with a wide posterior region and a thinner anterior region. Three smaller, paired cartilages—the arytenoids, corniculates, and cuneiforms—attach to the epiglottis and the vocal cords and muscle that help move the vocal cords to produce speech.

A very important function of the larynx is protecting the trachea from aspirated food. When swallowing occurs, the backward motion of the tongue forces a flap called the epiglottis, a flexible piece of elastic cartilage, attached to the thyroid cartilage covers the opening of the trachea. When in the “closed” position, the unattached end of the epiglottis rests on the glottis. The glottis is composed of the vestibular folds, the true vocal cords, and the space between these folds. To close over the entrance to the larynx. This prevents swallowed material from entering the larynx and moving deeper into the respiratory tract. If swallowed material does start to enter the larynx, it irritates the larynx and stimulates a strong cough reflex. This generally expels the material out of the larynx and into the throat.

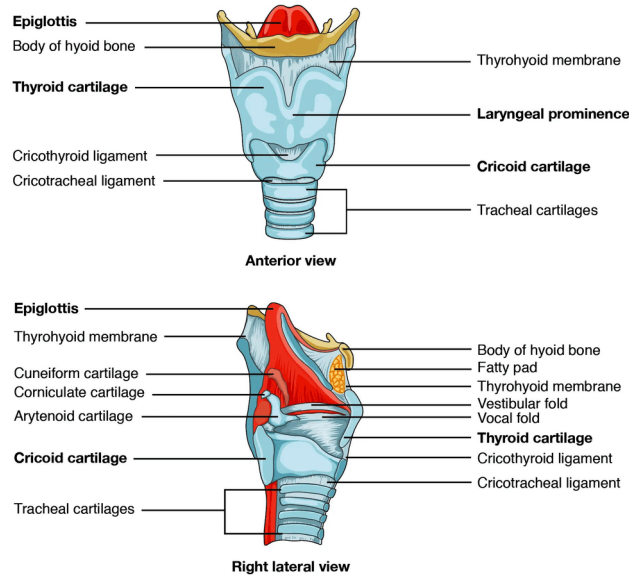


Figure 8.1.2: The larynx extends from the laryngopharynx and the hyoid bone to the trachea. The image shows the larynx from two different views: an anterior view (top) and a right lateral view (bottom). Key structures of the larynx are illustrated, including the thyroid cartilage, cricoid cartilage, epiglottis, arytenoid cartilages, vocal folds (true vocal cords), and vestibular folds (false vocal cords). Ligaments connecting the cartilages are also shown. (CC BY 4.0; via [Anatomy and Physiology](#)).

Figure 8.1.2 contains two labeled diagrams of the larynx (voice box).

Top diagram: Anterior (front) view

- Labels identify the epiglottis at the top and the body of the hyoid bone above the larynx.
- The thyrohyoid membrane spans between the hyoid region and the thyroid cartilage.
- The thyroid cartilage is shown with the laryngeal prominence on its front surface.
- Below the thyroid cartilage are the cricothyroid ligament and the cricoid cartilage.
- The cricotracheal ligament connects the cricoid cartilage to the tracheal cartilages below.

Bottom diagram: Right lateral (side) view

- Labels identify the epiglottis near the top, with a thyrohyoid membrane below it.
- Directly opposite the thyrohyoid membrane is the body of the hyoid bone (in the front of the neck), with a fatty pad just below it that is covered by another thyrohyoid membrane.
- Below the thyrohyoid membrane, and parallel to the fatty pad (but deeper in the larynx), we see the cuneiform cartilage.
- Directly below the cuneiform cartilage is the tiny corniculate cartilage, which sits at the top end of the arytenoid cartilage.
- The vestibular fold is shown as a thin band extending horizontally from the arytenoid cartilage toward the front of the neck.
- Directly below and parallel to the vestibular fold is the much broader vocal fold.
- Toward the front of the neck, the thyroid cartilage is shown in a vertical orientation, overlapping the vestibular and vocal folds.
- Just below the thyroid cartilage are the cricothyroid and cricotracheal ligaments.
- The cricoid cartilage is a large band that forms the lowest part of the trachea. It is widest at the posterior of the trachea, where it meets the arytenoid cartilage at the top and tracheal cartilages at the bottom. It narrows as moves toward the front of the neck, where it sits between the cricothyroid ligament and the cricotracheal ligaments.

The respiratory system produces sound by passing air through the upper airways and the mouth. Most of the sound people make is caused when air passing through the larynx causes the vibration of two flaps of tissue called the vocal cords (vocal folds). The

sound gets louder when more air flows through the larynx. Different muscle contractions in the larynx control the position and tension of the vocal cords and thus alter the pitch of sounds. The sounds made by the vocal cords are modified by the other upper airways, especially the nasal passages and the mouth. By changing the shape of these passages and moving the tongue, a person can create a multitude of sounds and form words. All the actions that produce and modify sounds from the respiratory system are controlled by the nervous system.

Lower Respiratory Tract

The trachea and other passages of the lower respiratory tract conduct air between the upper respiratory tract and the lungs. These passages form an inverted tree-like shape (Figure 3), with repeated branching as they move deeper into the lungs. All told, there are an astonishing 2,414 kilometres (1,500 miles) of airways conducting air through the human respiratory tract! It is only in the lungs, however, that gas exchange occurs between the air and the bloodstream.

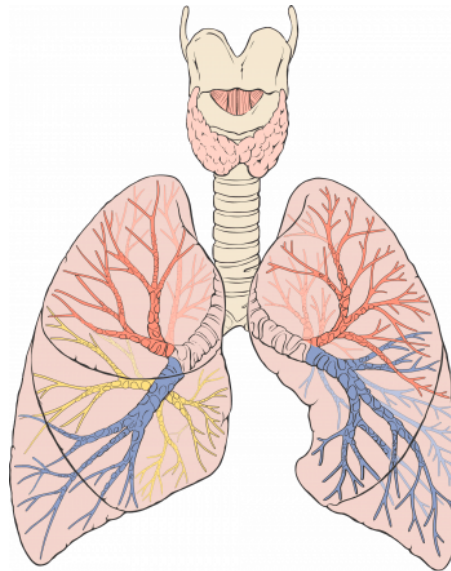


Figure 8.1.3: Illustration of the lower respiratory tract highlighting the trachea and branching bronchioles inside the lungs. (CC BY-NC-SA 4.0; Christine Miller via [Human Biology](#)).

Figure 8.1.3 shows the main air passages involved in breathing within the lungs. It traces the airway from the larynx at the top down through the trachea, where firm cartilage helps keep the passage open. From there, the airway divides into many smaller branches that spread throughout the lungs, forming a complex network that allows air to move efficiently to all regions for breathing.

Trachea

The trachea, or windpipe, is the widest passageway in the respiratory tract. It is about 2.5 cm (1 inch) wide and 10-15 cm (4-6 inch) long. It is formed by rings of cartilage, which make it relatively strong and resilient. The trachea connects the larynx to the lungs for the passage of air through the respiratory tract. The trachea branches at the bottom to form two bronchial tree.

Bronchi and Bronchioles

There are two main bronchial tubes, or bronchi (singular, bronchus), called the right and left bronchi. The bronchi carry air between the trachea and lungs. Each bronchus branches into smaller, secondary bronchi; and secondary bronchi branch into still smaller tertiary bronchi. The smallest bronchi branch into very small tubules called bronchioles. The tiniest bronchioles end in alveolar ducts, which terminate in clusters of minuscule air sacs, called alveoli (singular, alveolus), in the lungs. The respiratory zone begins where the terminal bronchioles join a respiratory bronchiole, the smallest type of bronchiole (Figure 4), which then leads to an alveolar duct, opening into a cluster of alveoli

Lungs

The lungs are the largest organs of the respiratory tract. They are pyramid shaped, paired organs connected to the trachea, suspended within the pleural cavity of the thorax. The lungs are surrounded by two thin membranes called pleura, which secrete fluid that allows the lungs to move freely within the pleural cavity. This is necessary so the lungs can expand and contract during breathing. In Figure 4, you can see that each of the two lungs is divided into sections. These are called lobes, and they are separated from each other by connective tissues. The right lung is larger and contains three lobes. The left lung is smaller and contains only two lobes. The smaller left lung allows room for the heart, which is just left of the center of the chest.

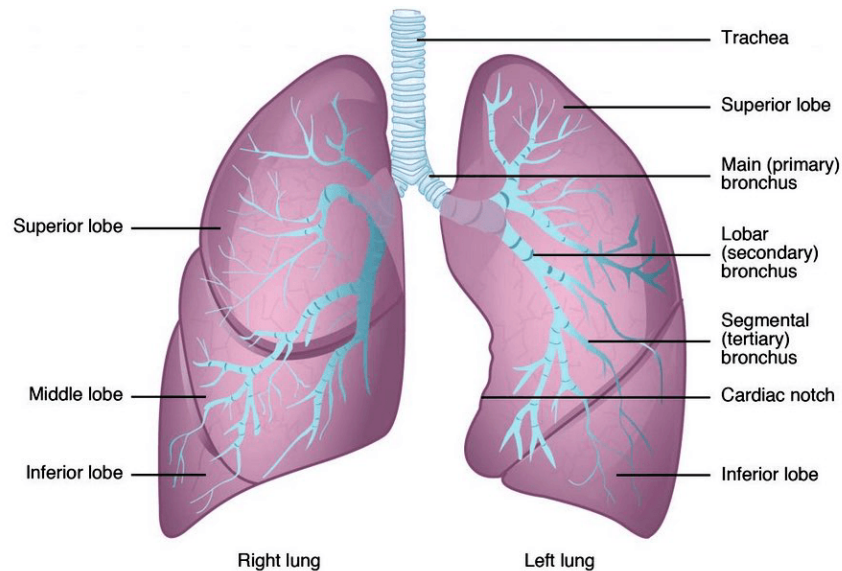


Figure 8.1.4: Human Lungs. Highlighting the right lung (with three lobes: superior, middle, and inferior) and the left lung (with two lobes: superior and inferior). Observe the branching pattern of the bronchi, including the primary, secondary, and tertiary bronchi, which progressively subdivide to deliver air to the alveoli for gas exchange. The cardiac notch, an indentation or depression on the anterior surface of the left lung, which is a space created by the heart to fit into the chest cavity. (CC BY-NC-SA 4.0; Jennifer Draper, Marie Kainoa Fialkowski Revilla, & Alan Titchenalvia [The Respiratory System](#)).

Figure 8.1.4 shows the right and left lungs with the main airway and branching bronchi.

- At the top center is the trachea, which descends and splits into the main (primary) bronchus entering each lung.
- Inside the lungs, the airway branches into a lobar (secondary) bronchus and then into smaller segmental (tertiary) bronchi.
- The right lung has three lobes. The largest is the superior lobe. Below it is the middle lobe, which is smaller in volume. Below that is the inferior lobe, which is the smallest of the three.
- The left lung has two lobes. The superior lobe comprises most of the volume. Below and to the right in this diagram we see the inferior lobe, which is much smaller. The superior lobe curves inward at the cardiac notch.

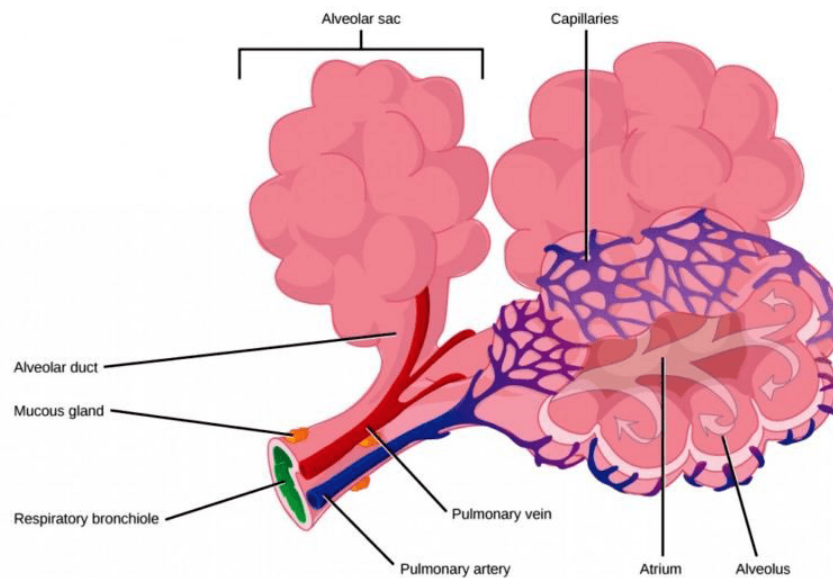


Figure 8.1.5: Terminal bronchioles are connected by respiratory bronchioles to alveolar ducts and alveolar sacs. Each alveolar sac contains 20 to 30 spherical alveoli and has the appearance of a bunch of grapes. Air flows into the atrium of the alveolar sac, then circulates into alveoli where gas exchange occurs with the capillaries. Mucous glands secrete mucous into the airways, keeping them moist and flexible. (credit: modification of work by Mariana Ruiz Villareal). (CC BY-NC-SA 4.0; Charles Molnar and Jabne Gair via [Concepts of Biology - 1st Canadian Edition](#)).

Figure 8.1.5 shows an alveolar cluster at the end of a small airway.

- A respiratory bronchiole leads into an alveolar duct.
- The alveolar duct opens into an alveolar sac, shown as a cluster of many small, rounded air spaces.
- One individual air space is labeled alveolus.
- A network of capillaries surrounds the alveoli, indicating where blood flows close to the air spaces.
- Two larger blood vessels are labeled pulmonary artery (bringing blood to the capillaries) and pulmonary vein (carrying blood away).
- An atrium (a shared open space leading into multiple alveoli) is labeled within the alveolar sac region.
- A mucous gland is labeled near the airway wall close to the bronchiole.

These tiny air sacs are the functional units of the lungs where gas exchange takes place. The two lungs may contain as many as 700 million alveoli, providing a huge total surface area for gas exchange to take place. In fact, alveoli in the two lungs provide as much surface area as half a tennis court! Each time you breathe in, the alveoli fill with air, making the lungs expand. O₂ in the air inside the alveoli is absorbed by the blood in the mesh-like network of tiny capillaries that surrounds each alveolus. The blood in these capillaries also releases CO₂ into the air inside the alveoli. Each time you breathe out, air leaves the alveoli and rushes into the outside atmosphere, carrying waste gases with it.

How Breathing Occurs

Breathing is a two-step process that includes drawing air into the lungs, or inhaling, and letting the air out of the lungs, or expiration/exhalation. Boyle's Law is fundamental to understanding respiration. Boyle's Law states that for a fixed amount of gas at a constant temperature, the pressure and volume of the gas are inversely proportional (Figure 8.1.6). This means that as the volume of the gas decreases, its pressure increases, and vice versa. The mathematical expression for Boyle's Law is $P \times V = k$ (where P is pressure, V is volume, and k is a constant) or, for two different states of the same gas, $P_1V_1 = P_2V_2$.

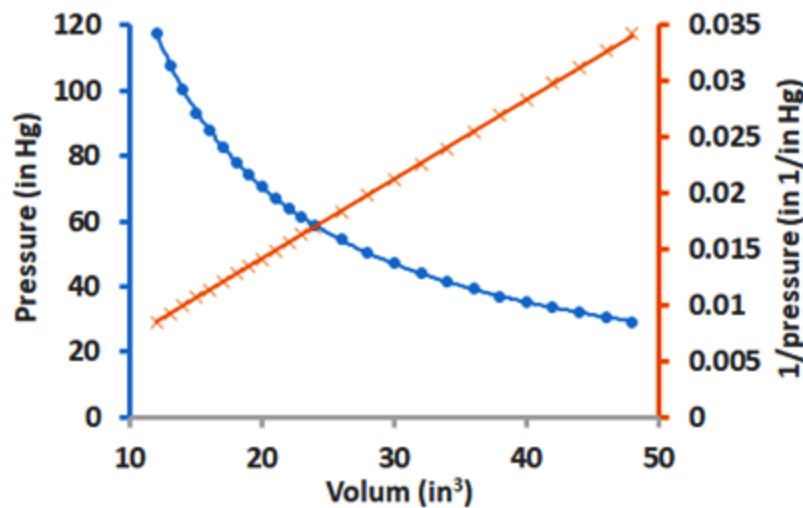


Figure 8.1.6: A Boyle's Law graph showing an inverse relationship between gas pressure and volume, meaning it will be a hyperbola with pressure (P, mmHg) on the y-axis and volume (V, in³) on the x-axis. As the volume of the gas increases, the pressure decreases, and vice versa. (Public Domain; Muhammad Arif Malik via [The pressure-volume relationship](#)).

Figure 8.1.6 shows the relationship between pressure and volume with two plotted curves and two vertical axes.

- The horizontal axis is volume (in³), ranging from about 10 to 50.
- The left vertical axis is pressure (in Hg), ranging from 0 to 120.
- A decreasing curve (blue) shows pressure dropping as volume increases: pressure is highest at low volume and steadily falls as volume rises.
- The right vertical axis is 1/pressure (in 1/in Hg), ranging from 0 to about 0.035.
- An increasing straight line (orange) shows 1/pressure rising as volume increases.
- Overall, the figure illustrates an inverse relationship between pressure and volume, and a direct relationship between volume and 1/pressure.

me of gas increases, the pressure decreases, and vice versa. This visual representation helps explain how changes in volume impact gas pressure within a closed system.

In the lungs, as the volume of the thoracic cavity increases (during inspiration), due to the contraction of the diaphragm and intercostal muscles, the pressure inside the lungs decreases. This pressure difference between the atmosphere and the lungs causes air to rush into the lungs. Conversely, as the thoracic cavity volume decreases (during expiration) due to relaxation of these muscles, the pressure inside the lungs increases, forcing air out. This continuous interplay of volume and pressure changes, governed by Boyle's Law, drives the process of ventilation, ensuring the constant exchange of gases essential for life (Figure 8.1.7).

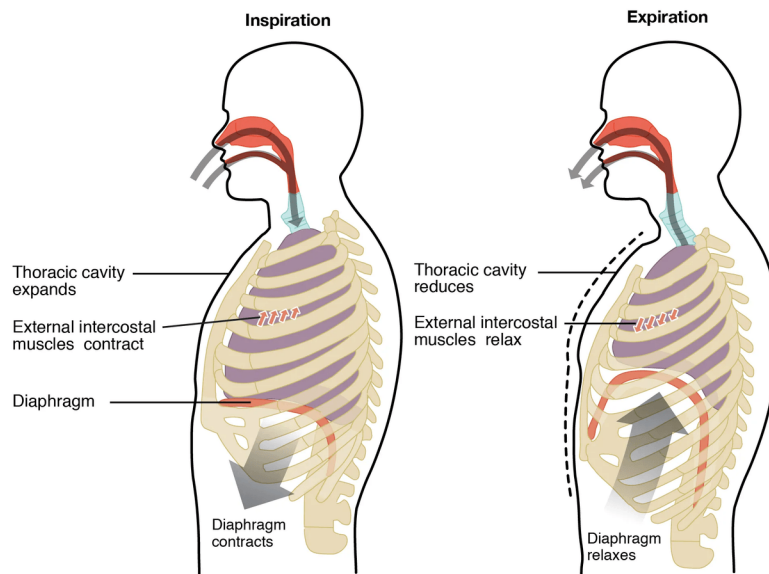


Figure 8.1.7: Normal Inspiration and Expiration. This illustration depicts the mechanics of normal breathing (inspiration and expiration). (CC BY-NC-SA 4.0; via [The Process of Breathing](#)).

Figure 8.1.7 compares inspiration (left) and expiration (right).

- Inspiration: Air moves into the airway. The thoracic cavity expands as the external intercostal muscles contract and lift the rib cage. The diaphragm contracts and moves downward, increasing chest volume.
- Expiration: Air moves out of the airway. The thoracic cavity reduces as the external intercostal muscles relax and the rib cage lowers. The diaphragm relaxes and moves upward into a dome shape, decreasing chest volume.

Control of Breathing

Breathing is one of the few vital bodily functions that can be controlled consciously as well as unconsciously. Think about using your breath to blow up a balloon. You take a long, deep breath, and then you exhale the air as forcibly as you can into the balloon. Both the inhalation and exhalation are consciously controlled.

Conscious Control of Breathing

You can control your breathing by holding your breath, slowing your breathing, or hyperventilating, which is breathing more quickly and shallowly than necessary. You can also exhale or inhale more forcefully or deeply than usual. Conscious control of breathing is common in many activities besides blowing up balloons, including swimming, speech training, singing, playing many different musical instruments, and doing yoga, to name just a few. There are limits on the conscious control of breathing. For example, it is not possible for a healthy person to voluntarily stop breathing indefinitely. Before long, there is an irrepressible urge to breathe. If you were able to stop breathing for a long enough time, you would lose consciousness. The same thing would happen if you were to hyperventilate for too long. Once you lose consciousness so you can no longer exert conscious control over your breathing, involuntary control of breathing takes over.

Spirometry: Lung volumes and Lung Capacities

Pulmonary function is tested to detect lung diseases or to monitor the progress of a disease. An instrument called a spirometer is used to measure the volume of air that moves air into and out of the lungs, and the process of taking the measurements is called spirometry. Respiratory capacity (pulmonary capacity) is the sum of two or more volumes. Factors such as age, sex, body build, and physical conditioning have an influence on lung volumes and capacities.



Figure 8.1.8: The Spirometer: A spirometer is a medical device used in a pulmonary function test to measure how much a person can move air out of their lungs. The test involves exhaling into a mouth piece attached to a dial. This provides data that helps healthcare professionals diagnose and monitor lung conditions like asthma and COPD. (CC BY-SA 4.0; Harmony Folse via [Spirometry and Lung Capacity](#)).

Figure 8.1.8 features a spirometer, a medical device prominently used in pulmonary function tests to measure the volume of air a person can exhale from their lungs. The process involves the patient exhaling into a mouthpiece connected to a dial, which records the airflow and volume. This test is crucial for healthcare professionals to diagnose and monitor lung conditions such as asthma and Chronic Obstructive Pulmonary Disease (COPD).

Spirometry tells a clinician whether the lungs are functioning within the normal range. Using the graph generated from spirometry, the clinician can make several measurements:

- Tidal volume (TV): the volume of air displaced in the lungs during normal (tidal) inhalation and exhalation. This is the amount of air exchanged by breathing under normal, or resting, conditions. Average: Adult male = 0.5 L, Adult female = 0.5 L
- Inspiratory reserve volume (IRV): the additional amount of air that can inflate the lungs after a tidal inhalation. Average: Adult male = 3.3 L, Adult female = 1.9 L
- Inspiratory capacity (IC): the total amount of air that can be inhaled into the lungs (TV+IRV). A forceful inhalation can determine the IC with spirometry. Average: Adult male = 3.8 L, Adult female = 2.4 L
- Expiratory reserve volume (ERV): the amount of air that can be forcefully exhaled from lungs after a tidal exhalation. Average: Adult male = 1.1 L, Adult female = 0.7 L
- Vital capacity (VC): the maximum amount of air that can be expelled from the lungs after a maximal inhalation. $VC = IRV + TV + ERV$ (see graph). The subject forcefully inhales and then forcefully exhales as much air as possible to determine the VC with spirometry. The vital capacity varies with height, gender and age of the subject. Average: Adult male = 4.8 L, Adult female = 3.1 L

Other important volumes or capacities that cannot be determined directly by spirometry include:

- Residual volume (RV): the amount of air left in the lungs after a forceful exhalation. This volume cannot be directly determined by spirometry because the amount cannot be expelled through the spirometer mouthpiece for measurement. This is the amount of air that always remains in the lungs, keeping the lungs from “collapsing.” Average: Adult male = 1.2 L, Adult female = 1.1 L.
- Functional residual capacity (FRC): the amount of air remaining in the lungs after a tidal exhalation. FRC is unknown in spirometry because the residual volume cannot be directly measured. Average: Adult male = 2.4 L, Adult female = 1.8 L.
- Total lung capacity (TLC): the total air capacity of the lungs. $TLC = VC + RV$. TLC is unknown in spirometry because the residual volume cannot be directly measured. Average: Adult male = 6.0 L, Adult female = 4.2 L.

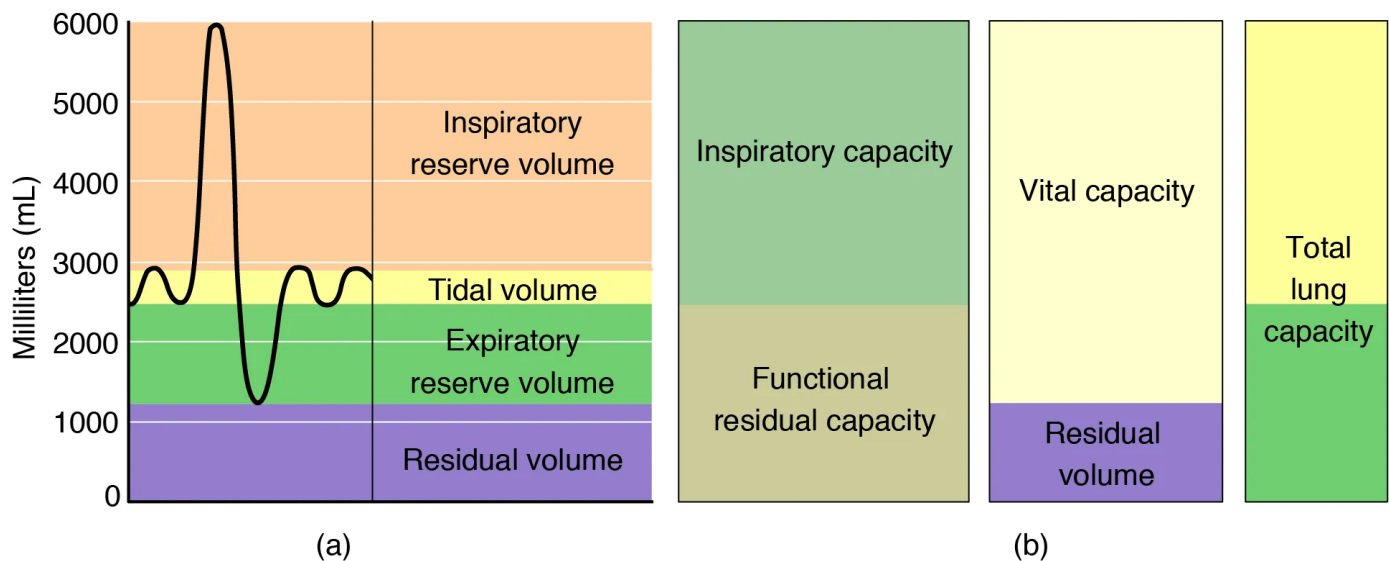


Figure 8.1.9: Respiratory Volumes and Capacities: These two graphs show (a) respiratory volumes and (b) the combination of volumes that results in respiratory capacity. (CC BY 4.0; Harmony Folsie via [Respiratory Volumes and Capacities](#)).

Figure 8.1.9 shows lung volumes and capacities using two side-by-side diagrams.

- On the left (panel a), the vertical axis represents air volume in milliliters, from 0 to about 6000 mL. A black wavy line shows normal breathing within a small range called tidal volume. Above tidal volume is inspiratory reserve volume, the extra air inhaled with a deep breath. Below tidal volume is expiratory reserve volume, the extra air exhaled after a normal exhalation. At the bottom is residual volume, the air remaining after maximal exhalation that cannot be breathed out.
- On the right (panel b), stacked blocks show how volumes combine into capacities. Inspiratory capacity equals tidal volume plus inspiratory reserve volume. Functional residual capacity equals expiratory reserve volume plus residual volume. Vital capacity equals inspiratory reserve volume plus tidal volume plus expiratory reserve volume. Total lung capacity equals vital capacity plus residual volume (all volumes combined).

These graph shows combinations such as vital capacity, inspiratory capacity, and total lung capacity, helping to understand the full spectrum of lung function.

Rate and Depth of Breathing Determine the Efficiency of Breathing

- Total pulmonary ventilation = the volume of air moved into/out of the lungs each minute. There is a formula to calculate total pulmonary ventilation, it is Respiratory Rate (breaths/min) times Tidal Volume (TV), which has the units mL/breath. This gives a measure of effectiveness of ventilation.
- Typically the resting adult Respiratory Rate (RR) is from 12-20 breaths per minute.
- Total Pulmonary Ventilation = $RR \times TV$. If $RR = 12$ breaths per minute and $TV = 500$ ml per breath, then ...Total Pulmonary Ventilation = $12 \text{ breaths/min} \times 500 \text{ ml/breath} = 6,000 \text{ ml/min}$, or 6.0 L/min

8.2: Activity 1

Reflections on the Respiratory System

The objective of this activity is to help students connect personal experiences with the function of the respiratory system by reflecting on times when their ability to breathe was affected.

Instructions

1. Take a moment to recall a time when you had a cold or another health issue that impacted breathing.
2. Write a short reflection describing your experience. Use the following prompts to guide your writing:
 - What symptoms did you experience? (e.g., cough, congestion, shortness of breath)
 - How did these symptoms affect your daily activities?
 - Did you learn anything new about your body or health from this experience?
3. Engage in a class discussion on the importance of the respiratory system and how various health issues can affect it. Consider questions like:
 - How do respiratory illnesses affect overall health?
 - What are some ways to support respiratory health?

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8.3: Activity 2

Structures of the Respiratory System

Identify and Describe Functions using a Sagittal View Model/Image.

1. Obtain a sagittal view model or image of the respiratory system numbered for identification.
2. Carefully look at the sagittal view of the respiratory system. Notice the numbered structures indicated on the model/image.
3. One by one, identify each anatomical structure corresponding to the indicated numbers.
4. For each identified structure, write a brief description of its function.
5. Use this prompt to guide your descriptions: What is the primary role of this structure in the respiratory system?

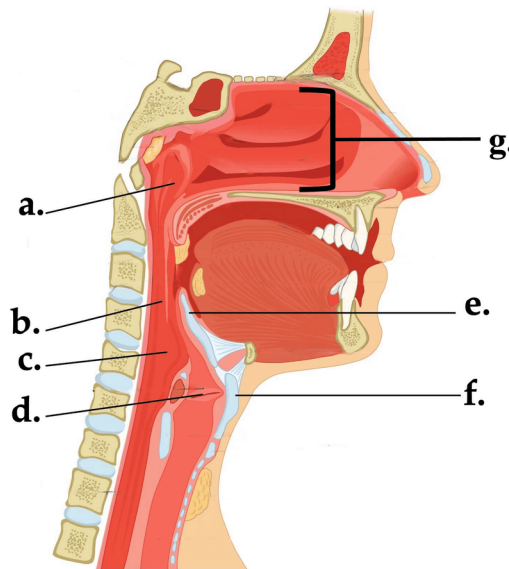


Figure 8.3.1: Sagittal diagram of head and neck showing nasopharynx, oropharynx, laryngopharynx, and more. (CC BY-NC-SA 4.0; via [Questions and Review](#)).

Figure 8.3.1 offers a sagittal view of the human respiratory system, with various components labeled by letters (a-f) for easy identification. This side-on perspective allows for a detailed understanding of the spatial arrangement and function of respiratory structures, aiding in recognizing how air flows through the system.

Structures for Identification

Match the following structures to the labeled letters in the Figure 8.3.1.

- Conchae in nasal cavity
- Nasopharynx, Oropharynx
- Thyroid cartilage
- Epiglottis of larynx
- Vocal folds of larynx
- Laryngopharynx

Table 8.3.1: Identification of labeled anatomical structures in a sagittal section of the human head and neck, with functional relationships.

Labeled Letters	Structures for Identification	Relating Structures to Functions
a		

Labeled Letters	Structures for Identification	Relating Structures to Functions
b		
c		
d		
e		
f		
g		

8.4: Activity 3

Dive Deep into the Anatomical Features of the Trachea and Lungs

Use the laboratory models to study anatomy of Trachea and Lungs. Answer following questions.

1. What are the primary anatomical features of the trachea, including the C-shaped cartilaginous rings and mucosal lining, and how do they contribute to its function in air conduction?
2. How do the different parts of the lungs, like the lobes, bronchi, and alveoli work together to help us breathe?
3. What histological characteristics of the trachea's mucosal lining are important for protecting the airway and filtering incoming air?

Case Study

Discuss the implications of structural changes on respiratory health, using specific case study.

Case Study 1 - The Smoker's Lungs: Discuss how the cilia and mucus glands in the trachea and lungs are affected by smoking, leading to chronic cough and reduced airflow.

Case Study 2 - The Pneumonia Patient: A 30-year-old patient is diagnosed with pneumonia, leading to fluid accumulation in the alveoli. Investigate how this affects gas exchange and the structural integrity of the lungs.

8.5: Activity 4

Exploring Ventilation with a Mammalian Pluck

A mammalian pluck is a preserved specimen consisting of lungs still attached to the trachea. It offers a fascinating, hands-on way to understand the process of ventilation in mammals.

Purpose of the Activity

By inflating the lungs through the trachea, you can observe how air fills the lobes, mimicking the natural breathing process. This hands-on demonstration highlights the expansion and relaxation of lung tissue. This setup vividly shows Boyle's Law in action, where changes in lung volume affect air pressure, drawing air in and out of the lungs.

Lab Activity Overview

Today we will be exploring the structures of the respiratory system interactively with the pluck.

Procedure:

1. When handling the mammalian pluck, wear disposable gloves. Aprons and goggles are also available for additional protection.
2. Examine the specimen. Describe the color, shape, size, and feel of the specimen. Is the trachea stiff or flexible? What allows the trachea to stay open and bend? Why is this important?
3. With the foot pump, inflate the lungs and observe how they respond.
 - What happened to the lungs when air was forced into them? Describe observation.
 - Do you think there is a limit to how much air can be pumped into the lungs? Explain
4. On a scale of 1 (least effective) to 5 (very effective), rate how effective the mammalian pluck interactive demonstration was in supporting your engagement and learning about the respiratory system.

Table 8.5.1: Student responses to the clarity and design of the sheep pluck lab activity using a 5-point Likert scale.

Survey Prompt (select one rating per row)	1 Least Effective	2 Slightly Effective	3 Moderately Effective	4 Effective	5 Very Effective
How clear and easy to use was the sheep pluck during the lab?					
Did the design of the sheep pluck help you visualize the key concepts of structure - function relationships?					

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8.6: Activity 5

How Breathing Occurs: Exploring with a Bell Jar Model

The bell jar balloon model is a classic hands-on demonstration to visualize how breathing works. It simulates the human respiratory system using simple materials, clearly showing how changes in pressure and volume allow air to move in and out of the lungs. This activity directly illustrates Boyle's Law: when the volume of a closed space increases, the pressure inside decreases, drawing air in—just as in real breathing.

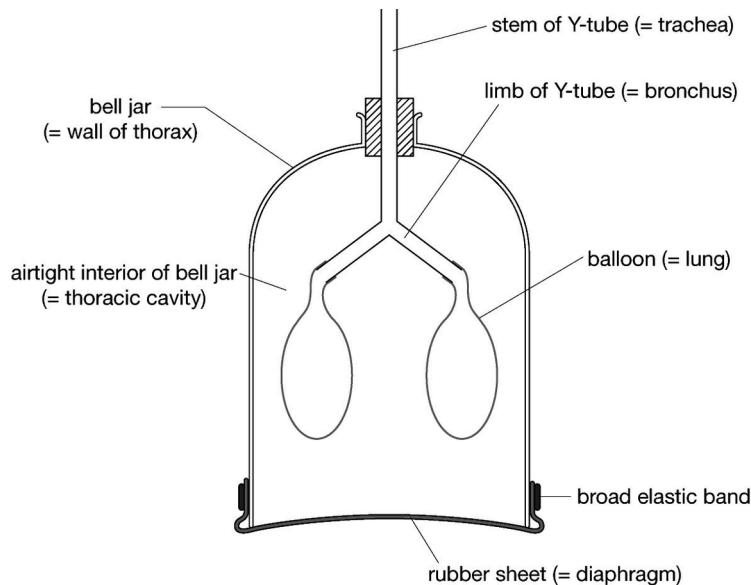


Figure 8.6.1: The Bell jar model is a simple, airtight setup that demonstrates the mechanics of human breathing based on the principles of Boyle's law. It simulates how changes in thoracic volume and pressure, driven by the diaphragm, cause air to move into and out of the lungs. (CC BY-SA 4.0; via WikiBooks).

Figure 8.6.1 showcases the Bell jar model, a straightforward, airtight setup that illustrates the mechanics of human breathing through Boyle's Law principles. The model simulates how changes in thoracic volume and pressure, influenced by diaphragm movement, result in air moving into and out of the lungs. Component Parts of the Model shown:

- Bell Jar: Represents the rib cage or chest cavity, acting as a rigid, transparent enclosure.
- Y-shaped Tube: Symbolizes the trachea (windpipe) and the two bronchi leading to the lungs, passing through an airtight stopper at the top of the bell jar.
- Two Balloons: Mimic the lungs, attached to the ends of the Y-shaped tube inside the bell jar.
- Rubber Sheet: Represents the diaphragm, stretched and sealed across the open bottom of the bell jar.

Instructions

1. What happens to the balloons when the rubber sheet is pulled down?
2. Release the rubber sheet (diaphragm). What happens to the balloons?

Review question

1. What does the model show about inhalation and exhalation?
2. Explain this observation in view of Boyle's Law.
3. What happens to the balloons when the rubber sheet is pushed up or released?
4. Explain this observation in view of Boyle's Law.

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8.7: Activity 6

Breath Holding and Oxygen Saturation: Exploring with an Oximeter

In this lab activity, you will investigate how breath-holding affects oxygen saturation levels in the blood, using a pulse oximeter. This experiment allows you to observe physiological responses to breath-holding and understand the relationship between O_2 levels, CO_2 buildup, and the body's urge to breathe.

Materials

- Pulse oximeter (to measure oxygen saturation).
- Stopwatch or timer.

Instructions

Work in pairs to investigate how breath-holding affects oxygen saturation levels in the blood, using a pulse oximeter.

- One partner will be the volunteer who holds their breath.
- The other partner will be the data recorder, monitoring and documenting the results.

Step 1: Baseline Measurement

- The volunteer should rest quietly for a few minutes to stabilize their breathing.
- Use the pulse oximeter to measure and record their baseline oxygen saturation (SpO_2) level before starting the breath-holding test.

Step 2: Breath Holding Test

- The volunteer takes a deep breath and holds it.
- Start the timer as they begin holding their breath.
- When the volunteer can no longer hold their breath, stop the timer and immediately measure their oxygen saturation using the pulse oximeter.

Safety Note: If the volunteer feels dizzy or uncomfortable at any point, they should exhale and resume normal breathing immediately.

Step 3: Record your observations in the table below:

Table 8.7.1: Oxygen saturation before and after breath-holding.

Condition	Duration (seconds)	Oxygen Saturation (%)
Baseline		
Breath-Hold		

Step 4: Analysis and Reflection

- Compare the breath-holding durations and oxygen saturation levels.
- How did oxygen saturation change during breath-holding?
- What does this indicate about the body's response to elevated carbon dioxide levels?
- What physiological changes occur when CO_2 levels rise due to breath-holding?

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8.8: Activity 7

Decoding Lung Volumes and Capacities: A Data Analysis Exercise

Human lung size is determined by genetics, gender, and height. At maximal capacity, an average lung can hold almost six liters of air, but lungs do not usually operate at maximal capacity. The air in the lungs is measured in terms of volumes and capacities.

- Lung volume measures the amount of air for one function (such as inhalation or exhalation).
- Lung capacity is any two or more volumes.

This activity will help you apply your understanding of respiratory volumes and capacities. You'll be working with data from a pulmonary function test performed on a healthy volunteer.

Scenario: A healthy volunteer undergoes a pulmonary function test, yielding the following results:

- Tidal Volume (TV): 400 ml
- Inspiratory Reserve Volume (IRV): 2800 ml
- Expiratory Reserve Volume (ERV): 1200 ml
- Residual Volume (RV): 1200 ml

Calculate Vital Capacity (VC), Inspiratory Capacity (IC), Functional Residual Capacity (FRC) and Total Lung Capacity (TLC) by computing the data provided above in the table.

Table 8.8.1: Definitions and relationships among lung volumes and capacities in human respiratory physiology.

Calculate	Value
Total Lung Capacity (TLC)	
Inspiratory Capacity (IC)	
Functional Residual Capacity (FRC)	
Inspiratory Reserve Volume (IRV)	
Tidal Volume (TV)	
Expiratory Reserve Volume (ERV)	
Residual Volume (RV)	
Vital Capacity (VC)	

Discussion Questions

1. Compare the calculated values to the typical ranges for a healthy adult (background information). Do any of the volunteer's values deviate significantly from the norm? If so, what might be some possible explanations for these deviations?
2. What factors can either positively or negatively impact respiratory health? Describe any two factors, one each for positive and negative impact.

8.9: Activity 8

Performing Spirometry in the Lab: Do It Yourself!

By focusing on personal performance, participants can connect more deeply with the learning experience, making the activity feel relevant and engaging.

Measure Tidal Volume (TV)

- Place a disposable mouthpiece over the stem of the spirometer. If the spirometer has a gap between 0 and 1000, set the dial to 1000.
- Sit upright and relax your shoulders. Breathe normally for one minute to settle your breathing.
- Pinch your nose closed and practice normal breathing through your mouth for 1–2 minutes until you feel comfortable.
- Inhale a normal breath (do not inhale through the spirometer), then purse your lips around the mouthpiece and exhale normally—do not force it out.
- Count the number of tick marks the dial moved and multiply by 100. Record this value below.

Repeat two more times.

- Trial 1: _____ mL
- Trial 2: _____ mL
- Trial 3: _____ mL

Average your measurements:

- TV: _____ mL

Minute Respiratory Volume (MRV)

The MRV represents the volume of air moving in and out of your lungs in one minute during normal quiet respiration.

- Count your normal respiratory rate (RR) for one minute. A breath includes one inhale and one exhale.
- RR: _____ (normal RR $\approx$ 12 breaths per minute)
- $MRV = RR \times TV$
- MRV: _____ mL/min

Measure Expiratory Reserve Volume (ERV)

- After three normal breaths (ending in expiration), pinch your nose and forcefully expel all remaining air into the spirometer.
- Record the value. Repeat two more times.
- Trial 1: _____ mL
- Trial 2: _____ mL
- Trial 3: _____ mL

ERV: _____ mL

Measure Vital Capacity (VC)

- After three deep breaths, take the largest, deepest breath possible.
- Pinch your nose with a nose clip, seal your lips around the mouthpiece, and exhale forcefully until your lungs feel empty. The exhalation should last at least six seconds.
- Count the tick marks and multiply by 100. Repeat two more times.
- Trial 1: _____ mL

- Trial 2: _____ mL
- Trial 3: _____ mL

VC: _____ mL

Calculate Inspiratory Capacity (IC)

- Formula: $IC = VC - ERV$
- IC: _____ mL

Calculate Inspiratory Reserve Volume (IRV)

- Formula: $IRV = IC - TV$
- IRV: _____ mL

Calculate Residual Volume (RV)

- Formula: $RV = VC \times \text{Age Factor}$
- Age Factors:
 - Age 16–34: 0.25
 - Age 35–49: 0.31
 - Age 50–69: 0.45
- RV: _____ mL

Calculate Total Lung Capacity (TLC)

- Formula: $TLC = TV + IRV + ERV + RV$
- TLC: _____ mL

Caution:

These data are for educational purposes only and should not be used to diagnose or treat any medical condition. Only a qualified healthcare professional is authorized to perform diagnostic tests and procedures. Do not attempt to self-diagnose using the laboratory data presented here.

Reflection Questions

1. What did I learn from the hands-on activity about lung volumes and capacities in respiratory health and disease?
2. What surprised me about the process?
3. How can I apply this knowledge to improve my health?
4. What questions do I still have?

Key Terms and Definitions

- **Adenoid:** Lymphatic tissue located between the back of the nasal cavity and the pharynx.
- **Allergies:** A condition in which the immune system reacts abnormally to a foreign substance.
- **Alveolar:** Pertaining to the alveoli, the small air sacs in the lungs responsible for gas exchange.
- **Alveoli:** Tiny air sacs in the lungs where the exchange of oxygen and carbon dioxide takes place.
- **Apnea:** Absence of breathing.
- **Asphyxia:** A condition caused by oxygen deprivation, leading to unconsciousness or death; suffocation.
- **Asthma:** A condition in which the airways become inflamed, narrow, and produce extra mucus, making breathing difficult.
- **Asthma Attacks:** Episodes of severe asthma symptoms such as coughing, wheezing, and shortness of breath.
- **Atelectasis:** Collapse of part or all of a lung, often due to airway blockage or external pressure.
- **Bradypnea:** Abnormally slow breathing.
- **Bronchi:** The main passageways into the lungs.
- **Bronchiolitis:** Inflammation of the bronchioles, usually caused by a viral infection; common in infants and young children.
- **Bronchioles:** Small branches of the bronchi that lead to the alveoli.
- **Bronchitis:** Inflammation of the bronchial tubes, often due to infection or environmental factors like smoking.
- **Bronchodilator:** A drug that relaxes bronchial muscles, expanding the air passages; used in conditions like asthma.
- **Bronchoscope:** A medical instrument with a light and camera used to examine the trachea, bronchi, and lungs.
- **Bronchoscopy:** A procedure using a bronchoscope to view the airways.
- **Bronchospasm:** Sudden constriction of the muscles in the bronchial walls.
- **Chest X-rays:** Imaging test using radiation to produce pictures of the chest's organs, bones, and tissues.
- **Chronic Bronchitis:** A form of bronchitis with chronic cough and mucus production for at least three months in two consecutive years.
- **Chronic Obstructive Pulmonary Disease (COPD):** A group of lung diseases that block airflow and make breathing difficult.
- **Cyanosis:** Bluish discoloration of the skin and mucous membranes due to poor oxygenation.
- **Cyanotic:** Pertaining to cyanosis; bluish or purplish skin discoloration from low oxygen levels.
- **Cystic Fibrosis:** A genetic disorder causing thick, sticky mucus that clogs airways and affects the lungs and digestive system.
- **Dysphonia:** Difficulty speaking due to voice problems.
- **Dyspnea:** Difficulty or discomfort in breathing; shortness of breath.
- **Emphysema:** A chronic lung disease involving overinflation of alveoli, reducing lung function and causing breathlessness.
- **Epiglottitis:** A flap of tissue that covers the trachea during swallowing to prevent aspiration.
- **Exhalation:** The process of breathing out air.
- **Gas Exchange:** The process in the lungs where oxygen enters the blood and carbon dioxide is removed.
- **Hemoglobin:** A protein in red blood cells that carries oxygen and returns carbon dioxide to the lungs.
- **Hypercapnia:** Excess carbon dioxide in the bloodstream, usually due to inadequate respiration.
- **Hyperpnea:** Excessively deep or rapid breathing; forced breathing.
- **Hyperventilation:** Breathing that is deeper and more rapid than normal.
- **Hypopnea:** Shallow or slow breathing.
- **Hypoventilation:** Reduced air movement into the lungs, causing increased carbon dioxide levels.
- **Hypoxemia:** Low oxygen levels in the blood.
- **Hypoxia:** Inadequate oxygen supply to the body or a specific region.
- **Influenza:** A contagious viral infection of the respiratory tract, commonly called the flu.
- **Inhalation:** The process of breathing in air.
- **Labored Breathing:** Breathing that requires more effort than normal; often a sign of distress.
- **Laryngitis:** Inflammation of the larynx, often causing hoarseness or voice loss.
- **Larynx:** The organ forming an air passage to the lungs and holding the vocal cords; also known as the voice box.
- **Lobectomy:** Surgical removal of a lobe of an organ, such as a lobe of the lung.
- **Lobes:** Divisions of the lungs; the right lung has three lobes, and the left lung has two.
- **Lung Cancer:** A type of cancer that begins in the lungs and may spread to lymph nodes or other organs.
- **Lungs:** The main organs of the respiratory system, responsible for the exchange of oxygen and carbon dioxide.
- **Mechanical Ventilator:** A machine that provides respiratory support for patients who cannot breathe effectively on their own.
- **Mucus:** A slippery secretion produced by mucous membranes for lubrication and protection.
- **Nasal Cannula:** A device used to deliver supplemental oxygen or increased airflow to a patient in need of respiratory support.
- **Nebulizer:** A device that converts medication into mist for inhalation, often used to treat asthma and other respiratory

conditions.

- **Obstructive Sleep Apnea (OSA):** A sleep disorder characterized by pauses in breathing or shallow breathing during sleep.
- **Perfusion:** The passage of fluid through the circulatory or lymphatic system to an organ or tissue.
- **Pharyngitis:** Inflammation of the pharynx, often resulting in a sore throat.
- **Pharynx:** Commonly known as the throat; located behind the mouth and nasal cavity, and above the esophagus and larynx.
- **Pleural Effusion:** Accumulation of fluid in the pleural space between the lungs and chest cavity.
- **Pneumonia:** An infection that inflames the air sacs in one or both lungs, which may fill with fluid or pus.
- **Pulmonary Arteries:** Arteries that carry blood from the right ventricle of the heart to the lungs for oxygenation.
- **Pulmonary Circulation:** The part of the circulatory system that carries blood between the heart and lungs.
- **Pulmonary Edema:** Fluid buildup in the alveoli of the lungs, often caused by heart or kidney failure.
- **Pulmonary Embolism (PE):** A blockage in a pulmonary artery, usually caused by a blood clot that travels from another part of the body.
- **Pulmonary Function Tests (PFTs):** Tests that measure how well the lungs take in and release air and move gases like oxygen.
- **Pulmonologist:** A physician specializing in diseases and disorders of the respiratory system.
- **Pulse Oximeter:** A small device that clips to a body part (usually a finger) to measure oxygen saturation in the blood.
- **Respiration:** The process of inhaling oxygen and exhaling carbon dioxide; essential for gas exchange in the lungs and tissues.
- **Respiratory Rate:** The number of breaths taken per minute.
- **Respiratory Therapists:** Health professionals who care for patients with breathing or cardiopulmonary disorders.
- **Rhinitis:** Inflammation of the nasal mucosa.
- **Septum:** The structure separating the left and right airways in the nose, dividing the nostrils.
- **Sinusitis:** Inflammation of the sinus cavities.
- **Spirometry:** A test that measures lung function by assessing how much and how quickly air is inhaled and exhaled.
- **Sputum:** Mucous secretions from the respiratory tract expelled through the mouth.
- **Sputum Culture:** A test to detect bacteria or fungi infecting the lungs or airways.
- **Stethoscope:** A medical instrument used to listen to internal sounds, especially heart and lung sounds.
- **Surfactant:** A substance that reduces surface tension in the lungs, helping stabilize the alveoli.
- **Tachypnea:** Rapid breathing.
- **Thoracic Cavity:** The body area between the neck and diaphragm that houses the lungs and heart.
- **Thoracic Surgeon:** A surgeon specializing in procedures involving the chest, including the lungs, heart, and esophagus.
- **Trachea:** The windpipe; a tube connecting the larynx to the bronchi, allowing air to enter the lungs.
- **Tracheostomy:** A surgical procedure creating an opening in the neck into the trachea for direct airway access.
- **Tuberculosis (TB):** A serious infectious disease, mainly affecting the lungs, caused by *Mycobacterium tuberculosis*.
- **Upper Respiratory Infection:** A viral infection affecting the nose, nasal cavities, sinuses, and pharynx.
- **Ventilation:** The movement of air in and out of the lungs.
- **Wheezing:** A high-pitched whistling sound during breathing, often heard during exhalation and associated with asthma or lung disease.

INDEX

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GLOSSARY

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 - 1: Nervous system Organization, Histology and Basic Physiology - [CC BY 4.0](#)
 - 1.1: From Nerve Cells to Nerve Signals - [CC BY 4.0](#)
 - 1.2: Activity 1 - [CC BY 4.0](#)
 - 1.3: Activity 2 - [CC BY 4.0](#)
 - 1.4: Activity 3 - [CC BY 4.0](#)
 - 1.5: Activity 4 - [CC BY 4.0](#)
 - 1.6: Activity 5 - [CC BY 4.0](#)
 - 1.7: Activity 6 - [CC BY 4.0](#)
 - 1.8: Activity 7 - [CC BY 4.0](#)
 - 1.9: Activity 8 - [CC BY 4.0](#)
 - 1.10: Glossary - [CC BY 4.0](#)
 - 2: Spinal Cord Anatomy - Physiology, Spinal Nerves and reflexes - [CC BY 4.0](#)
 - 2.1: Spinal Cord Anatomy - Key structures - [CC BY 4.0](#)
 - 2.2: Background Information - [CC BY 4.0](#)
 - 2.3: Activity 1 - [CC BY 4.0](#)
 - 2.4: Activity 2 - [CC BY 4.0](#)
 - 2.5: Activity 3 - [CC BY 4.0](#)
 - 2.6: Activity 4 - [CC BY 4.0](#)
 - 2.7: Activity 6 - [CC BY 4.0](#)
 - 2.8: Activity 7 - [CC BY 4.0](#)
 - 2.9: Activity 8 - [CC BY 4.0](#)
 - 2.10: Glossary - [CC BY 4.0](#)
 - 3: Brain Structure and Function- Exploring with Dissection and Cranial Nerves - [CC BY 4.0](#)
 - 3.1: Background Information - [CC BY 4.0](#)
 - 3.2: Terminology Checklist - [CC BY 4.0](#)
 - 3.3: Activity 1 - [CC BY 4.0](#)
 - 3.4: Activity 2 - [CC BY 4.0](#)
 - 3.5: Activity 3 - [CC BY 4.0](#)
 - 3.6: Activity 4 - [CC BY 4.0](#)
 - 3.7: Activity 5 - [CC BY 4.0](#)
 - 3.8: Activity 6 - [CC BY 4.0](#)
 - 3.9: Activity 7 - [CC BY 4.0](#)
 - 3.10: Activity 8 - [CC BY 4.0](#)
 - 3.11: Activity 9 - [CC BY 4.0](#)
 - 3.12: Glossary - [CC BY 4.0](#)
 - 4: Exploring General and Special Senses - [CC BY 4.0](#)
 - 4.1: Background Information - [CC BY 4.0](#)
 - 4.2: Activity 1 - [CC BY 4.0](#)
 - 4.3: Activity 2 - [CC BY 4.0](#)
 - 4.4: Activity 3 - [CC BY 4.0](#)
 - 4.5: Activity 4 - [CC BY 4.0](#)
 - 4.6: Activity 5 - [CC BY 4.0](#)
 - 4.7: Activity 6 - [CC BY 4.0](#)
 - 4.8: Activity 7 - [CC BY 4.0](#)
 - 4.9: Activity 8 - [CC BY 4.0](#)
 - 4.10: Activity 9 - [CC BY 4.0](#)
 - 4.11: Activity 10 - [CC BY 4.0](#)
 - 4.12: Activity 11 - [CC BY 4.0](#)
 - 4.13: Activity 12 - [CC BY 4.0](#)
 - 4.14: Activity 13 - [CC BY 4.0](#)
 - 4.15: Activity 14 - [CC BY 4.0](#)
 - 4.16: Activity 15 - [CC BY 4.0](#)
 - 4.17: Glossary - [CC BY 4.0](#)
 - 5: Blood Anatomy, Blood Grouping, and Hematocrit Analysis - [CC BY 4.0](#)
 - 5.1: Background Information - [CC BY 4.0](#)
 - 5.2: Activity 1 - [CC BY 4.0](#)
 - 5.3: Activity 2 - [CC BY 4.0](#)
 - 5.4: Activity 3 - [CC BY 4.0](#)
 - 5.5: Activity 4 - [CC BY 4.0](#)
 - 5.6: Activity 5 - [CC BY 4.0](#)
 - 5.7: Activity 6 - [CC BY 4.0](#)

- 5.8: Activity 7 - *CC BY 4.0*
- 5.9: Glossary - *CC BY 4.0*
- 6: Exploring the Mammalian Heart- A Hands-On Anatomy Lab - *CC BY 4.0*
 - 6.1: Background Information - *CC BY 4.0*
 - 6.2: Activity 1 - *CC BY 4.0*
 - 6.3: Activity 2 - *CC BY 4.0*
 - 6.4: Activity 3 - *CC BY 4.0*
 - 6.5: Activity 4 - *CC BY 4.0*
 - 6.6: Activity 5 - *CC BY 4.0*
 - 6.7: Activity 6 - *CC BY 4.0*
 - 6.8: Glossary - *CC BY 4.0*
- 7: Blood Vessels, Blood Pressure and ECG (Electrocardiogram) - *CC BY 4.0*
 - 7.1: Background Information - *CC BY 4.0*
 - 7.2: Activity 1 - *CC BY 4.0*
 - 7.3: Activity 2 - *CC BY 4.0*
 - 7.4: Activity 3 - *CC BY 4.0*
 - 7.5: Activity 4 - *CC BY 4.0*
 - 7.6: Activity 5 - *CC BY 4.0*
 - 7.7: Activity 6 - *CC BY 4.0*
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- 7.11: Activity 10 - *CC BY 4.0*
- 7.12: Activity 11 - *CC BY 4.0*
- 7.13: Activity 12 - *CC BY 4.0*
- 7.14: Glossary - *CC BY 4.0*
- 8: Respiratory System Anatomy and Physiology - *CC BY 4.0*
 - 8.1: Background Information - *CC BY 4.0*
 - 8.2: Activity 1 - *CC BY 4.0*
 - 8.3: Activity 2 - *CC BY 4.0*
 - 8.4: Activity 3 - *CC BY 4.0*
 - 8.5: Activity 4 - *CC BY 4.0*
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