

Integrated Human Anatomy and Physiology Lab Manual III: Metabolism, Regulation, Defense, Excretion

Lakshmikanta Sengupta and Susmita Sengupta

De Anza College

Biology

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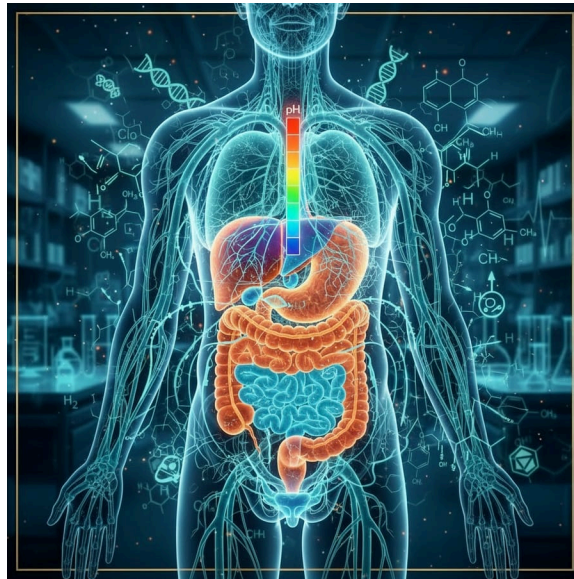


Integrated Human Anatomy and Physiology Lab

Manual III:

Metabolism, Regulation, Defense, Excretion

Digestion, Endocrine, Lymphatic and Urogenital Systems



Thumbnail: Digestive System and pH Balance. (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](#).

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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.

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- 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

This volume is written for a UC- and CSU-transferable Human Anatomy and Physiology laboratory course focused on the endocrine, lymphatic, digestive, urinary, and reproductive systems. It aligns with lower-division expectations at four-year institutions and in health-related programs by emphasizing accurate terminology, careful technique, and strong integration of structure and function.

The manual presents these body systems as essential contributors to homeostasis and as common sites of clinical concern, including endocrine disorders, immune dysfunction, gastrointestinal disease, renal impairment, and infertility. This framing helps students connect laboratory learning to authentic health and clinical contexts.

Lab activities are grounded in research on how students learn science. Students engage in frequent retrieval practice through labeling, short written explanations, and brief oral review activities. Learning tasks are intentionally sequenced so that students move from foundational identification to more complex reasoning and application. Across the manual, students are asked to:

- identify structures
- map relationships among structures and systems
- explain underlying mechanisms
- apply learning to case-based or clinical scenarios

The manual also uses visuals, models, and data displays—such as hormone profiles, lymph flow diagrams, renal clearance graphs, and urinalysis results—to present key concepts through both words and images. This approach supports comprehension by helping students connect verbal explanations with visual representations of complex processes.

Students are encouraged to work collaboratively in pairs or small groups, explain ideas to one another, and respond to brief reflection prompts. These strategies are intended to support confidence, meta cognition, communication, and a stronger sense of belonging in science learning environments.

Framework

This lab manual is structured to help the endocrine, lymphatic, digestive, urinary, and reproductive systems feel like a continuation of the earlier anatomy and physiology sequence rather than a separate body of content. Each lab intentionally revisits and connects to systems studied earlier—such as the nervous, cardiovascular, respiratory, and musculoskeletal systems—so that students continue to build an integrated understanding of how body systems interact.

Activities throughout the manual are organized around recurring physiological themes. One central theme is regulation through hormones and feedback loops. This theme is emphasized in labs on the endocrine system, metabolism, and reproductive physiology, where students trace how signaling pathways help coordinate growth, reproduction, and energy balance.

A second theme is defense, fluid balance, and transport. This theme is highlighted in labs on the lymphatic and urinary systems and in their close relationship to the circulatory system. Across the manual, structured prompts, cross-references, and integrative questions help students apply these recurring ideas to new content and build a coherent, systems-level understanding appropriate for UC- and CSU-transferable coursework.

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 supports comprehension and helps ensure that students and instructors 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 content plays an essential role in understanding structures, processes, and clinical relevance, this manual is designed to be usable by all learners.

The manual is developed to support content that is perceivable, operable, understandable, and robust across print and digital formats, including use with common assistive technologies. Instructional images and figures include meaningful alternative text that communicates the purpose of the visual. Images that are decorative rather than instructional 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 identify 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 with appropriate headers 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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Author Images	Team Bios
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	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: IMMERSIVE JOURNEY THROUGH THE DIGESTIVE SYSTEM

Introduction

In this lab, you'll delve into the digestive system's anatomy and function. This system tirelessly perform complex tasks like breaking down complex chemical to simpler forms, absorbing nutrients, and eliminating wastes in a choreographed biologic symphony. As you journey through the lab, you'll discover structural adaptations of organs of the alimentary canal, a continuous tube running from the mouth to the anus — like the stomach and intestines that facilitate digestion and absorption. Additionally, you'll explore the critical contributions of accessory organs such as the liver, gallbladder, and pancreas, highlighting their roles in secreting enzymes and bile that aid in breaking down nutrients.

Learning Objectives

- Identify each primary organ of the digestive system, such as the stomach and intestines, and clearly describe their specific functions in digestion and absorption.
- Explore and explain the roles of accessory organs like the liver, pancreas, and gallbladder, highlighting how their secretions aid in digestion.
- Describe the two sets of teeth, including the dental formula and tooth anatomy, to understand their role in mechanical digestion.
- Identify the histological features of various digestive organs, relating these structures to their specific digestive functions and understanding their roles in nutrient processing.
- Map the journey of bile from the liver to the duodenum, naming each structure along this path, and analyze the potential impact of gallstones on bile flow.

1.1: Background Information

1.2: Activity 1

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1.1: Background Information

Overview

The easiest way to understand the digestive system is to divide its organs into two main categories. The first group is the organs that make up the alimentary canal. Accessory digestive organs comprise the second group and are critical for orchestrating the breakdown of food and the assimilation of its nutrients into the body. Accessory digestive organs, despite their name, are critical to the function of the digestive system.

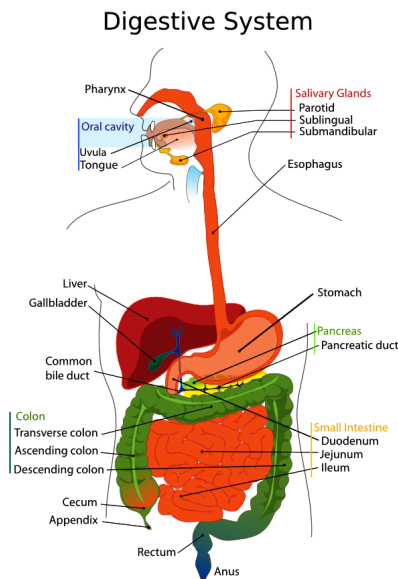


Figure 1.1.1: Labeled diagram of the human digestive system showing the full digestive tract and associated organs. (CC BY 4.0; Jason Jones via [Introduction to Digestive System](#)).

Figure 1.1.1 depicts the components of the Digestive System. The system is divided into the alimentary canal and accessory organs, each contributing uniquely to breaking down food and absorbing nutrients. Alimentary Canal consists of continuous tube, running from the mouth to the anus, includes the oral cavity, pharynx, esophagus, stomach, colon (transverse colon, ascending colon, descending colon) and both the small intestine (duodenum, jejunum, ileum). Each segment is adapted to perform specific functions, such as transporting food, breaking it down mechanically and chemically, and absorbing nutrients. The image also presents the cecum, appendix, rectum and anus. Accessory Organs: include the uvula, tongue, salivary glands (parotid, sublingual and submandibular), liver, gallbladder, common bile duct, pancreas, and pancreatic duct which secrete vital enzymes and bile into the digestive tract.

Alimentary Canal Organs

Alimentary Canal Organs also called the gastrointestinal (GI) tract or gut, the alimentary canal (aliment- = “to nourish”) is a one-way tube about 7.62 meters (25 feet) in length during life and closer to 10.67 meters (35 feet) in length when measured after death, once smooth muscle tone is lost. This tube begins at the mouth (oral cavity) and terminates at the anus. Between those two points, the canal is modified as the pharynx, esophagus, stomach, and small and large intestines to fit the functional needs of the body. Both the mouth and anus are open to the external environment; thus, food and wastes within the alimentary canal are technically considered to be outside the body. Only through the process of absorption do the nutrients in food enter into and nourish the body’s “inner space.”

Oral Cavity

The cheeks, tongue, and palate frame the mouth, which is also called the oral cavity (or buccal cavity), is the beginning of the digestive system, and is responsible for mechanical digestion, where food is broken down into smaller pieces by teeth, and

chemical digestion, where enzymes in saliva begin to break down carbohydrates. This arch is called the palate. The anterior region of the palate serves as a wall (or septum) between the oral and nasal cavities as well as a rigid shelf against which the tongue can push food. It is created by the maxillary and palatine bones of the skull and, given its bony structure, is known as the hard palate. If you run your tongue along the roof of your mouth, you'll notice that the hard palate ends in the posterior oral cavity, and the tissue becomes fleshier. This part of the palate, known as the soft palate, is composed mainly of skeletal muscle. You can therefore manipulate, subconsciously, the soft palate—for instance, to yawn, swallow, or sing.

Pharynx

The pharynx is a muscular tube that connects the mouth to the esophagus. The pharynx (throat) is involved in both digestion and respiration. It receives food and air from the mouth, and air from the nasal cavities. When food enters the pharynx, involuntary muscle contractions close off the air passageways. There are three subdivisions of the pharynx. The most superior, the nasopharynx, is involved only in breathing and speech. Nasopharynx is separated from the oral cavity by the hard and soft palate. The other two subdivisions, the oropharynx and the laryngopharynx, are used for both breathing and digestion. The oropharynx begins inferior to the nasopharynx and is continuous below with the laryngopharynx. Oropharynx is separated from the oral cavity by the uvula. The inferior border of the laryngopharynx connects to the esophagus, whereas the anterior portion connects to the larynx, allowing air to flow into the bronchial tree. Figure 1.1.2 also shows the epiglottis and glottis to signal the beginning of the larynx.

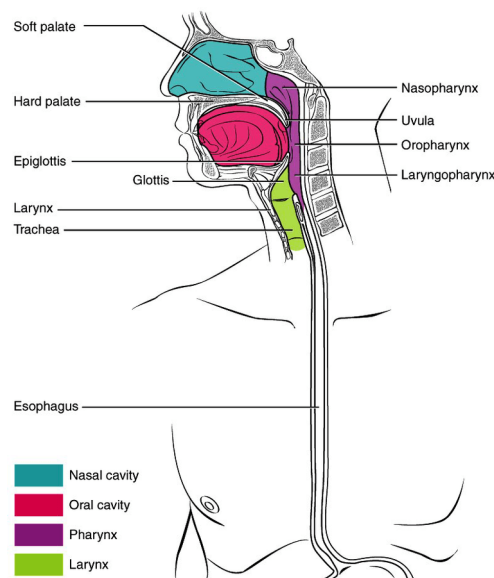


Figure 1.1.2: This diagram illustrates the human respiratory system, highlighting the nasal cavity (blue), oral cavity (red), pharynx (purple), and larynx (green). Key anatomical structures such as the soft palate, hard palate, epiglottis, glottis, larynx, trachea, esophagus, nasopharynx, uvula, oropharynx, and laryngopharynx are labeled. (CC BY 4.0; Whitney Menefee, Julie Jenks, Chiara Mazzasette, & Kim-Leiloni Nguyen via [Mouth, Pharynx, and Esophagus](#)).

Figure 1.1.2 is a side-view diagram shows the upper airway and throat structures from the nasal cavity down to the trachea.

- The roof of the mouth is labeled hard palate (front) and soft palate (back).
- Behind the nasal cavity, the upper part of the throat is labeled nasopharynx.
- Behind the mouth, the middle part of the throat is labeled oropharynx.
- Below that, the lower part of the throat is labeled laryngopharynx.
- A small projection at the back of the soft palate is labeled uvula.
- At the entrance to the airway, the epiglottis is labeled above the glottis.
- The voice box region is labeled larynx, which continues downward into the trachea (windpipe).
- A separate tube behind the airway is labeled esophagus (food pathway).

Esophagus

The esophagus is a muscular tube approximately 25.4 cm (10 in) long that connects the pharynx to the stomach, running posterior to the trachea and penetrating the diaphragm through the esophageal hiatus to enter the abdomen. It features two sphincters:

the upper esophageal sphincter, controlling food entry from the pharynx, and the lower esophageal sphincter, which manages food passage into the stomach while preventing acid reflux. Food travels through the esophagus via peristalsis, rhythmic muscle contractions that propel the food bolus toward the stomach. The esophageal mucosa secretes lubricating fluids to ease this passage. The lower esophageal sphincter, aided by the muscular diaphragm, opens to allow food into the stomach and closes to prevent acid reflux. Incomplete closure of this sphincter can lead to heartburn or gastroesophageal reflux disease (GERD).

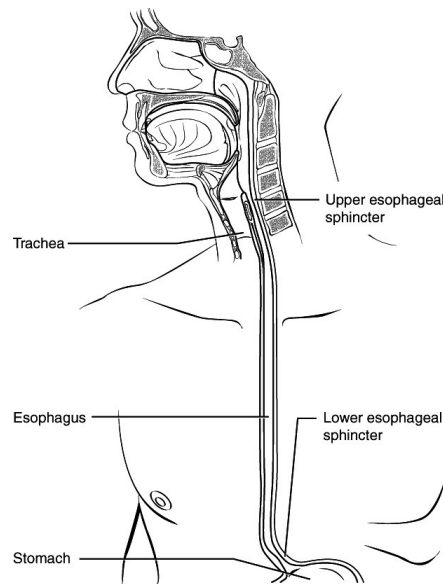


Figure 1.1.3: Esophagus. The upper esophageal sphincter controls the movement of food from the pharynx to the esophagus. The lower esophageal sphincter controls the movement of food from the esophagus to the stomach. (CC BY 4.0; Whitney Menefee, Julie Jenks, Chiara Mazzasette, & Kim-Leiloni Nguyen via [Mouth, Pharynx, and Esophagus](#)).

Figure 1.1.3 provides a comprehensive view of the esophagus and its relationship with nearby structures. It highlights how the trachea and esophagus run parallel through the neck and thoracic cavity, with the esophagus positioned posterior to the trachea. The Upper Esophageal Sphincter, located at the junction of the pharynx and esophagus, controls the entry of food into the esophagus and prevents air from entering the digestive tract during respiration. The Lower Esophageal Sphincter, located at the junction of the esophagus and stomach, opens to allow food into the stomach. The stomach is the destination for food after it passes through the lower esophageal sphincter, where digestion intensifies.

Stomach

The stomach is located in the upper abdomen, primarily in the left upper quadrant. It is a highly distensible, J-shaped organ that connects the esophagus to the duodenum of the small intestine. For both macroscopic and microscopic observation, the stomach is divided into four main regions:

- **Cardia:** The first part of the stomach, where the esophagus empties its contents.
- **Fundus:** The dome-shaped, superior region of the stomach that expands and fills with air when food is ingested.
- **Body:** The main, central section of the stomach where most chemical digestion occurs.
- **Pylorus:** The lower, funnel-shaped region that connects the stomach to the duodenum. It includes the antrum and the pyloric sphincter.

The convex lateral border is the greater curvature, and the concave medial border is the lesser curvature. The entry and exit of the stomach are regulated by two muscular sphincters:

- **Cardiac sphincter:** Located at the junction of the esophagus and cardia.
- **Pyloric sphincter:** A powerful ring of smooth muscle that controls the flow of chyme into the duodenum.

The inner surface of the stomach is not smooth but is thrown into large folds called rugae, which allow the stomach to expand significantly to accommodate a meal. The stomach wall is composed of four distinct layers, which is a common feature of the GI tract:

1. **Mucosa:** The innermost layer, consisting of a simple columnar epithelium. This layer contains numerous gastric pits, which

- lead to deeper gastric glands.
2. Submucosa: A layer of dense connective tissue containing blood vessels, lymphatic vessels, and nerves.
3. Muscularis externa: This layer is unique to the stomach because it has three layers of smooth muscle: an inner oblique layer, a middle circular layer, and an outer longitudinal layer. This extra oblique layer allows for the churning motion that mechanically breaks down food.
4. Serosa: The outermost layer, which is a serous membrane continuous with the peritoneum.

The stomach performs several key functions in the digestive process:

- The stomach's ability to stretch and relax allows it to serve as a storage reservoir for food, releasing small, manageable amounts into the small intestine over several hours.
- The three muscular layers of the muscularis externa vigorously churn and mix the food bolus with gastric juices.
- The acidic environment and the enzyme pepsin begin the breakdown of proteins into smaller peptides. Gastric lipase initiates the digestion of some triglycerides (fats).

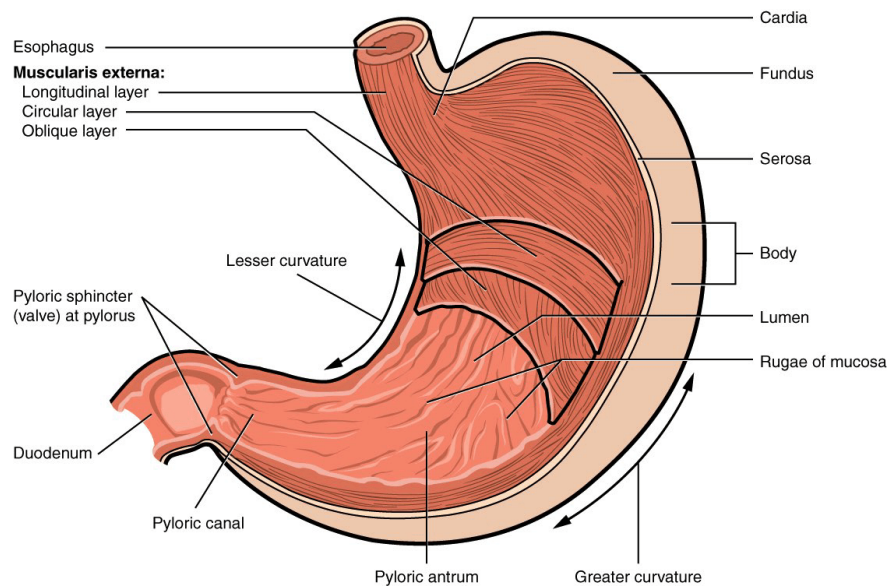


Figure 1.1.4: Stomach. The stomach has four major regions: the cardia, fundus, body, and pylorus. The addition of an inner oblique smooth muscle layer gives the muscularis the ability to vigorously churn and mix food. (CC BY 4.0; Whitney Menefee, Julie Jenks, Chiara Mazzasette, & Kim-Leiloni Nguyen via [Stomach](#)).

Figure 1.1.4 is a labeled cross-sectional diagram of the human stomach. It shows the esophagus entering at the top, leading into the cardia and fundus. The body contains rugae, or folds, in the mucosal lining. The pyloric antrum leads to the pyloric canal and then to the duodenum. The muscularis externa is shown with three layers: longitudinal, circular, and an inner oblique layer. This inner oblique smooth muscle layer enhances the stomach's ability to churn and mix food, aiding digestion. The diagram also labels the lesser and greater curvatures along the outer edges of the stomach.

Small Intestine

The small intestine as depicted in Figure 1.1.1 is where most of the digestion and absorption of nutrients takes place. It consists of three segments, each with specialized functions:

- As the first segment, approximately 25 cm long, the duodenum receives partially digested food from the stomach, along with digestive enzymes from the pancreas and bile from the liver. Its surface is covered with folds and projections known as villi and microvilli, significantly enhancing its surface area for efficient nutrient absorption.
- Stretching about 2.5 meters, the jejunum is where most nutrient absorption occurs, including carbohydrates, proteins, and fats. Like the duodenum, it has numerous folds and villi to maximize its absorptive surface area.
- Ileum, the final segment, approximately 3.5 meters long, absorbs remaining nutrients such as vitamin B12 and electrolytes. It also contributes to immune function through Peyer's patches, clusters of lymphatic tissue that help defend against harmful bacteria.

Mesentery

The mesentery is a double-layered fold of peritoneum that suspends and anchors the small intestine in the abdominal cavity. It provides support, allows movement, and houses blood vessels, lymphatics, and nerves that supply the intestines.

Ileocecal Valve

A sphincter muscle located at the junction between the ileum and cecum, which prevents the backflow of fecal matter from the large intestine into the small intestine.

Large Intestine

The large intestine, also known as the colon, is shorter and wider than the small intestine, measuring about 5 feet (1.5 meters) in length and is responsible for the absorption of water and electrolytes from undigested food and the formation of feces. The large intestine. It is subdivided into the cecum, colon, rectum, and anal canal.

- Cecum: The first part of the large intestine is a pouch-like structure that connects to the small intestine via the ileocecal valve. The appendix, a small, worm-like tube, is attached to the cecum.
- Colon: The longest section of the large intestine, the colon has four parts:
 - Ascending colon: Travels upward on the right side of the abdomen.
 - Transverse colon: Extends across the abdomen, from right to left.
 - Descending colon: Travels down the left side of the abdomen.
 - Sigmoid colon: An S-shaped final curve that leads to the rectum.
- Rectum: The final, straight section of the large intestine that stores feces temporarily.
- Anal Canal: The short, terminal portion of the large intestine that ends at the anus. It is controlled by involuntary smooth muscle internal anal sphincter and voluntary skeletal muscle external anal sphincter.

Accessory Digestive Organs and Structures

Accessory organs and structures in the digestive system, beyond the main tract, include the teeth, tongue, and salivary glands, which work to prepare food for swallowing by tearing, grinding, mixing, and lubricating it. The salivary glands, liver, gallbladder, and pancreas—are essential for chemical digestion and nutrient absorption.

Teeth

During the course of your lifetime, you have two sets of teeth (one set of teeth is a dentition). Your 20 deciduous teeth, or baby teeth, first begin to appear at about 6 months of age. Between approximately age 6 and 12, these teeth are replaced by 32 permanent teeth. Human teeth are composed of several layers, each serving a specific purpose. The enamel, the hardest substance in the body, covers the outer surface, protecting the softer dentin beneath. Within the dentin lies the pulp cavity, housing nerves and blood vessels that keep the tooth vital. The root anchors the tooth to the jawbone through the periodontal ligament, providing stability and support.

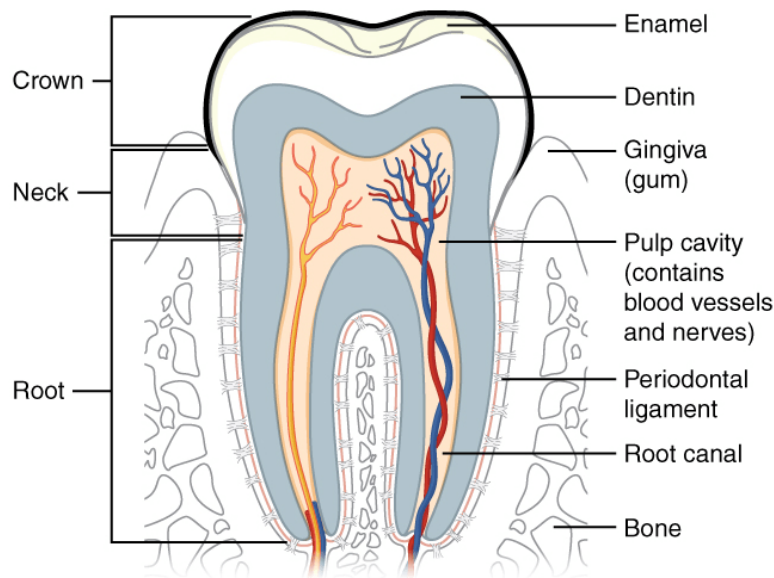


Figure 1.1.5: The Structure of the Tooth. This longitudinal section through a molar in its alveolar socket shows the relationships between enamel, dentin, and pulp. (CC BY 4.0; Whitney Menefee, Julie Jenks, Chiara Mazzasette, & Kim-Leiloni Nguyen via [Mouth, Pharynx, and Esophagus](#)).

Figure 1.1.5 depicts the internal structure of a tooth, including the gingiva, root canal, and periodontal ligaments.

- **Enamel:** The outermost layer and the hardest, most mineralized substance in the human body. It protects the crown of the tooth above the gum line from decay and wear.
- **Dentin:** Located beneath the enamel, dentin is a porous, slightly softer layer that supports the enamel and contributes to the tooth's strength and flexibility.
- **Pulp:** Found at the center of the tooth, the pulp contains nerves and blood vessels. It occupies the pulp chamber and extends into the root canals, providing nourishment and sensory function.

Teeth play a critical role in mechanical digestion. They tear, grind, and break down food into smaller pieces, making it easier to swallow and increasing the surface area for digestive enzymes to work on. This mechanical process is essential for efficient nutrient absorption later in the digestive tract. Moving from the center of the mouth toward the side, these are as follows:

- **Incisors:** The eight incisors (four upper and four lower) are the sharp front teeth designed for biting into food.
- **Canines:** Positioned next to the incisors, the four canines, or cuspids, have pointed edges ideal for tearing and piercing tough or fleshy foods.
- **Premolars:** The eight premolars, or bicuspid, are located behind the canines. They have a flatter shape with rounded cusps, perfect for mashing food.
- **Molars:** The twelve molars are the largest teeth, featuring several pointed cusps for crushing food, preparing it for swallowing. This group includes the wisdom teeth, the third molars, which often erupt in early adulthood or remain impacted, sometimes requiring removal.

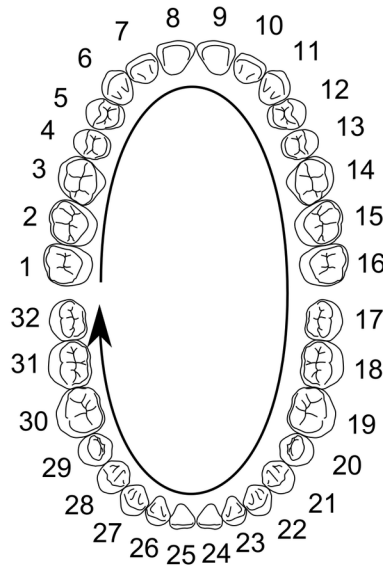


Figure 1.1.6: Dental chart showing teeth 1 to 32. (CC BY-SA 3.0; via Wikimedia Commons).

Figure 1.1.6 shows a top-down view of the dental arch with each tooth position numbered.

- Numbers 1 through 16 label tooth positions along the upper arch from one back molar area, around the front teeth, to the opposite back molar area.
- Numbers 17 through 32 continue the numbering around the lower arch, returning to the starting side.
- An arrow indicates the direction the numbering progresses around the mouth, moving from the back teeth toward the front teeth and then around to the opposite side.

The dental formula for adults is expressed as 2-1-2-3, indicating two incisors, one canine, two premolars, and three molars in each quadrant of the mouth. In children, the formula is 2-1-0-2, reflecting the absence of premolars in the primary dentition. This formula helps in identifying and categorizing different types of teeth and their respective functions.

Tongue

The human tongue is a highly flexible, muscular organ made up of both intrinsic muscles (which alter its shape by lengthening, shortening, curling, and flattening) and extrinsic muscles (which move the tongue within the mouth). Its surface is covered with papillae, small bumps that house taste buds for detecting sweet, salty, sour, bitter, and umami flavors, and also provide touch sensitivity. The tongue is divided into the tip, body, and root—with the tip and sides being the most movable, and the root anchoring the tongue to the floor of the mouth. The tongue positions food for chewing and swallowing, mixes it with saliva, and helps form a bolus for safe swallowing.

Salivary Glands

Outside the oral mucosa are three pairs of major salivary glands, which secrete the majority of saliva into ducts that open into the mouth. These exocrine glands are constantly secreting saliva, either directly into the oral cavity or indirectly through ducts.

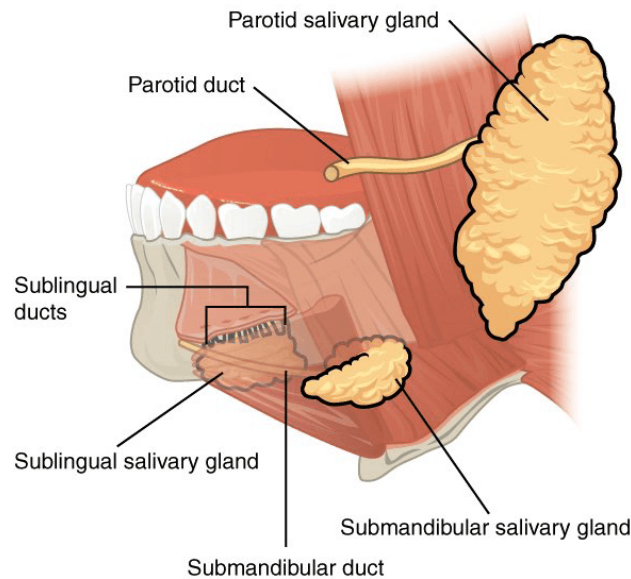


Figure 1.1.7: Anatomical illustration of the oral cavity highlighting the three major salivary glands—parotid, submandibular, and sublingual—along with their respective ducts. (CC BY 4.0; via Wikiversity).

Figure 1.1.7 shows the major salivary glands and their ducts.

- The parotid salivary gland is shown near the side of the face, with the parotid duct extending forward into the mouth.
- The submandibular salivary gland is shown beneath the jaw, with the submandibular duct running into the floor of the mouth.
- The sublingual salivary gland is shown under the tongue area, with multiple sublingual ducts opening into the floor of the mouth.

Peritoneum

The peritoneum is a crucial serous membrane in the abdominopelvic cavity, consisting of two main layers. The parietal peritoneum lines the abdominal and pelvic walls, while the visceral peritoneum wraps around the abdominal organs. Between these layers lies the peritoneal cavity, a potential space filled with lubricating serous fluid that reduces friction between organs. The peritoneum's relationship with abdominal organs helps classify them into two categories:

- **Intraperitoneal Organs:** These are located within the peritoneal cavity and are almost completely enveloped by visceral peritoneum, like the stomach, spleen, and liver.
- **Retroperitoneal Organs:** Positioned outside the peritoneal cavity, these organs, such as the kidneys and pancreas, are only covered by peritoneum on their anterior surface.

The peritoneum also forms various folds that support and connect organs:

- **Mesentery:** A double layer of peritoneum that attaches the intestines to the abdominal wall, providing stability and a conduit for blood vessels and nerves.
- **Omenta:** Double-layered folds, including the greater omentum, which drapes over the intestines, and the lesser omentum, connecting the stomach to the liver.

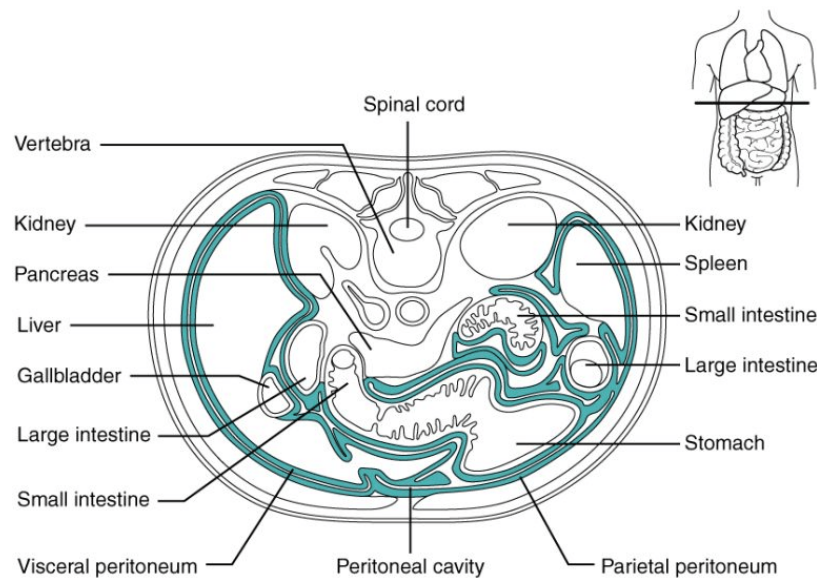


Figure 1.1.8: Detailed abdominal cross-section illustrating major organs and the two layers of the peritoneum. (CC BY 4.0; via [Endocrine & Digestive System](#)).

Figure 1.1.8 is a cross-sectional view through the abdomen showing the peritoneum and the peritoneal cavity in relation to abdominal organs.

- The outer body wall is shown as a thick boundary around the section. A vertebra and the spinal cord are located toward the back of the section.
- The thin membrane lining the inside of the body wall is the parietal peritoneum.
- The thin membrane covering the surfaces of the abdominal organs is the visceral peritoneum.
- The peritoneal cavity is the fluid-filled space between the parietal and visceral layers. The liver, gallbladder, stomach, pancreas, spleen, kidneys, small intestine, and large intestine lie within this cavity.
- The liver and gallbladder are not fully enveloped by the visceral peritoneum.

Liver

The liver, the largest gland in the body, weighs about three pounds in adults and is located in the right upper quadrant of the abdominal cavity, just below the diaphragm. This vital organ is protected by the ribs and is divided into a large right lobe and a smaller left lobe, with additional subdivisions identified as the quadrate and caudate lobes. It is anchored to the abdominal wall and diaphragm by ligaments.

The porta hepatis, often referred to as the "gate to the liver," is a key site where the hepatic artery and hepatic portal vein enter the liver, alongside the common hepatic duct. The common hepatic duct plays an essential role in transporting bile, a substance secreted by hepatocytes to emulsify fats in the small intestine. On average, the liver produces about one liter of bile daily, underscoring its critical function in digestion.

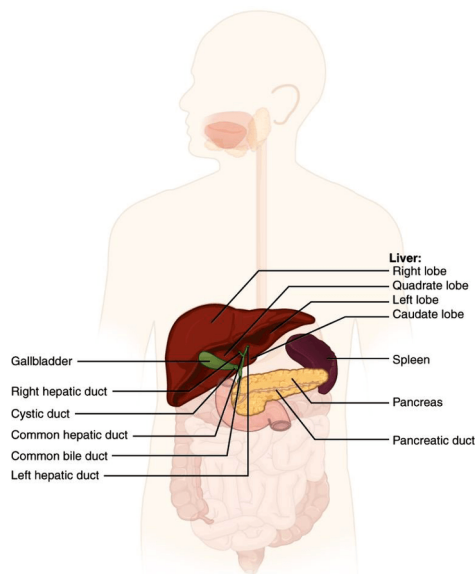


Figure 1.1.9: Detailed illustration of the hepatobiliary system and its connection to the pancreas and spleen within the digestive tract. (CC BY 4.0; via [Endocrine & Digestive System](#)).

Figure 1.1.9 shows the liver, gallbladder, pancreas, spleen, and the major bile and pancreatic ducts.

- The liver is shown in the upper right abdomen and is labeled by lobes: right lobe, left lobe, quadrate lobe, and caudate lobe.
- A small sac under the liver is labeled the gallbladder.
- Bile drainage pathways are labeled:
 - Right hepatic duct and left hepatic duct drain bile from the liver.
 - These join to form the common hepatic duct.
 - The cystic duct connects the gallbladder to the common hepatic duct.
 - The common bile duct carries bile downward toward the small intestine.
- The pancreas is shown below the liver, and the pancreatic duct is labeled running through it.
- The spleen is labeled on the upper left side of the abdomen.

Gallbladder

The gallbladder is 8 to 10 cm (approximately 3 to 4 in) long and is nested in a shallow area on the posterior aspect of the right lobe of the liver. This muscular sac stores, concentrates, and, when stimulated, propels the bile into the duodenum via the common bile duct. It is divided into three regions. The fundus is the widest portion and tapers medially into the body, which in turn narrows to become the neck.

The neck angles slightly superiorly as it approaches the hepatic duct. The cystic duct is 1 to 2 cm (less than 1 in) long and turns inferiorly as it bridges the neck and hepatic duct. The simple columnar epithelium of the gallbladder mucosa is organized in rugae, similar to those of the stomach. The gallbladder has a layer of smooth muscle fibers, which, when they contract, eject the gallbladder's contents through the cystic duct and into the common bile duct. Visceral peritoneum reflected from the liver capsule holds the gallbladder against the liver and forms the outer coat of the gallbladder. The gallbladder's mucosa absorbs water and ions from bile, concentrating it by up to 10-fold.

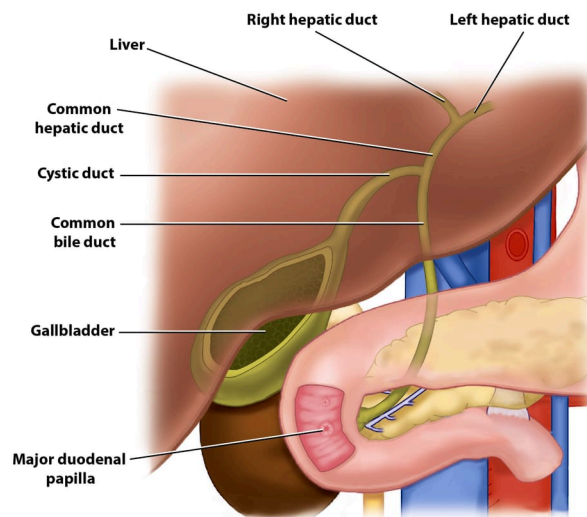


Figure 1.1.10: Illustration of the biliary system detailing hepatic ducts, cystic duct, common bile duct, and their connection to the duodenum. (CC BY-NC-SA 4.0; Jennifer Lange et al. via [Accessory Organs in Digestion- Liver, Pancreas, and Gallbladder](#)).

Figure 1.1.10 shows the gallbladder and its connection to the liver and digestive tract through a network of ducts. The right and left hepatic ducts merge to form the common hepatic duct, which joins the cystic duct from the gallbladder to create the common bile duct. This duct carries bile to the major duodenal papilla in the small intestine, aiding digestion.

Pancreas

The soft, oblong, glandular pancreas lies transversely in the retroperitoneum behind the stomach. Its head is nestled into the “c-shaped” curvature of the duodenum with the body extending to the left about 15.2 cm (6 in) and ending as a tapering tail in the hilum of the spleen. It is a curious mix of exocrine (secreting digestive enzymes) and endocrine (releasing hormones into the blood) functions.

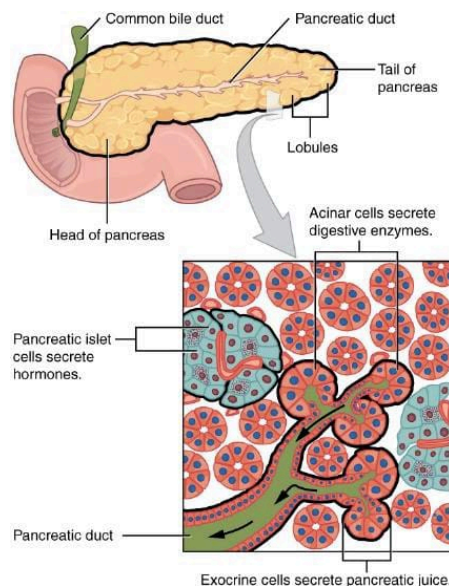


Figure 1.1.11: Illustration of pancreatic anatomy and histology, highlighting endocrine and exocrine functions within the digestive system. (CK-12; Suzanne Wakim & Mandeep Grewal via [Pancreas](#).)

Figure 1.1.11 shows the head and tail of the pancreas, its lobules, and ducts. The inset highlights two cell types: pancreatic islet cells, which secrete endocrine hormones like insulin and glucagon to regulate blood sugar, and acinar cells, which produce digestive enzymes and bicarbonate. These exocrine substances flow into the pancreatic ducts and aid digestion by breaking down

carbohydrates, proteins, and fats in the small intestine. This figure emphasizes the pancreas' dual role in endocrine and exocrine functions.

The exocrine part of the pancreas arises as little grape-like cell clusters, each called an acinus (plural = acini), located at the terminal ends of pancreatic ducts. These acinar cells secrete enzyme-rich pancreatic juice into tiny merging ducts that form two dominant ducts. The larger pancreatic duct fuses with the common bile duct (carrying bile from the liver and gallbladder) just before entering the duodenum via a common opening (the hepatopancreatic ampulla). The smooth muscle sphincter of the hepatopancreatic ampulla controls the release of pancreatic juice and bile into the small intestine. The pancreas produces over a liter of pancreatic juice each day, composed mostly of water along with some salts, sodium bicarbonate, and several digestive enzymes. Sodium bicarbonate is responsible for the slight alkalinity of pancreatic juice (pH 7.1 to 8.2), which serves to buffer the acidic gastric juice in chyme, inactivate pepsin from the stomach, and create an optimal environment for the activity of pH-sensitive digestive enzymes in the small intestine. Pancreatic enzymes are active in the digestion of sugars, proteins, and fats.

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1.2: Activity 1

GI Match-and-Map Lab Activity

The objective is to connect each part of the gastrointestinal (GI) tract to what it does. This interactive matching + mapping lab builds anatomy recognition and physiology understanding in one go. Visualize the one-way flow of food and why each segment matters.

Materials

- Full size digestive system 3D laboratory model

Instructions

- Match each lettered GI part in Column A to the correct numbered description in Column B.
- Read all items first on how to complete:
 - Do not assume same-row items are related—Columns A and B are independent lists.
 - In the “Match” column, write the pair (e.g., A-14) or just the number that matches the letter in that row.
 - Review as a team.

Table 1.2.1: Summary of gastrointestinal (GI) parts and their primary functions.

Column A (letters = GI parts)	Column B (numbers = descriptions)	Match (B number for the letter on this row) A
A. Mouth (oral cavity)	1. Start of carbohydrate digestion by amylase	
B. Teeth	2. Mechanical breakdown and bolus formation	
C. Tongue	3. Taste and lingual lipase release	
D. Oropharynx	4. Shared food/air pathway during swallowing reflex	
E. Laryngopharynx	5. Pathway just before entry into the esophagus	
F. Upper esophageal sphincter (UES)	6. Skeletal muscle ring that opens to start swallowing	
G. Esophagus	7. Place where peristalsis begins after swallowing	
H. Lower esophageal sphincter (LES, cardiac sphincter)	8. Valve that prevents acid reflux into the esophagus	

Column A (letters = GI parts)	Column B (numbers = descriptions)	Match (B number for the letter on this row) A
I. Stomach: cardia	9. Entry region of the stomach near the LES	
J. Stomach: fundus	10. Gas-collecting “dome” of the stomach	
K. Stomach: body	11. Main churning and mixing region with rugae	
L. Stomach: pylorus (antrum)	12. Grinding/emptying region of the stomach	
M. Pyloric sphincter (pyloric orifice)	13. Exit opening of the stomach; regulates chyme release	
N. Duodenum	14. First 12 inches of the small intestine; receives bile and pancreatic juice	
O. Major duodenal papilla	15. Site where bile and pancreatic ducts enter	
P. Jejunum	16. Primary site of digestion and most nutrient absorption	
Q. Ileum	17. Site of vitamin B12 and bile salt reabsorption; Peyer’s patches	
R. Ileocecal valve	18. Flap/one-way gate between small and large intestine	
S. Cecum	19. Blind pouch at the start of the large intestine	

1.3: Activity 2

Measuring the Length of the GI Tract

This quick, hands-on lab helps students connect body size to GI anatomy using simple body-based estimates. You'll take a few easy measurements on yourself (or a partner), convert to centimeters, and compare your "student data" to a class reference. These are rough, educational estimates—not clinical measurements.

Instructions

- Work in pairs with a flexible tape measure and calculator (or phone).
- Use gentle, surface measurements only—no pressing. Be respectful and mindful of personal space.
- Record values in centimeters (cm). If you measure in inches, multiply by 2.54 to convert.
- Compute the total length at the bottom, then convert to meters (divide by 100).

Table 1.3.1: GI tract lengths with measurement instructions and reference values.

GI Tract organs/parts with instructions to measure	Student Data Length (cm)	Reference Length (cm)
Mouth = oral Cavity from front of your lips to the back of your jaw along your cheek		10
Esophagus from the back of your jaw to just below your rib cage		38
Stomach Find the length of the stomach by spreading the fingers of your hand and measuring the span from the thumb to the little finger		18
Small Intestine Measure your height in inches and multiply it by four		650
Large Intestine It is about as tall as you are		163
Total Length		879 = 8.8 m

Reflection Prompts

1. What surprised you most in today's activity?
 - Expected: What did you think would happen?
 - Observed: What actually happened (include one number or fact)?
 - Why: What mechanism or assumption explains the gap?
2. Extension idea (optional): graph class heights vs estimated small intestine length—look for a trend.

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1.4: Activity 3

Estimating Small Intestine Absorbing Surface Area

Your small intestine is a master of absorption thanks to folds at multiple scales. In this activity, you'll estimate how much surface area you have for nutrient uptake using a simplified "tube surface area" model, then scale it up for large folds and villi. These are educational estimates, not clinical measurements.

What you Need

- Your small intestine length (from your earlier activity).
- Calculator

Let's calculate the surface area of your small intestine!

Key idea and simplified formula

- Lateral surface area of a tube: $2 \times \pi \times \text{radius} \times \text{length}$
- For this lab we simplify: $\pi \approx 3$ and radius ≈ 2 cm
- So, Surface Area (SA) $\approx 2 \times 3 \times 2 \times \text{length} = 12 \times \text{length}$
- Units: if length is in cm, SA is in cm^2 ; to convert to m^2 , divide by 10,000

Step-by-Step Instructions

1. Base surface (smooth tube)
 - Write your small intestine length L (cm): _____
 - $\text{SA0} = 12 \times L \text{ (cm}^2\text{)} = \text{_____}$
 - Convert SA0 to m^2 : $\text{SA0}_{\text{m}^2} = \text{SA0} \div 10,000 = \text{_____}$
2. Add large folds (plicae circulares) $\rightarrow 3\times$ increase
 - i. $\text{SA1} = 3 \times \text{SA0 (cm}^2\text{)} = \text{_____}$
 - ii. $\text{SA1}_{\text{m}^2} = \text{SA1} \div 10,000 = \text{_____}$
3. Add microscopic folds (villi) $\rightarrow$ additional $10\times$ increase
 - i. $\text{SA2} = 10 \times \text{SA1 (cm}^2\text{)} = \text{_____}$
 - ii. $\text{SA2}_{\text{m}^2} = \text{SA2} \div 10,000 = \text{_____}$
 - iii. Shortcut: $\text{SA2} = 360 \times L$ (because $12 \times 3 \times 10 = 360$)

Quick Example using the Reference Length (L = 650 cm)

- i. $\text{SA0} = 12 \times 650 = 7,800 \text{ cm}^2 = 0.78 \text{ m}^2$
- ii. $\text{SA1} = 3 \times 7,800 = 23,400 \text{ cm}^2 = 2.34 \text{ m}^2$
- iii. $\text{SA2} = 10 \times 23,400 = 234,000 \text{ cm}^2 = 23.4 \text{ m}^2$

Student Worksheet Fields (fill these)

- i. L (your small intestine length, cm): _____
- ii. SA0 (smooth tube), cm^2 and m^2 : _____ $\text{cm}^2 = \text{_____ m}^2$
- iii. SA1 (with large folds), cm^2 and m^2 : _____ $\text{cm}^2 = \text{_____ m}^2$
- iv. SA2 (with villi), cm^2 and m^2 : _____ $\text{cm}^2 = \text{_____ m}^2$

Think and Discuss

- i. Why does surface area, not just length, matter for absorption?
- ii. If two people have the same L but different radii, how does that change SA_0 ?

1.5: Activity 4

Two-Station Histology Sprint

Students rotate between two lab stations—1) Esophagus and 2) Stomach—to observe, photograph, and compare the four basic layers of the GI tract: mucosa, submucosa, muscularis externa, and adventitia/serosa. The goal is to link “what you see” to “what it does” and produce a concise comparison write-up.

Learning Goals

- Identify and label the four layers in esophagus and stomach.
- Note at least two unique features per organ that support its function.
- Create a short, evidence-based comparison connecting structure to function.

Materials

- Light microscopes (or high-res digital images)
- Prepared slides: esophagus and stomach (ideally fundus/body)

Warm-up Prompts (Students, 2 minutes)

- Write the four layers of the GI tract organs from lumen outward.
- Predict one key difference you expect to see between organs.

Two-Station Histology Sprint — Esophagus vs Stomach Student Worksheet

Station 1 — Esophagus (observe, note, and photograph)

- Photo 1: attach or sketch here
 - Mag: _____ X: Region (upper/middle/lower): _____

Layer checklist and quick notes

- Mucosa: stratified squamous non-keratinized; lamina propria; muscularis mucosae
 - Notes: _____
- Submucosa: mucous (esophageal) glands; Meissner's plexus
 - Notes: _____
- Muscularis externa: inner circular, outer longitudinal; muscle type (upper skeletal → middle mixed → lower smooth)
 - Notes: _____
- Adventitia/Serosa: mostly adventitia (thorax); short abdominal segment with serosa
 - Notes: _____
- Function link (1–2 bullets): How do these features support abrasion-resistant transport?

Station 2 — Stomach (fundus/body preferred)

- Photo 2: attach or sketch here
 - Mag: _____x : Region (cardia/fundus/body/pylorus)

Layer checklist and quick notes

- Mucosa: simple columnar; surface mucous cells; gastric pits → glands (parietal cells: HCl; chief cells: pepsinogen;

enteroendocrine)

- Notes: _____
- Submucosa: no glands; supports rugae (mucosa + submucosa folds)
 - Notes: _____
- Muscularis externa: three layers—inner oblique, middle circular (thick near pylorus), outer longitudinal
 - Notes: _____
- Serosa: intraperitoneal (mesothelium visible at low power as a smooth outer coat)
 - Notes: _____
- Function link (1–2 bullets): How do these features support mixing, storage, and chemical digestion?

1.6: Activity 5

Leader-Line Molar Map — Number-to-Structure ID

1. Identify key external and internal parts of a molar using a diagram with numbered leader lines.
2. Match each number to the correct structure using the features of the molar tooth provided in the Table 1.6.1

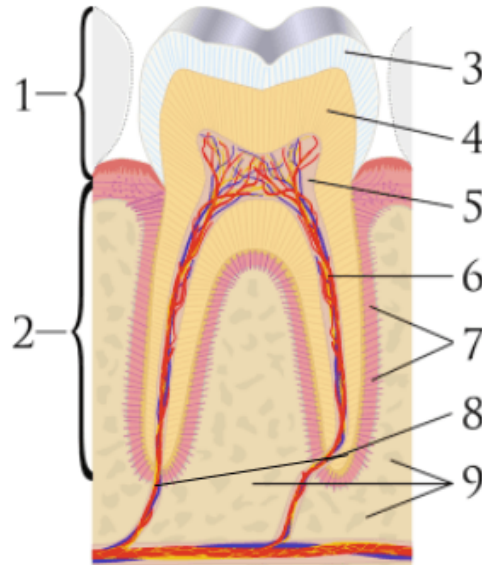


Figure 1.6.1: Detailed diagram of tooth anatomy highlighting crown and root regions, enamel, dentin, pulp, and vascular structures. (CC BY-NC-SA 4.0; via [Tooth Structure and Identification](#)).

Figure 1.6.1 illustrates the structure of the tooth. This longitudinal section through a molar in its alveolar socket shows the nine key features indicated by numbers for identification.

Table 1.6.1: Features of a molar tooth and their corresponding numbered labels.

Feature of the molar tooth	Identifying Number
Root canal	
Mandible/maxilla bone	
Pulp	
Apical foramen	
Dentin	
Enamel	
Peridontals ligament	
Crown	
Root	

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1.7: Activity 6

Match-and-Map — Hepatobiliary and Pancreatic Junctions

In this beginner-friendly matching lab, you identify and connect key structures where the liver, gallbladder, pancreas, and duodenum meet.

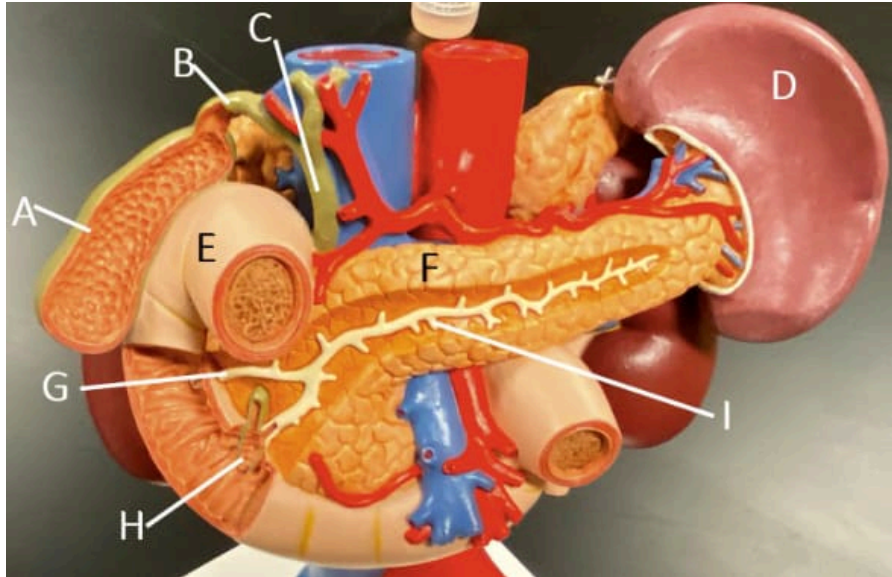


Figure 1.7.1: Labeled anatomical model illustrating digestive organs and vascular structures, including pancreas and spleen. (CC BY-NC-SA 4.0; John Polos via [Upper Abdominal Organs Model - Atlas](#)).

Table 1.7.1: Fill in the names of structures for letters A–I in the hepatobiliary and pancreatic model.

Matching Letter	Feature of the Hepatobiliary and Pancreatic Junctions
	Accessory pancreatic duct
	Duodenum
	Spleen
	Hepatopancreatic ampulla
	Cystic duct
	Common bile duct
	Gallbladder
	Pancreas
	Main pancreatic duct

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Key Terms and Definitions

- **Absorption** – The process in which nutrients enter the bloodstream after food molecules have been broken down during chemical digestion.
- **Anal** – Pertaining to the anus, the opening at the end of the digestive tract from which feces exit the body.
- **Anus** – The opening at the end of the digestive tract where feces leave the body.
- **Appendectomy** – Surgical removal of the appendix.
- **Appendicitis** – Inflammation of the appendix.
- **Appendix** – A tube-shaped sac attached to and opening into the lower end of the large intestine.
- **Ascending colon** – The first part of the colon which travels upward on the right side of the abdomen.
- **Bile** – A bitter, greenish-brown alkaline fluid that aids digestion, secreted by the liver and stored in the gallbladder.
- **Bilirubin** – A yellowish pigment formed in the liver by the breakdown of red blood cells.
- **Bolus** – A soft mass of food that is an appropriate size for swallowing.
- **Cecum** – The first section of the large intestine, into which the ileum opens.
- **Celiac disease** – A serious autoimmune disorder that occurs in genetically predisposed people where ingestion of gluten leads to damage in the small intestine.
- **Cholecystectomy** – Surgical removal of the gallbladder.
- **Cholecystitis** – Inflammation of the gallbladder, often due to a gallstone blocking the cystic duct.
- **Cholelithiasis** – The formation of gallstones in the gallbladder.
- **Chyme** – The pulpy acidic fluid that passes from the stomach to the small intestine, consisting of gastric juices and partly digested food.
- **Cirrhosis** – A chronic disease of the liver marked by degeneration of cells, inflammation, and fibrous thickening of tissue. Often caused by alcoholism or hepatitis.
- **Colonoscopy** – A test that allows a doctor to look at the inner lining of the large intestine using a thin, flexible tube called a colonoscope.
- **Colostomy** – A surgical procedure that brings one end of the large intestine out through the abdominal wall to carry stool out of the body.
- **Crohn's disease** – A chronic inflammatory bowel disease that affects the lining of the digestive tract.
- **Defecation** – The final step in digestion when undigested materials are expelled from the body as feces.
- **Descending colon** – The part of the colon that travels downward on the left side of the abdomen.
- **Digestion** – The process by which food is broken down into absorbable units.
- **Diverticula** – Small, bulging pouches that can form in the lining of the digestive system.
- **Duodenum** – The first section of the small intestine, immediately beyond the stomach, leading to the jejunum.
- **Dysentery** – An inflammatory disorder of the intestine, especially the colon, resulting in severe diarrhea with blood and mucus, fever, and abdominal pain.
- **Emesis** – The act of vomiting or ejecting stomach contents through the mouth.
- **Endoscope** – An instrument used for visual examination of the interior of a hollow body organ.
- **Epiglottis** – A flap of cartilage at the root of the tongue, depressed during swallowing to cover the opening of the windpipe.
- **Esophagus** – The muscular tube that conveys food and liquids from the throat to the stomach.
- **Gallbladder** – A small organ where bile is stored before release into the small intestine.
- **Gallstone** – A small, hard crystalline mass formed abnormally in the gallbladder or bile ducts from bile pigments, cholesterol, and calcium salts.
- **Gastric juice** – A digestive fluid secreted by the stomach, containing hydrochloric acid, pepsin, and other enzymes.
- **Gastroenterologist** – A physician specializing in diseases of the digestive system.
- **Gastroenterology** – The study of the digestive system and its disorders.
- **Gastroesophageal reflux disease (GERD)** – A chronic condition where stomach acid or bile flows into the esophagus and irritates its lining.
- **Gingivitis** – Inflammation of the gums.
- **Hard palate** – The bony front part of the palate.
- **Hemorrhoid** – A swollen vein or group of veins in the region of the anus.
- **Hepatitis** – Inflammation of the liver, usually caused by viral infection or toxins.
- **Hernia** – A condition in which part of an organ protrudes through the wall of its cavity, often involving the intestine.
- **Hiatal hernia** – A type of hernia where abdominal organs slip through the diaphragm into the chest cavity.
- **Ileocecal valve** – A sphincter muscle valve that separates the small intestine and the large intestine.
- **Ileum** – The third portion of the small intestine, between the jejunum and the cecum.

- **Irritable bowel syndrome** – A disorder affecting the large intestine, causing cramping, pain, bloating, gas, diarrhea, and constipation.
- **Jaundice** – Yellowing of the skin or eyes due to excess bilirubin.
- **Jejunum** – The part of the small intestine between the duodenum and ileum.
- **Laparoscope** – A thin tube with a camera and light used for viewing the abdominal or pelvic cavities.
- **Large intestine** – The last part of the digestive system, absorbing water and electrolytes, forming and storing feces.
- **Liver** – A large glandular organ in the abdomen involved in many metabolic processes.
- **Lower esophageal sphincter** – A ring of muscle at the end of the esophagus that prevents backflow of stomach contents.
- **Oral cavity** – The mouth area, including lips, cheeks, palate, and floor of the mouth.
- **Pancreas** – A large gland behind the stomach that secretes digestive enzymes into the duodenum.
- **Pancreatitis** – Inflammation of the pancreas.
- **Peptic ulcer disease** – Ulcers on the lining of the stomach, esophagus, or small intestine, often caused by H. pylori or NSAIDs.
- **Peristalsis** – Involuntary muscle contractions that push contents through the digestive tract.
- **Peritoneum** – A serous membrane lining the abdominal cavity and covering organs.
- **Peritonitis** – Inflammation of the peritoneum.
- **Pharynx** – The muscular tube extending from the nasal cavities and mouth to the esophagus (throat).
- **Pyloric sphincter** – A ring of muscle at the end of the stomach regulating food flow into the small intestine.
- **Rectum** – The final section of the large intestine, terminating at the anus.
- **Reflux** – Backward flow of stomach contents into the esophagus, causing heartburn.
- **Salivary** – Related to or producing saliva.
- **Sigmoid colon** – The S-shaped last part of the colon, leading into the rectum.
- **Sigmoidoscopy** – Examination of the sigmoid colon using a sigmoidoscope.
- **Small intestine** – Part of the intestine where most digestion and absorption occur, between the stomach and large intestine.
- **Soft palate** – The fleshy, flexible part at the back of the roof of the mouth.
- **Stomach** – A sac-like organ that mixes food with gastric juices to begin protein digestion.
- **Sublingual** – Underneath the tongue.
- **Tongue** – A muscular organ aiding in tasting, swallowing, and speaking.
- **Transverse colon** – The middle part of the colon that travels across the abdomen.
- **Ulcerative colitis** – A chronic inflammatory bowel disease that causes inflammation in the lining of the large intestine (colon) and rectum.
- **Upper GI endoscopy** – A procedure using a thin scope with a light and camera to examine the upper digestive tract (esophagus, stomach, and duodenum).
- **Uvula** – A fleshy extension at the back of the soft palate that hangs above the throat.
- **Villi** – Small, finger-like projections on the intestinal wall that increase surface area for absorption.
- **Visceral** – Relating to the internal organs of the body, especially those in the abdomen.
- **Vomiting** – The act of ejecting stomach contents through the mouth.

2: EXPLORING THE CHEMICAL AND PHYSICAL PROCESSES OF DIGESTION

Introduction

In this laboratory activity, you will examine the roles of carbohydrates, fats, and proteins in providing energy and perform experiments and demonstrations to understand the role of enzymes in the breakdown of macronutrients (e.g., amylase for carbohydrates or lipase for fats). You will also identify and understand the main components of a Nutrition Facts label (serving size, calories, macronutrients, etc.) and be better prepared to appreciate the science behind dietary guidelines, energy balance, and the role of metabolism in maintaining homeostasis.

Learning Objectives

- Examine the role of key digestive enzymes like amylase, pepsin, and pancreatic lipase in breaking down carbohydrates, proteins, and fats.
- Conduct experiments to analyze the effectiveness of digestive enzymes in various conditions, using indicators to assess the degree of digestion of different substrates.
- Explore how physical processes, such as chewing and churning, break down food into smaller particles, facilitating chemical digestion.

2.1: Background Information

2.2: Activity 1

2.3: Activity 2

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2.5: Activity 4

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2.7: Glossary

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2.1: Background Information

Overview

Digestion, metabolism, and nutrition are interconnected biological processes that convert food into energy and the building blocks necessary to sustain life. Nutrition is the study of food and its effect on health and growth. It is the process of consuming, absorbing, and utilizing nutrients from food to support life. Human body needs a variety of essential nutrients to function correctly.

- **Macronutrients:** These are needed in larger quantities to provide energy.
 - **Carbohydrates:** Body's main source of energy.
 - **Proteins:** Used for building and repairing tissues.
 - **Fats (Lipids):** Store energy, protect organs, and help with nutrient absorption.
- **Micronutrients:** These are needed in smaller quantities to support metabolism and other functions.
 - **Vitamins:** Organic compounds that are vital for many bodily functions.
 - **Minerals:** Inorganic elements necessary for growth and metabolism.
- **Water:** Essential for numerous bodily functions, including transporting nutrients and regulating body temperature.

The large molecules found in intact food cannot pass through the cell membranes. Digestion is the mechanical (physical breakdown of food into smaller pieces, which begins with chewing in the mouth and continues with churning in the stomach) and chemical (use of enzymes and acids to break down complex molecules into simpler ones) process of breaking down complex food into smaller, absorbable molecules called nutrients. This process occurs in the gastrointestinal (GI) tract and makes nutrients available for the body's cells to use.

- Carbohydrates are broken down into simple sugars (e.g., glucose).
- Proteins are broken down into amino acids.
- Fats are broken down into fatty acids and glycerol.

Metabolism is the sum of all chemical reactions in the body's cells that convert or use energy. After nutrients are absorbed from digestion, they are either used immediately for energy or stored for later use. Two main processes:

- **Catabolism:** The breakdown of large molecules (like carbohydrates and fats) into smaller units to release energy. This energy is used for bodily functions, muscle contractions, and heating the body.
- **Anabolism:** The constructive process of building and storing, which uses energy to create larger, more complex molecules. This is essential for cell growth, tissue repair, and storing energy for future use.

Energy currency is the primary energy currency of the cell is Adenosine Triphosphate (ATP).

- When a phosphate group is removed from ATP, it releases energy and becomes Adenosine
- Diphosphate (ADP). Catabolic reactions generate ATP from ADP, while anabolic reactions use the energy stored in ATP.

Enzymes and pathways are metabolic reactions occur in sequences called metabolic pathways. Each step is catalyzed by a specific enzyme, which increases the rate of the reaction. These pathways are tightly regulated to ensure the cell's energy needs are met efficiently.

Enzymatic Digestion of Macronutrients

Carbohydrates

The digestion of carbohydrates begins in the mouth. The salivary enzyme amylase begins the breakdown of food starches into maltose, a disaccharide. The esophagus produces no digestive enzymes but does produce mucous for lubrication. The acidic environment in the stomach stops the action of the amylase enzyme.

The next step of carbohydrate digestion takes place in the duodenum. The chyme from the stomach enters the duodenum and mixes with the digestive secretion from the pancreas, liver, and gallbladder. Pancreatic juices also contain amylase, which

continues the breakdown of starch and glycogen into maltose, a disaccharide. Maltase breaks down maltose into glucose. Other disaccharides, such as sucrose and lactose are broken down by sucrase and lactase, respectively. Sucrase breaks down sucrose into glucose and fructose, and lactase breaks down lactose into glucose and galactose. The monosaccharides (glucose) thus produced are absorbed and then can be used in metabolic pathways to harness energy. The monosaccharides are transported across the intestinal epithelium into the bloodstream to be transported to the different cells in the body. The steps in carbohydrate digestion are summarized in Figure 2.1.1 and Table 2.1.1.

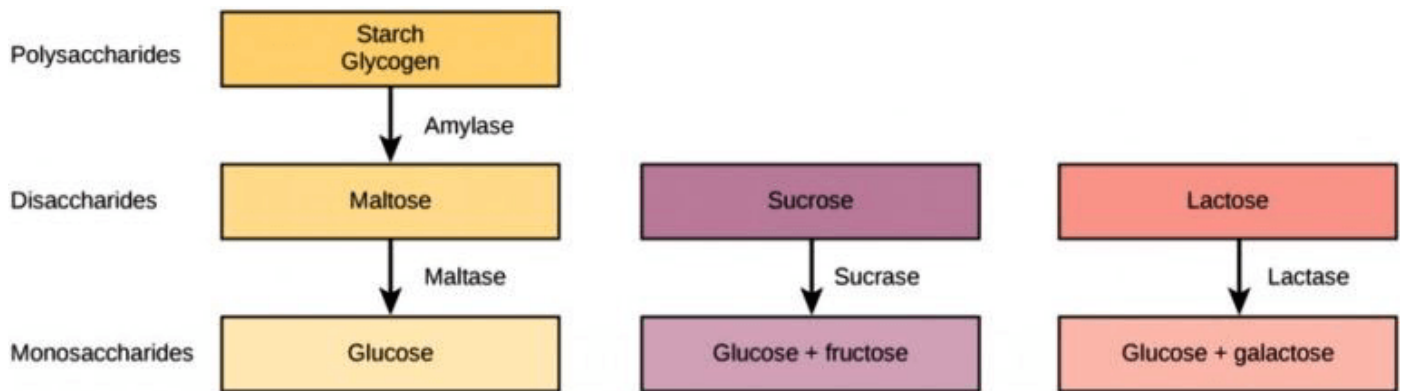


Figure 2.1.1: Digestion of carbohydrates is performed by several enzymes. Starch and glycogen are broken down into glucose by amylase and maltase. Sucrose and lactose are broken down by sucrase and lactase, respectively. (CC BY 4.0; Charles Molnar and Jane Gair via [Digestive System and Process](#)).

Figure 2.1.1 shows how carbohydrates are broken down by digestive enzymes into simple sugars.

- The left pathway shows polysaccharides (starch and glycogen) being broken down by amylase into the disaccharide maltose, then broken down by maltase into the monosaccharide glucose.
- The middle pathway shows the disaccharide sucrose being broken down by sucrase into glucose and fructose.
- The right pathway shows the disaccharide lactose being broken down by lactase into glucose and galactose.
- The diagram groups the substances by level: polysaccharides, disaccharides, and monosaccharides.

Protein

Table 2.1.1: Digestive enzymes, their sources, sites of action, substrates, and resulting end products.

Enzyme	Produced By	Site of Action	Substrate	End Products
Salivary amylase	Salivary glands	Mouth	Polysaccharides (Starch)	Disaccharides (maltose), oligosaccharides
Pancreatic amylase	Pancreas	Small intestine	Polysaccharides (starch)	Disaccharides (maltose), monosaccharides
Oligosaccharidases	Lining of the intestine; brush border membrane	Small intestine	Disaccharides	Monosaccharides (e.g., glucose, fructose, galactose)

The stomach's highly acidic environment is the primary site of initial protein breakdown. Hydrochloric acid (HCl) in gastric juice denatures proteins by uncoiling their complex three dimensional structures. This exposes the polypeptide chains, making them more accessible to enzymes. The chief cells in the stomach secrete pepsinogen, an inactive enzyme precursor called a zymogen. The low pH from the HCl activates pepsinogen, converting it into its active form, pepsin. Pepsin breaks the long polypeptide chains into smaller polypeptides and oligopeptides. As the acidic chyme enters the small intestine (duodenum), the pancreas releases bicarbonate to neutralize the acidity, creating a more neutral pH for intestinal enzymes. The pancreas secretes several powerful protein-digesting enzymes (proteases) as inactive zymogens to protect itself from being digested.

- Trypsinogen and chymotrypsinogen are activated by an enzyme in the intestinal wall called enteropeptidase, becoming active trypsin and chymotrypsin, respectively.

- Trypsin and chymotrypsin break polypeptides into smaller peptides.

The microvilli lining the small intestine's wall contain "brush border" enzymes. These enzymes, such as carboxypeptidase, break down the small peptides into dipeptides, tripeptides, and single amino acids. The end products of protein digestion—single amino acids, dipeptides, and tripeptides—are absorbed into the cells lining the small intestine (enterocytes). The steps in protein digestion are summarized in Figure 2.1.2, Figure 2.1.3 and Table 2.1.2.

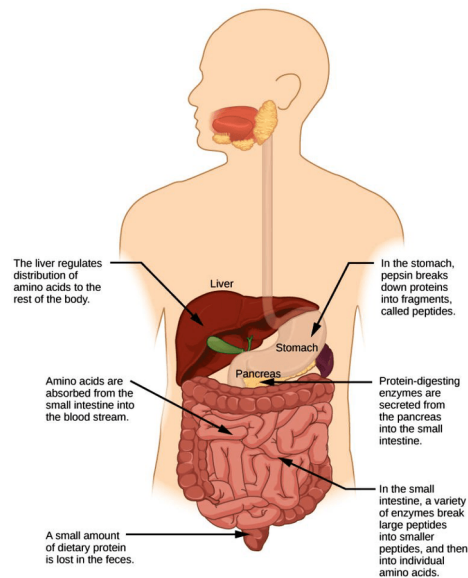


Figure 2.1.2: Protein digestion is a multistep process that begins in the stomach and continues through the intestines. (CC BY 4.0; Charles Molnar and Jane Gair via [Digestive System and Process](#)).

Figure 2.1.2 is a labeled overview of protein digestion and absorption in the digestive tract, with arrows pointing to specific organs and text call outs describing what happens in each location.

- **Stomach:** Pepsin breaks down proteins into fragments, called peptides
- **Pancreas:** Protein-digesting enzymes are secreted from the pancreas into the small intestine.
- **Small intestine:** a variety of enzymes break large peptides into smaller peptides, and then into individual amino acids.”
- **Absorption:** Amino acids are absorbed from the small intestine into the blood stream.
- **Liver:** Regulates distribution of amino acids to the rest of the body.
- **Waste:** A small amount of dietary protein is not absorbed and is lost in the feces.

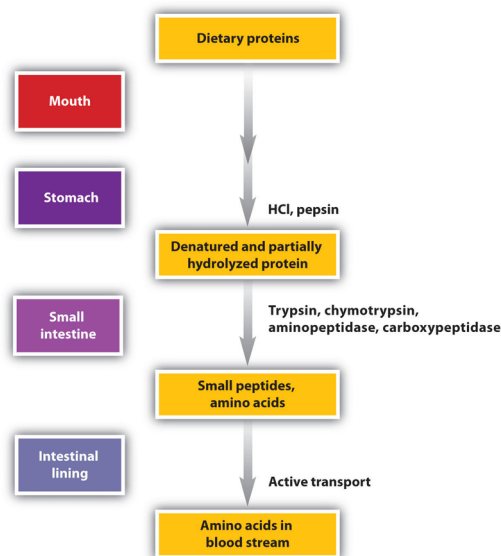


Figure 2.1.3: Copy and Paste Caption here. (CC BY-NC-SA 3.0; Deboleena Roy via [Digestion of Proteins](#)).

Figure 2.1.3 is a flowchart that shows the steps of protein digestion and absorption from the digestive tract into the bloodstream. Protein digestion and absorption occur in stages across the digestive tract. Dietary proteins enter the digestive system and, in the stomach, hydrochloric acid (HCl) and pepsin denature proteins and partially hydrolyze them. In the small intestine, the enzymes trypsin, chymotrypsin, aminopeptidase, and carboxypeptidase further break the proteins into small peptides and individual amino acids. At the intestinal lining, amino acids are absorbed by active transport into the bloodstream, resulting in amino acids circulating in the blood.

Table 2.1.2: Protein-digesting enzymes, their sources, sites of action, substrates, and resulting products

Enzyme	Produced By	Site of Action	Substrate	End Products
Pepsin	Stomach chief cells	Mouth	Proteins	Peptides
- Trypsin - Elastase - Chymotrypsin	Pancreas	Small intestine	Proteins	Peptides
Carboxypeptidase	Pancreas	Small intestine	Peptides	Amino acids and peptides
- Aminopeptidase - Dipeptidase	Lining of intestine	Small intestine	Peptides	Amino acids

Lipids

Triglycerides are esters and esters can undergo hydrolysis. Lipid digestion begins in the stomach. Lingual lipases present in the saliva are activated when they reach the acidic conditions of the stomach. Gastric lipases secreted in the stomach start the hydrolysis of the ester functional groups in triglycerides. Most of the digestion of triglycerides happen in small intestine. A hormone secreted in this region stimulates the gallbladder to discharge bile. The principal constituents of bile are the bile salts, which emulsify large, water-insoluble lipid droplets, disrupting some of the hydrophobic interactions holding the lipid molecules together and suspending the resulting smaller globules (micelles) in the aqueous digestive medium. These changes greatly increase the surface area of the lipid particles, allowing for contact with the enzyme lipases and thus rapid digestion of the fats.

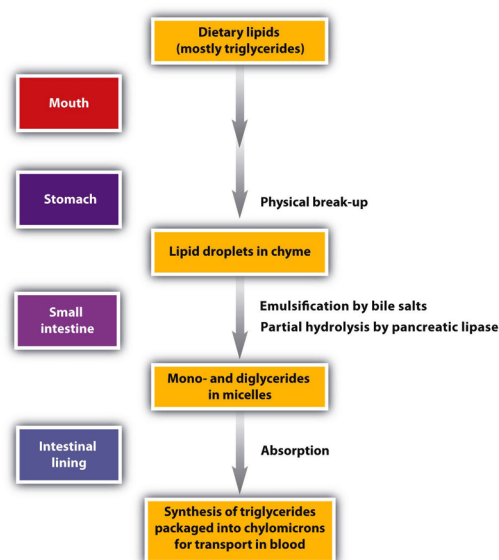


Figure 2.1.4: The Principal Events and Sites of Triglyceride Digestion. Lipids are digested and absorbed in the small intestine. (CC BY 3.0; Deboleena Roy via [Digestion of Triglycerides](#)).

Figure 2.1.4 is a flowchart describes lipid digestion and absorption across the digestive tract.

- The process begins with dietary lipids (mostly triglycerides).

- Locations listed are mouth, stomach, small intestine, and intestinal lining.
- In the stomach, lipids undergo physical break-up, forming lipid droplets in chyme.
- In the small intestine, bile salts emulsify the lipid droplets, and pancreatic lipase partially hydrolyzes them, producing mono- and diglycerides in micelles.
- At the intestinal lining, these products are absorbed.
- After absorption, lipids are re-formed by synthesis of triglycerides and are packaged into chylomicrons for transport in the blood.

Vitamins

Vitamins are essential organic compounds produced by plants or animals, crucial for metabolism, growth, and cellular function. They are classified into two main types:

- Fat-Soluble Vitamins (A, D, E, K): These are absorbed with dietary fats and stored in the liver and fatty tissues. While beneficial, excessive intake can lead to toxicity.
- Water-Soluble Vitamins (C and B-complex): These dissolve in water and are not stored in the body, except for B12. Excess amounts are excreted in urine, necessitating regular intake.

Minerals

Minerals are inorganic elements absorbed from the earth through plants or consumed via animals, serving as building blocks for teeth, bones, and other cells. They fall into two categories:

- Macrominerals: Required in larger quantities (over 100 mg/day).
- Trace Minerals: Needed in smaller quantities (less than 100 mg/day).

Deficiency and Over Consumption

While deficiencies can lead to severe health issues, excessive intake, particularly of fat-soluble vitamins, can also be harmful. Common causes include inadequate diet, malabsorption conditions like celiac disease, and dietary restrictions such as veganism that may necessitate supplements. Example Conditions:

- Iron Deficiency Anemia: Causes fatigue and weakness due to low iron levels.
- Scurvy: Resulting from severe vitamin C deficiency, leading to poor wound healing and bleeding gums.
- Osteoporosis: Linked to long-term calcium deficiency, affecting bone density.

2.2: Activity 1

Demonstrating Digestion of Starch

Starch is a plant-based energy storage molecule composed of two distinct glucose polymers: amylose and amylopectin. Amylose is a predominantly linear polysaccharide, while amylopectin is a highly branched structure, and their relative proportions influence the properties of the starch in foods. Amylase (e.g., salivary amylase or α -amylase from the pancreas) is the enzyme that breaks down starch into maltose or shorter glucose chains.

In this lab activity, you'll explore the digestion of starch initiated by salivary amylase, an enzyme secreted by the salivary glands that begins breaking down complex carbohydrates into simpler sugars. This process is crucial for efficient carbohydrate digestion and energy production.



Equation 2.2.1 is the chemical reaction catalyzed by the enzyme amylase. The long polysaccharide starch is broken down (hydrolyzed) by the enzyme amylase. The products are glucose molecules (a monosaccharide) and maltose (a disaccharide).

The rate and extent of starch digestion depend on factors such as pH, temperature, enzyme concentration, and reaction time. Starch can be detected by the addition of a small amount of iodine solution. Benedict's test will detect presence of reducing sugars.

Iodine Test Results for Starch: Observing Color Changes

The iodine test is a simple yet effective way to determine the presence of starch in a solution. When iodine is added to a sample, observe the following color changes:

- **Blue-Black Color:** Indicates the presence of starch. This color change occurs because iodine interacts with the helical structure of starch molecules, causing the distinct blue-black color.
- **Yellow or Brown Color:** Suggests that starch is absent or has been broken down. In this case, the iodine does not bind to any starch, resulting in a yellow or brown appearance, similar to the color of the iodine solution itself.

Try Iodine Test for Starch Yourself! Set up the Control

Prepare three test tubes to explore how iodine interacts with different solutions. Follow these steps to observe the color changes:

- **Preparation:**
 - Test Tube T1: Add 2 mL of 1% boiled starch solution.
 - Test Tube T2: Add 2 mL of 1% glucose solution.
 - Test Tube T3: Add 2 mL of 1% maltose solution.
- **Adding Iodine:**
 - Carefully add 5 drops of iodine solution to each test tube.
 - Gently shake each tube to mix the contents thoroughly.
- Record the change of color, if any, observed in the following table.

Table 2.2.1: Color Change Observations and Interpretations for Carbohydrate-Iodine Reactions

Test Tube	Observation (Color Changed or Not Changed)	Interpretation
T1 (Starch + Iodine)		
T2 (Glucose + Iodine)		
T3 (Maltose + Iodine)		

Benedict's Test for Simple Sugars

Benedict's reagent is an aqueous solution containing copper(II) sulfate (CuSO_4), sodium carbonate (Na_2CO_3), and sodium citrate. The copper(II) sulfate gives the reagent its characteristic blue color.

Benedict's test is based on the reduction of copper(II) ions present in the Benedict's reagent to copper(I) oxide, facilitated by the presence of reducing sugars in a sample, such as glucose, fructose, and maltose.

It works through a heat-induced redox reaction that changes the reagent's blue color to a range of colors, from green to brick-red, depending on the concentration of reducing sugar present.

- Blue to Green/Yellow: Indicates a low concentration of reducing sugars.
- Yellow to Orange: Suggests a moderate concentration.
- Orange to Brick Red: Signals a high concentration of reducing sugars.

Key Points to Consider:

- The intensity of the color change provides a qualitative measure of the sugar concentration.
- Non-reducing sugars, like sucrose, do not cause this color change unless they are first hydrolyzed into reducing sugars.

Try Benedict's Test for Simple Sugars Yourself! Set up the Control

Try it yourself!

- Prepare three test tubes (marked B1, B2 and B3) by adding 5 ml of Benedict's reagent to each.
- Place 4ml of 1% starch solution in test tube B1, 4ml of 1% glucose solution in B2, and 4ml of 1% maltose in the B3.
- Heat in a boiling water bath for 3 - 5 min. Cool.

Interpretation

The concentration of reducing sugar is indicated by the intensity of the color change and precipitate.

- Negative result: The solution remains the original clear blue color, indicating no reducing sugar is present. An example is a test performed on a sucrose solution, since sucrose is a non-reducing sugar.
- Positive results: Any color change from blue indicates a positive result.
 - Trace (green): A small amount of reducing sugar is present.
 - Low (yellow): A low concentration of reducing sugar is present.
 - Moderate (orange-red): A moderate concentration of reducing sugar is present.
 - High (brick-red): A large amount of reducing sugar is present, producing a dense, reddish-brown precipitate.
- Record the change of color, if any, observed in the following table.

Table 2.2.2: Color Change Observations and Interpretations for Carbohydrate Reactions with Benedict's Reagent

Test Tube	Observation (Color Changed or Not Changed)	Interpretation
B1 (Starch + Benedict reagent)		
B2 (Glucose + Benedict reagent)		
B3 (Maltose + Benedict reagent)		

Digestion of Starch by Salivary Amylase

Materials

- 1% boiled starch solution (substrate for amylase)
- 1% glucose solution
- Pancreatin solution (3% - contains pancreatic amylase)
- 1% Maltose solution (as a positive control for product formation)

- 1% Iodine solution (indicator for starch presence; turns blue-black with starch)
- Distilled water
- 2N HCl
- Benedict's solution
- pH paper
- Water baths (37°C) and/or Hot plates (beakers with water 100°C)
- Test tubes
- Test tube clamp
- Disposable pipets
- Spot plate
- Graduated cylinders
- Beaker (Pyrex, for boiling water)
- Droppers
- Paraffin
- Sharpie or other marker (for labeling tubes) and blue tape
- Ice (for chilling samples)
- Hot plate or Bunsen burner (for heating samples)
- Timer or stopwatch (to measure reaction times)

Procedure

Safety Tips:

1. Do not burn yourself with boiling water or the reagent when you perform the Benedict test.
2. Use the test tube clamps to pick up test tubes from the beakers on the hot plates.
3. Put the test tubes inside a test tube holder before carrying them to your bench.

Follow these detailed steps to investigate how salivary amylase breaks down starch:

Iodine test for starch and Benedict's test for reducing sugars

1. Label four test tubes numbers 1C, 2C, 3C, 4C.
2. Add solutions as described in Table below. Add the enzyme LAST.
3. Shake the tubes and determine and record the pH of each reaction mixture in Table 2.2.2.
4. Place the test tubes in a water bath at 37°C and incubate for 45 minutes. Shake the tubes every 15 minutes.
5. After 45 minutes of incubation, both iodine and Benedict's test will be used for detection for starch and reducing sugar. Glucose is called reducing sugar because it is capable of transferring hydrogen to other compounds. Such a process is known as reduction or Redox reaction.
6. Divide each of the 4 samples of incubated solutions by pouring half of it into a clean test tube.
7. Now, there are eight tubes.
8. Label one test tube rack SET 1 - for Iodine test (place 4 test tubes 1C, 2C, 3C, 4C).
9. Test SET 1 tubes for starch by adding 5 drops (1 drop = 0.05 mL) iodine solution to each.
10. Shake the test tubes and record the color of the iodine solution in table 2.
11. Label other test tube rack SET 2 - for Benedict's test (place 4 test tubes 1C, 2C, 3C, 4C).
12. Test the second set of 4 test tubes for reducing sugar by adding 5 ml Benedict's reagent to each, and placing in a boiling water bath for 5 min.
13. Shake the test tubes and record the color of the iodine solution in Table 2.2.4.

Table 2.2.3: Experimental Setup for Testing Alpha-Amylase Activity on Boiled Starch Solution

Test Tube number	Substrate (1% boiled starch solution)	Other reagents	Enzyme (2% alpha amylase)
1C	5.0 ml	None	5.0 ml
2C	5.0 ml	5.0 ml dist. Water	None
3C	None	5.0 ml dist. Water	5.0 ml

Test Tube number	Substrate (1% boiled starch solution)	Other reagents	Enzyme (2% alpha amylase)
4C	5.0 ml	5 drops 0.5N HCl	5.0 ml

Table 2.2.4: Results of Starch Digestion with Alpha-Amylase: Iodine and Benedict's Tests

Iodine Test		Benedict's Test		Explain what is happening	
Test Tube	pH	Presence of starch (yes/no)	Presence of reducing sugar (yes/no)		
1C					
2C					
3C					
4C					

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2.3: Activity 2

Digestion of Triglycerides with Pancreatin

Triglycerides are the main form of lipid found in animal fats (such as milk cream) and vegetable oils, however they must be digested to fatty acids and glycerol via pancreatic lipase to be absorbed. Since lipids are not soluble in water they will form large droplets to minimize contact with the surrounding aqueous environment. This limits their interaction with lipase thus making their digestion very slow and inefficient. To avoid this problem, the liver produces bile, a greenish fluid with properties similar to soap that helps to emulsify lipids, i.e., break them up into smaller droplets. Bile is stored in the gall bladder until partially digested meal reaches the duodenum. This triggers the release of bile into the duodenum to help emulsify the lipids.

This lab will explore the digestion of triglycerides using Pancreatin, a mixture of several digestive enzymes including lipase. You'll observe how triglycerides are broken down into smaller molecules such as Diglycerides, monoglycerides, and free fatty acids. As their name implies, fatty acids are acidic (they release H^+ into solution) due to their carboxyl groups. The release of fatty acids from neutral triglycerides will thus result in an increase in the H^+ concentration (i.e., lowering of the pH value). In this exercise, changes in pH will be detected by observing changes in color of the pH indicator.

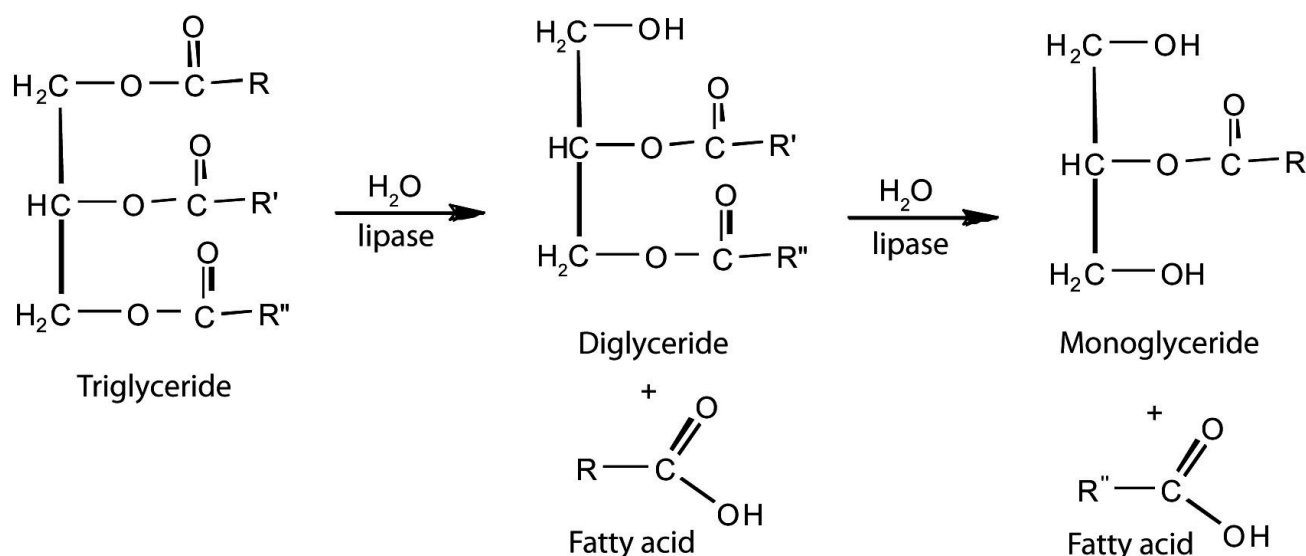


Figure 2.3.1: Digestion of triglycerides. Demonstrates how lipase enzymes facilitate the breakdown of triglycerides, a common dietary fat, into smaller components — diglyceride, monoglyceride, and free fatty acids. (CC BY 3.0; Deboleena Roy via [Digestion of Tryglycerides](#)).

Materials

- Pancreatin solution (0.5% - contains pancreatic lipase)
- Bile salts (powder)
- 1% Triglyceride solution (cream or oil)
- Litmus solution (pH indicator)
- pH paper or pH meter
- Test tubes
- Water bath set to 37°C (body temperature)
- Distilled water
- Test tube rack
- Pipettes and pipette suction pump
- Stopwatch or timer
- Marker for labeling

Procedure

1. Prepare Test Tubes by labeling four test tubes as 1A, 2A, 3A, 4A, and add solutions as designated in Table 2.3.3.
2. Add the enzyme last.
3. Note:
 - Litmus is a pH indicator which changes color from red (below pH 4.5) through various shades of violet to blue (above pH 8.3).
 - Enzymatic digestion of fat (triglyceride) releases fatty acids (e.g. butyric acid) which react with litmus and change its color to red.
4. Pancreatin is a commercial preparation of dried pancreatic enzymes.
5. Shake the tubes to mix thoroughly, make note of the color of each tube, and place in a water bath at 37°C. Incubate for 60 - 90 minutes.
6. Shake tubes and record their color in Table 2.3.2 every 5 minutes for the first 15 minutes, then for every 15 minutes until no color change is observed between color tests.
7. Interpretation: If pH decreases, that means a lowering of pH in the experimental test tube suggests that triglycerides are being hydrolyzed by lipase in Pancreatin, releasing free fatty acids.
8. Choose terms to describe the colors such as: milky blue, milky violet, milky purple, pinkish purple, reddish purple, transparent blue, transparent red. Write your results in Table 2.3.2.
9. Complete the tables to summarize the results of triglyceride digestion by pancreatic lipase.

Table 2.3.1: Effect of Pancreatic Lipase on Cream Substrate Under Different Conditions

Test Tube	Substrate (Cream)	Bile salts	Distilled Water	Latorndic (Litmus Solution)	Enzyme (Pancreatic Lipase) (Add Last)
1A	3.0 ml	pinch	skip	3.0 ml	3.0 ml
2A	3.0 ml	pinch	3.0 ml	3.0 ml	skip
3A	3.0 ml	skip	skip	3.0 ml	3.0 ml
4A	Skip	pinch	3.0 ml	3.0 ml	3.0 ml

Table 2.3.2: Color observations during digestion tests of milk fat by pancreatic lipase

Colors in test tubes during incubation									
Test Tube	0 min	5 min	10 min	15 min	30 min	45 min	60 min	75 min	90 min
1A									
2A									
3A									
4A									

Table 2.3.3: Evaluation of fatty acid presence and digestion rate of cream in test tubes.

Test Tube	Presence of Fatty Acids (Yes/No)	Is the digestion of cream, fast, slow or is there no digestion at all?	Brief explanation of each result.
1A			
2A			
3A			
4A			

2.4: Activity 3

Demonstration of emulsifying properties of Bile Salts

In this lab activity, you'll explore how bile salts, produced by the liver and stored in the gallbladder, play a crucial role in digesting fats through the process of emulsification. This involves breaking down large fat globules into smaller droplets, increasing the surface area for pancreatic lipase to act upon and effectively digest the fats. This process is essential for the absorption of dietary fats and fat-soluble vitamins in the small intestine.

Materials

- Bile salts (powder)
- Distilled water
- Oil/Cream
- Paraffin

Procedure

1. Obtain 2 test tubes.
2. Label one tube "NB" (no bile), and one tube "B" (bile).
3. To each tube, add 3.0 mL of distilled water.
4. Add 3.0 mL of vegetable oil to each tube.
5. To the tube labeled "B" only, add a small pinch of bile salts (available on the cart).
6. Now cover each tube with a small square of Paraffin, and cover the opening and Paraffin of each tube with your thumb.
7. Shake each tube vigorously for at least 30 seconds, keep observing each tube after shaking and record appearance in Table 6.
8. Return the test tubes to your test tube rack.
9. After 10 minutes, observe each tube and record appearance in Table 6.
10. Describe the appearance of the contents of the tube with oil and water only ("NB"), and the tube with oil, water, and bile salts ("B").
11. How do the differences in the appearances of the tubes' contents reflect the activity of bile?
12. Use the Table 2.4.1 to organize your observations and conclusions about the role of bile in emulsifying fats.

Table 2.4.1: Observations and conclusions about the role of bile in emulsifying fats

Test Tube Label	Contents	Appearance After Shaking	Appearance After 10 Minutes	Interpretation of Bile Activity
NB (No Bile)	3.0 mL water + 3.0 mL vegetable oil			
B (Bile)	3.0 mL water + 3.0 mL vegetable oil + Bile salts			

13. Describe the implications of bile salt deficiency on fat digestion and nutrient absorption.

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2.5: Activity 4

Simulating Mechanical Digestion

Objective: Gain insight into how mechanical digestion impacts the rate at which substances dissolve, simulating the breakdown of food in the digestive system.

Materials

- Antacid Tablets: Act as surrogate food items for the experiment.
- Vinegar: Represents stomach acid, facilitating dissolution.
- Clear Cups: Provide visibility for observing the dissolution process.
- Rolling Pin or Pestle: Used to crush tablets, simulating chewing.

Procedure

1. Prepare Solutions:
 - Fill each of the three clear cups with 20 mL of vinegar.
2. Experiment with Whole Tablet:
 - Place one intact antacid tablet into the first cup.
 - Start the timer and record how long it takes to fully dissolve.
3. Experiment with Quartered Tablet:
 - Break the second antacid tablet into four equal pieces.
 - Place the pieces into the second cup.
 - Start the timer and record the dissolution time.
4. Experiment with Crushed Tablet:
 - Use the rolling pin or pestle to crush the third antacid tablet into a fine powder.
 - Add the powder to the third cup.
 - Start the timer and record the dissolution time.

Instructions

- Dissolution Time: Record the time it takes for each tablet condition (whole, quartered, crushed) to fully dissolve in vinegar. Use a stopwatch for precision.
- Visual Observations: Note any visual changes during the dissolution process, including effervescence, tablet integrity, and clarity of the solution.
- Interpretation: Reflect on the observed differences in dissolution time and relate them to the concept of surface area and mechanical digestion.

Table 2.5.1: Recording Dissolution Times and Observations

Test Condition	Dissolution Time (seconds)	Visual Observations	Interpretation
Whole Tablet			
Quartered Tablet			
Crushed Table			

Reflection Prompts - Students to think critically and answer

1. How does increasing the surface area of food particles enhance the efficiency of digestive enzymes?
2. Discuss how the mechanical actions of the stomach and intestines (like peristalsis and segmentation) contribute to breaking down food and mixing it with digestive juices.

3. Based on the experiment, what real-life dietary habits could optimize digestion and absorption of nutrients?

2.6: Activity 5

Simulation of Mouth and Stomach

Objective: Model and understand the digestion processes occurring in the mouth and stomach.

Materials

- Plastic sealable Bag: Represents the digestive tract.
- Cracker and Water: Simulate food and saliva.
- Vinegar: Acts as stomach acid.
- Baking Soda: Optional, to simulate chemical reactions.

Procedure

Mouth Simulation

1. Prepare the Bag: Place a cracker and a small amount of water into the plastic bag.
2. Simulate Chewing: Seal the bag and "chew" by mashing the contents with your hands. This mimics the mechanical breakdown of food in the mouth.

Stomach Simulation

1. Add Stomach Acid: Open the bag and add a small amount of vinegar to simulate stomach acid.
2. Simulate Churning: Reseal the bag and knead it to mimic the churning action of the stomach.

Observation

- Note the transformation of the cracker from a solid to a pulpy mixture (chyme).
- Pay attention to any bubbling if baking soda is used, indicating a chemical reaction.

Table 2.6.1: Observations of Digestion Simulation in Mouth and Stomach

Step	Observations	Texture Changes	Chemical Reactions (if any)
Mouth Simulation			
Stomach Simulation			

Analysis and Reflection

1. Increased Surface Area: Discuss how the mechanical breakdown enhances the surface area for enzymes to act upon.
2. Mechanical vs. Chemical Digestion: Reflect on the differences between physical and chemical processes in digestion.
3. Sequential Process: Consider how these processes work together in the body to ensure efficient digestion.

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Key Term and Definitions

- **Absorption** – Passage of digested products from the intestinal lumen through mucosal cells and into the bloodstream or lacteals.
- **Aminopeptidase** – Protease that breaks down peptides into single amino acids; secreted by the brush border of the small intestine.
- **Amylase** – Enzyme secreted by both the salivary glands and the pancreas; breaks down starches into sugars.
- **Bile** – Digestive juice produced by the liver; important for digestion of lipids.
- **Bolus** – Mass of food resulting from chewing action and wetting by saliva.
- **Carboxypeptidase** – Protease that breaks down peptides into single amino acids; secreted by the brush border of the small intestine.
- **Chemical digestion** – Enzymatic breakdown of food.
- **Chylomicron** – Small lipid globule.
- **Chyme** – Soupy mixture of partially digested food and stomach juices.
- **Chymotrypsin** – Pancreatic protease; breaks down peptides into free amino acids that can be absorbed by the intestinal wall.
- **Defecation** – Elimination of undigested substances from the body in the form of feces.
- **Digestion** – Mechanical and chemical breakdown of food into small organic fragments.
- **Dipeptidase** – Protease that breaks down peptides into single amino acids; secreted by the brush border of the small intestine.
- **Duodenum** – First part of the small intestine where a large part of digestion of carbohydrates and fats occurs.
- **Elastase** – Pancreatic protease.
- **Esophagus** – Tubular organ that connects the mouth to the stomach.
- **Essential nutrient** – Nutrient that cannot be synthesized by the body; it must be obtained from food.
- **Gallbladder** – Organ that stores and concentrates bile.
- **Ingestion** – Taking food into the GI tract through the mouth.
- **Jejunum** – Second part of the small intestine.
- **Lactase** – Enzyme that breaks down lactose (a sugar found in dairy products) into glucose and galactose.
- **Large intestine** – Digestive system organ that reabsorbs water from undigested material and processes waste matter.
- **Lipase** – Enzyme produced in small amounts by the mouth and stomach, and in larger amounts by the pancreas; responsible for the breakdown of lipids (fats) into fatty acids and glycerol.
- **Liver** – Organ that produces bile for digestion and processes vitamins and lipids.
- **Maltase** – Enzyme that breaks down maltose into glucose.
- **Mastication** – Chewing.
- **Mechanical digestion** – Chewing, mixing, and segmentation that prepares food for chemical digestion.
- **Mineral** – Inorganic, elemental molecule that carries out important roles in the body.
- **Pancreas** – Gland that secretes digestive juices.
- **Pepsin** – Enzyme found in the stomach whose main role is protein digestion.
- **Peristalsis** – Muscular contractions and relaxations that propel food through the GI tract.
- **Propulsion** – Voluntary process of swallowing and the involuntary process of peristalsis that moves food through the digestive tract.
- **Segmentation** – Alternating contractions and relaxations of non-adjacent segments of the intestine that move food forward and backward, breaking it apart and mixing it with digestive juices.
- **Small intestine** – Organ where digestion of protein, fats, and carbohydrates is completed.
- **Stomach** – Sac-like organ containing acidic digestive juices.
- **Sucrase** – Enzyme that breaks down sucrose into glucose and fructose.
- **Trypsin** – Pancreatic protease that breaks down protein.
- **Vitamin** – Organic substance necessary in small amounts to sustain life.

3: ANATOMY AND HORMONAL SYMPHONY OF THE ENDOCRINE SYSTEM

Introduction

In this lab, you'll embark on a detailed exploration of the endocrine system, delving into the anatomy of its glands and the hormones they produce. The endocrine system plays a pivotal role in maintaining homeostasis by regulating metabolism, growth, reproduction, and stress responses. By examining both the structural and functional aspects of this system, you'll gain a comprehensive understanding of how hormones act as chemical messengers to coordinate various physiological processes.

Learning Objectives

- Locate and describe the major endocrine glands, such as the pituitary, thyroid, adrenal, and pancreas, understanding their unique structures and positions within the body.
- Explore the specific hormones secreted by each gland, their target organs, and their physiological effects. This includes hormones like insulin, cortisol, and thyroxine, among others.
- Evaluate the role of negative and positive feedback loops in regulating hormone levels to maintain physiological balance.
- Investigate how disturbances in these mechanisms can lead to endocrine disorders, such as acromegaly, diabetes and hypothyroidism, goiter, hyperthyroidism, Grave's disease, hyperparathyroidism, Cushing's syndrome, to understand the impact of hormonal imbalances on overall health.

[3.1: Background Information](#)

[3.2: Activity 1](#)

[3.3: Activity 2](#)

[3.4: Activity 3](#)

[3.5: Activity 4](#)

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[3.7: Glossary](#)

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3.1: Background Information

Overview

In the human body, communication is a vital process wherein signals are transmitted from a sender to one or more receivers to coordinate actions and maintain homeostasis. Two major organ systems facilitate this "long-distance" communication, the nervous system and the endocrine system. Together, they ensure the body's internal balance and enable it to respond effectively to changes in the environment.

The nervous system uses both electrical and chemical signaling. Electrical signals, or action potentials, and neurotransmitters like serotonin and norepinephrine, facilitate rapid and localized communication. The nervous system is designed to protect us from danger through its interpretation of and reactions to stimuli. But a primary function of the sympathetic and parasympathetic nervous systems is to interact with the endocrine system to elicit chemicals that provide another system for influencing our feelings and behaviors.

The nervous and endocrine systems have complementary roles. While the nervous system manages rapid external changes, the endocrine system maintains internal stability and controls reproduction. They work together harmoniously, with neural signals often triggering swift endocrine responses. An example of this is the rapid release of adrenal hormones during stress, which is crucial for immediate adaptation.

A gland in the endocrine system is made up of groups of cells that function to secrete hormones. A hormone is a chemical that moves throughout the body to help regulate emotions and behaviors. When the hormones released by one gland arrive at receptor tissues or other glands, these receiving receptors may trigger the release of other hormones, resulting in a series of complex chemical chain reactions. This method is generally slower in response compared to neural signals, taking seconds to hours to manifest effects. This is evident in processes such as the fight-or-flight response or reproductive functions. Hormones can have multiple roles; for instance, oxytocin is involved in labor, breastfeeding, and emotional bonding.

Table 3.1.1: Comparison of Endocrine and Nervous Systems

	Endocrine system	Nervous system
Signaling mechanism(s)	Chemical	Chemical/electrical
Primary chemical signal	Hormones	Neurotransmitters
Distance traveled	Long or short	Always short
Response time	Fast or slow	Always fast

Endocrine System Structures and Functions

The endocrine system is a network of glands, tissues, and cells that play a crucial role in maintaining homeostasis by producing and releasing hormones into the bloodstream. The interstitial fluid and the blood vessels then transport the hormones throughout the body. Key organs within the endocrine system include the pituitary gland ("master gland") due to controlling other endocrine glands, the thyroid gland, which regulates metabolism, and the pancreas, critical for blood sugar regulation through insulin and glucagon production. Endocrine tissues are also present in other organs, such as the ovaries and testes, which produce sex hormones essential for reproductive functions. Endocrine cells are specialized to recognize and respond to specific signals, ensuring precise hormone release to maintain balance and adapt to changes in the internal and external environments. The intricate interactions between these cells, tissues, and organs exemplify the system's complexity and importance.

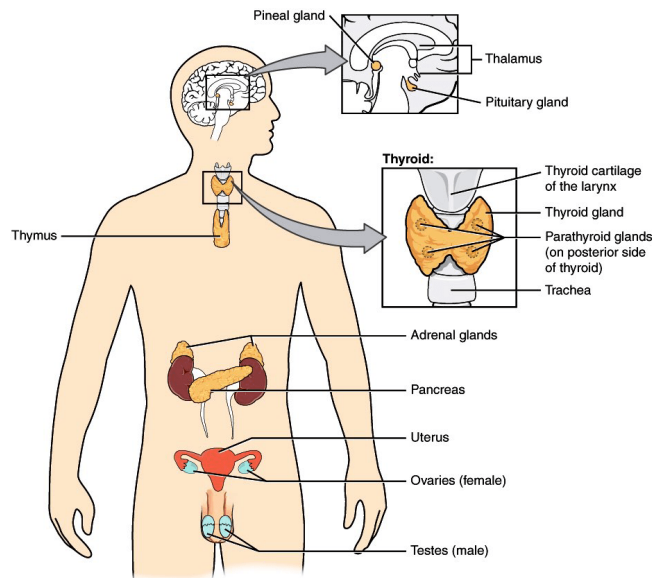


Figure 3.1.1: Endocrine System. Endocrine glands and cells are located throughout the body and play an important role in maintaining equilibrium (homeostasis). (CC BY 4.0; via [Building a Medical Terminology Foundation](#)).

Figure 3.1.1 maps major endocrine glands in the body and includes close-up insets for the brain and thyroid region.

- In the brain inset, three structures are labeled: pineal gland, thalamus, and pituitary gland.
- In the neck inset labeled “Thyroid,” the diagram labels the thyroid cartilage of the larynx, thyroid gland, parathyroid glands (noted as being on the posterior side of the thyroid), and the trachea.
- On the main body diagram, the thymus is labeled in the upper chest.
- In the upper abdomen, the adrenal glands are shown above the kidneys, and the pancreas is labeled across the abdomen.
- In the pelvis, reproductive endocrine organs are labeled: ovaries (female) and uterus, and testes (male).

The ductless endocrine glands are not to be confused with the body’s exocrine system, whose glands release their secretions through ducts. Examples of exocrine glands include the sebaceous and sweat glands of the skin. As just noted, the pancreas also has an exocrine function: most of its cells secrete pancreatic juice through the pancreatic and accessory ducts to the lumen of the small intestine.

How Hormones Work

Hormones mediate changes in target cells by binding to specific hormone receptors. In this way, even though hormones circulate throughout the body and come into contact with many different cell types, they only affect cells that possess the necessary receptors. Receptors for a specific hormone may be found on many different cells or may be limited to a small number of specialized cells. For example, thyroid hormones act on many different tissue types, stimulating metabolic activity throughout the body. When a cell displays more receptors in response to a hormone, this is called up-regulation, but when a cell reduces its number of receptors for a particular hormone, this is called down regulation.

Receptor binding alters cellular activity and results in an increase or decrease in normal body processes. Depending on the location of the protein receptor on the target cell and the chemical structure of the hormone, hormones can mediate changes directly by binding to intracellular hormone receptors and modulating gene transcription, or indirectly by binding to cell surface receptors and stimulating signaling pathways.

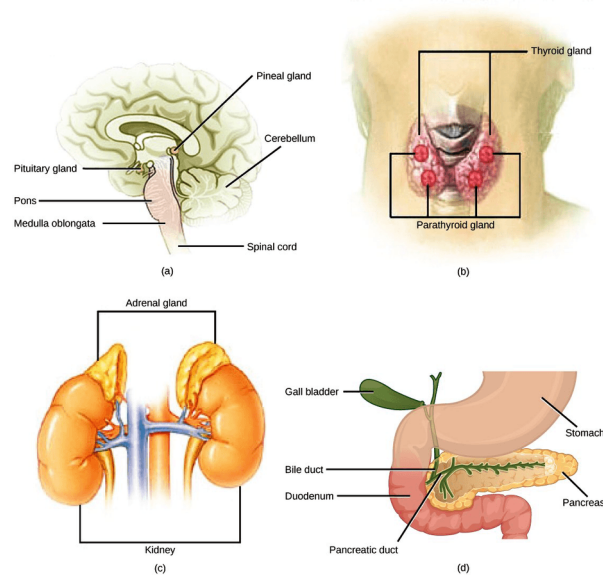


Figure 3.1.2: Endocrine organs: brain glands, thyroid, parathyroid, adrenal glands, and pancreas. (CC BY 4.0; via [Endocrine System](#)).

Figure 3.1.2 contains four labeled panels (a–d) showing endocrine-related organs and nearby anatomical structures.

Panel (a): Brain and brainstem (side view). From top to bottom in the diagram:

- The pineal gland is located within the brain, above the base of the brain.
- The pituitary gland is located at the base of the brain, just above the brainstem.
- The pons is located within the brainstem, parallel to the cerebellum.
- Adjacent to and below the pons is the medulla oblongata, with the spinal cord beginning just below it.

Panel (b): Neck glands

- The thyroid gland is shown in the neck region.
- Small glands labeled parathyroid gland are shown associated with the thyroid.

Panel (c): Kidneys and adrenal glands

- Two kidneys are shown.
- The adrenal gland is labeled on top of each kidney.

Panel (d): Pancreas and biliary/intestinal connections

- The bulk of the stomach is shown at the top of the diagram, with the gall bladder adjacent to it on the left.
- The bile duct is shown moving behind the stomach and into the pancreas, which nestles under the stomach and above the small intestine, adjacent to the duodenum (the section where the stomach meets the small intestine).
- The pancreatic duct leads from the pancreas toward the duodenum

Endocrine Glands: Descriptions

Pituitary Gland (hypophysis)

The pituitary gland is a small, pea-sized gland near the center of the brain. It is regulated by the hypothalamus and connected to it by a thin stalk. The pituitary has two lobes:

- Posterior lobe: Stores and secretes oxytocin and antidiuretic hormone (ADH), which are produced by the hypothalamus.
- Anterior lobe: Synthesizes and secretes hormones under the influence of the hypothalamus.

Many pituitary hormones regulate other endocrine glands. Because of this broad regulatory role, the pituitary gland is often called

the “master gland” of the endocrine system.

Thyroid Gland

The thyroid gland is a butterfly-shaped organ located anterior to the trachea and inferior to the larynx. The central region is the isthmus, and it is flanked by the left and right lobes. Thyroid tissue is composed mostly of thyroid follicles. The thyroid produces thyroid hormones (TH), including thyroxine, which increase the rate of metabolism in cells throughout the body.

Parathyroid Glands

The parathyroid glands are typically four small glands located in the neck behind the thyroid gland. They secrete parathyroid hormone (PTH), which helps maintain blood calcium levels within a narrow range. PTH stimulates bone to release calcium into the bloodstream.

Pineal Gland

The pineal gland is a tiny gland near the center of the brain. It secretes melatonin, a hormone that helps regulate the sleep-wake cycle and other body processes. Melatonin production is stimulated by darkness and inhibited by light.

Pancreas

The pancreas is located deep in the upper abdomen between the stomach and the spine. It has both exocrine and endocrine functions:

- Exocrine function: Produces digestive enzymes (such as lipase, amylase, and proteases) and bicarbonate. These secretions help digest fats, carbohydrates, and proteins and help neutralize stomach acid in the small intestine.
- Endocrine function: The islets of Langerhans produce hormones that regulate blood glucose, especially:
 - Insulin: Lowers blood sugar by signaling cells to take up glucose for energy.
 - Glucagon: Raises blood sugar by signaling the liver to release stored glucose.

Adrenal Glands

The adrenal glands sit above the kidneys and produce hormones involved in fluid balance, metabolism, immune function, and stress responses.

- Adrenal cortex: Produces:
 - Mineralocorticoids (such as aldosterone) for fluid and electrolyte balance
 - Glucocorticoids (such as cortisol) for metabolism and stress response
 - Androgens, which are precursors to sex hormones
- Adrenal medulla: Secretes epinephrine and norepinephrine during stress. These hormones increase heart and lung activity and raise blood sugar to support a rapid response.

The adrenal glands provide a clear example of the close relationship between the nervous and endocrine systems.

Gonads (ovaries and testes)

The gonads include the ovaries and testes. In addition to producing gametes, they secrete hormones that support sexual development and reproduction.

- Testes: Produce testosterone and other hormones, including:
 - Inhibin B, which helps regulate sperm production
 - Anti-Müllerian hormone, which plays a role in fetal developmentTestosterone supports male sexual development and secondary sex characteristics.
- Ovaries: Secrete estrogen and progesterone. Estrogen supports development of female secondary sex characteristics and puberty-related changes. Estrogen and progesterone also support pregnancy and regulate the menstrual cycle.

Thymus Gland

The thymus gland is located in the upper anterior mediastinum (between the lungs and behind the sternum). It produces hormones including thymosin, thymopoietin, and thymulin, which support T-cell development, maturation, and function. The thymus is most active from birth through adolescence and then gradually shrinks and is replaced by fatty tissue.

Revisiting the Concept of Homeostasis

The endocrine and nervous systems work together to maintain homeostasis by coordinating and integrating various physiological processes. The hypothalamus, a region of the brain, acts as a link between the nervous and endocrine systems. The hypothalamus contains neurosecretory cells that synthesize and secrete hormones, which are then stored and released by the posterior pituitary gland. The hypothalamus also regulates the anterior pituitary gland through releasing and inhibiting hormones, which control the secretion of various tropic hormones.

The endocrine system uses feedback loops to regulate hormone levels, which are crucial for maintaining homeostasis. The endocrine system's ability to regulate these feedback loops is crucial for maintaining homeostasis. Disruptions can lead to conditions like hyperthyroidism or hypothyroidism, where feedback mechanisms fail, resulting in hormone imbalances. Understanding these loops underscores the importance of the endocrine system in keeping our internal environment stable and responsive.

Negative feedback loops are a common mechanism by which hormones maintain homeostasis when a physiological variable deviates from its set point, hormones are released to counteract the change and restore balance. A classic example in the endocrine system is the regulation of thyroid hormones. Hypothalamus releases thyrotropin-releasing hormone (TRH) that stimulates the secretion of TSH in the pituitary gland. Increased free T4 and T3 inhibit the release of TRH and TSH through a negative feedback loop. As a result, T3 and T4 secretion and iodine uptake are reduced.

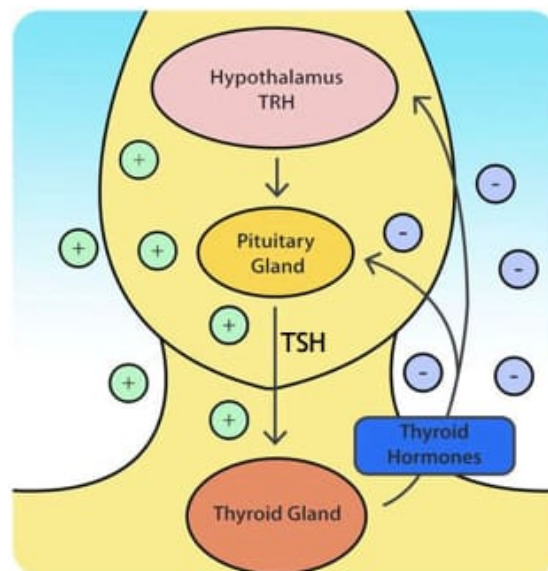


Figure 3.1.3: Negative feedback loop. This diagram shows how the thyroid gland is regulated by a negative feedback loop that also involves the hypothalamus and pituitary gland. (CC BY-NC 3.0; via CK 12, [Endocrine Hormones](#)).

Figure 3.1.3 illustrates the regulation of the thyroid gland through a negative feedback loop involving the hypothalamus and pituitary gland. The process begins when the hypothalamus releases thyrotropin-releasing hormone (TRH), signaling the pituitary gland to secrete thyroid-stimulating hormone (TSH). TSH then stimulates the thyroid gland to produce thyroid hormones, which are crucial for metabolism regulation. As levels of thyroid hormones increase in the bloodstream, they signal back to the hypothalamus and pituitary to reduce TRH and TSH production, maintaining hormone balance.

Positive feedback loops, although less common, also play a role in maintaining homeostasis. In positive feedback loops, hormones amplify the initial stimulus, leading to a rapid and intense response until a specific endpoint is reached. For instance, during childbirth, oxytocin stimulates uterine contractions, which in turn stimulate the release of more oxytocin, creating a positive feedback loop that continues until the baby is delivered.

- Stimulus: Uterine contractions during labor.
- Response: Contractions trigger the release of oxytocin.
- Effect: Oxytocin increases the intensity of contractions, leading to more oxytocin release.
- Completion: This cycle continues, amplifying contractions until the baby is born.

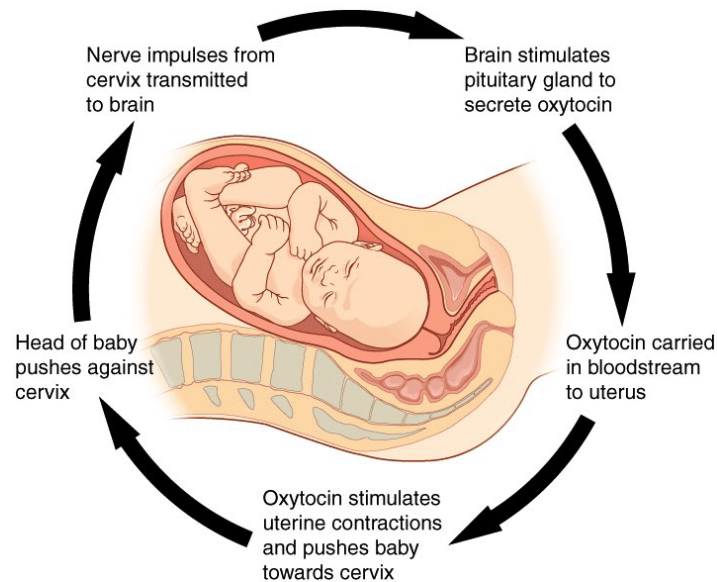


Figure 3.1.4: Positive Feedback Loop. Normal childbirth is driven by a positive feedback loop. A positive feedback loop results in a change in the body's status, rather than a return to homeostasis. (CC BY 4.0; via [Homeostasis](#)).

Figure 3.1.4 illustrates oxytocin release during labor is often described as a positive feedback loop:

1. During labor, oxytocin stimulates uterine contractions and pushes the baby toward the cervix.
2. Cervical stretching begins: As labor progresses, the cervix becomes stretched and stimulated as the head of the baby pushes against the cervix.
3. Nerve impulses from the cervix are transmitted to the brain: Sensory nerves send signals to the brain, especially to the hypothalamus and then the pituitary gland.
4. The brain stimulates the pituitary gland to secrete oxytocin into the bloodstream.
5. Oxytocin acts on the uterus: Oxytocin is carried in the bloodstream to the uterus and increases the strength and frequency of uterine contractions.
6. More cervical stretching occurs: Stronger contractions increase pressure on the cervix, causing more stretching and stimulation.
7. The cycle intensifies: Increased cervical stimulation triggers more oxytocin release, which further strengthens contractions, continuing the loop until delivery.

Endocrine Gland Histology

Understanding the histology of endocrine glands is fundamental to comprehending their functions and how they contribute to maintaining homeostasis. By examining the arrangement of cells, the presence of specific features like follicles or cords, and the vascularity of the tissue, we gain crucial insights into the structural organization of endocrine glands with their physiological roles in regulating metabolism, growth, reproduction, and numerous other essential processes — all vital components of maintaining a stable internal environment (homeostasis). Essentially, histology provides the key to unlock the secrets of how these glands orchestrate the body's complex hormonal symphony.

Connecting Structure and Function in Endocrine Glands

Pituitary Gland

Anterior (Adenohypophysis):

- **Histology:** Appears more cellular and stains darker than the posterior pituitary due to its glandular nature; composed of epithelial cells arranged in cords and clusters, surrounded by a rich network of fenestrated sinusoidal capillaries.
- **Hormones:** Growth Hormone (GH), Prolactin (PRL), Adrenocorticotropic Hormone (ACTH), Thyroid Stimulating Hormone (TSH), Follicle Stimulating Hormone (FSH), Luteinizing Hormone (LH).
- **Functions:** Growth, lactation, stress response, metabolism, reproduction.

Posterior (Neurohypophysis):

- **Histology:** Appears lighter-staining and less cellular than the anterior lobe; consists of neural tissue rather than glandular cells.
- **Hormones:** Oxytocin, Antidiuretic Hormone (ADH or Vasopressin).
- **Functions:** Uterine contraction, milk ejection, water reabsorption.

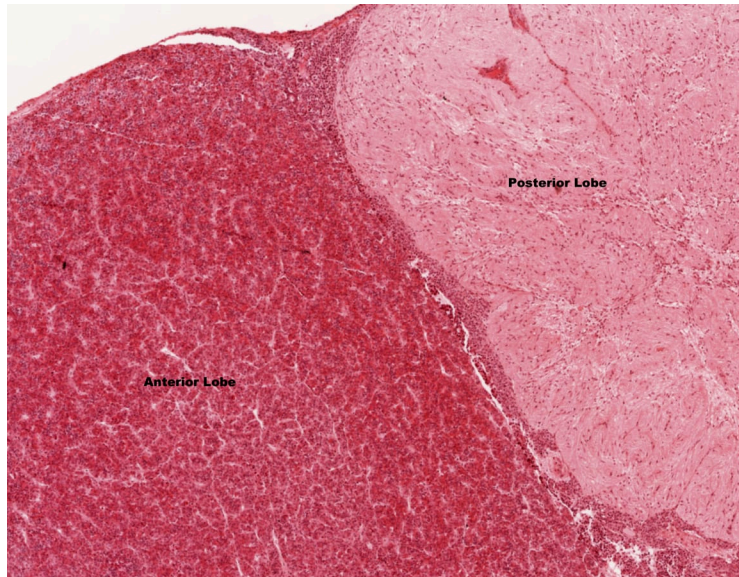


Figure 3.1.5: Microscopic differentiation between the anterior and posterior lobes of the pituitary gland, highlighting structural contrasts. (CC BY-NC-SA 4.0; Yancy Aquino via [Pituitary Gland and Hypothalamus](#)).

The above Figure 3.1.5 represents a histological section of the pituitary gland showing two anatomically distinct regions. The anterior lobe, located on the left, is more densely cellular and has a compact, granular tissue organization, while the posterior lobe, on the right, is less cellular and has a looser, fibrous structure. The sharp boundary between these regions demonstrates their distinct histological organization and functional differentiation.

Thyroid Gland

- **Histology:**
 - **Follicles:** Spherical structures lined by simple cuboidal follicular cells.
 - **Colloid:** Central extracellular space filled with thyroglobulin (precursor to thyroid hormones).
 - **C Cells (Parafollicular Cells):** Scattered cells between follicles that secrete calcitonin.
- **Hormones:** T3, T4, Calcitonin.
- **Functions:** Metabolism, calcium regulation.

Parathyroid Gland

- **Histology:**
 - **Chief (Principal) Cells:** Prominent central nuclei surrounded by pale cytoplasm; produce parathyroid hormone (PTH).
 - **Oxyphil Cells:** Larger but fewer; express genes related to calcium sensing and PTH regulation.
- **Hormones:** Parathyroid Hormone (PTH).
- **Functions:** Calcium regulation.

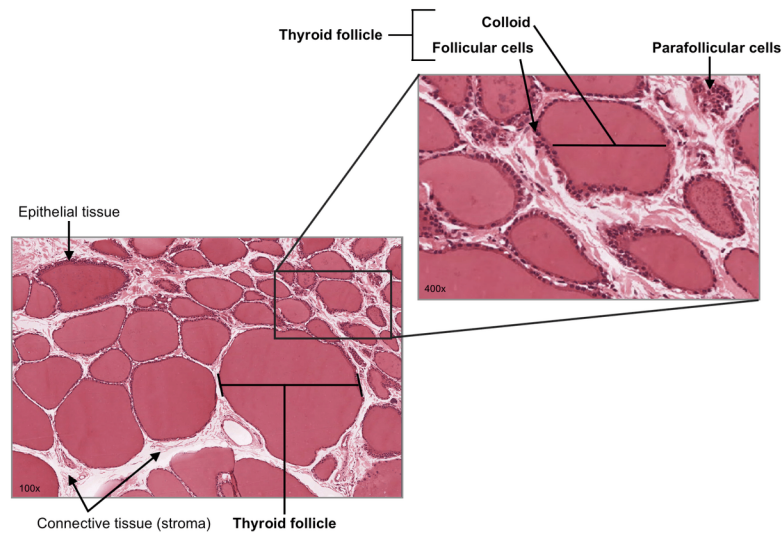


Figure 3.1.6: Detailed histological view of thyroid gland at low and high magnification, illustrating follicles, colloid, and cell types. (CC BY-NC-SA 4.0; via [Thyroid Gland and Parathyroid Gland](#)).

The Figure 3.1.6 shows a histological section of the thyroid gland with a lower-magnification view and a higher-magnification inset.

- The lower-magnification image (labeled 100 times) shows many round to oval thyroid follicles of varying sizes. Each follicle has a central lumen filled with colloid and is surrounded by a thin layer of epithelial tissue. The follicles are separated by connective tissue (stroma).
- A boxed region is enlarged in the higher-magnification inset (labeled 400 times). In this inset, a single thyroid follicle is labeled to identify:
 - Colloid in the center of the follicle.
 - Follicular cells forming the epithelial lining around the colloid.
 - Parafollicular cells located in the tissue adjacent to the follicle (outside the follicular lining).

Adrenal Gland

1. Adrenal Cortex:

- Histology:
 - Zona Glomerulosa: Columnar cells in clusters
 - Zona Fasciculata: Polygonal cells in columns
 - Zona Reticularis: Round cells in irregular cords
- Hormones: Aldosterone, Glucocorticoids, Gonadocorticoids
- Functions:
 - Regulate sodium and potassium concentration
 - Stress response and metabolism
 - Puberty and sex drive

2. Medulla:

- Histology: Chromaffin cells are columnar in shape, arranged in clusters, and noticeably basophilic
- Hormones: Epinephrine, Norepinephrine
- Functions: Sympathetic nervous system effects; fight-or-flight response

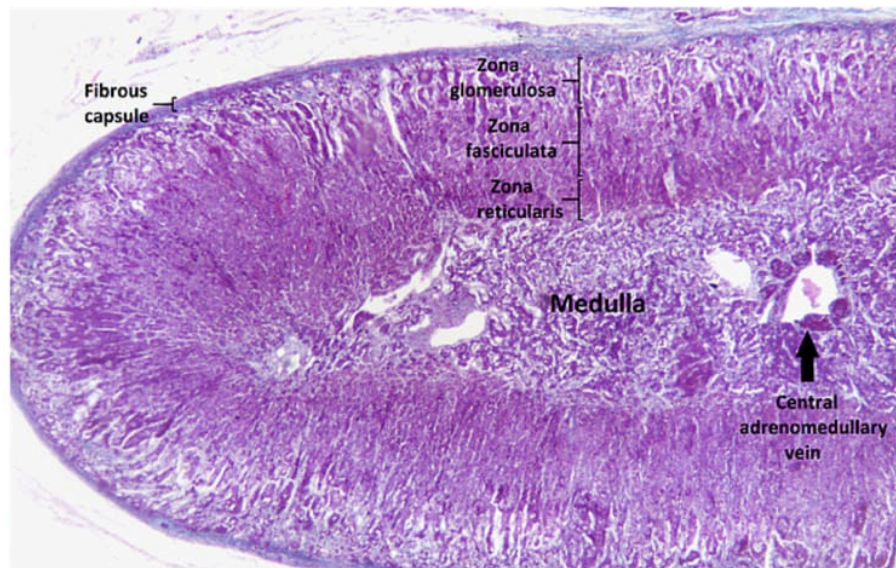


Figure 3.1.7: Adrenal gland histology. Microscopic view of the adrenal gland showcasing the three distinct layers of the cortex (zona glomerulosa, zona fasciculata, zona reticularis) and the medulla, highlighting the unique cellular organization of each region. (CC BY-NC-SA 4.0; Aylin Marz; Ganesan Kamatchi; Joseph D'Silva; Krishnan Prabhakaran; Rajeev Chandra; and Solomon Isekeije via [The Endocrine System](#)).

Figure 3.1.7 shows the adrenal gland under the microscope, highlighting its structural organization. The outer fibrous capsule encloses the cortex, which is divided into three zones: zona glomerulosa (secretes mineralocorticoids like aldosterone), zona fasciculata (produces glucocorticoids such as cortisol), and zona reticularis (secretes androgens). The inner medulla contains chromaffin cells that release catecholamines (epinephrine and norepinephrine) and is associated with the central adrenomedullary vein.

Pancreas

Islets of Langerhans:

- Histology: Clusters of endocrine cells within the exocrine pancreas (acini), including alpha cells (produce glucagon) and beta cells (produce insulin).
- Hormones: Insulin, Glucagon
- Functions: Blood glucose regulation

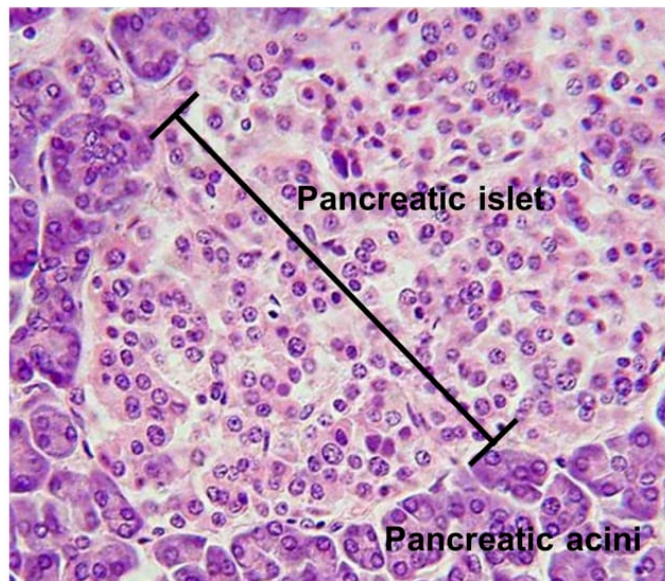


Figure 3.1.8: Microscopic view of pancreatic tissue highlighting the structural contrast between endocrine islets and exocrine acini. (CC BY-NC-SA 4.0; Aylin Marz; Ganesan Kamatchi; Joseph D'Silva; Krishnan Prabhakaran; Rajeev Chandra; and Solomon Isekeije via [The Endocrine System](#)).

Figure 3.1.8 is the microscope image shows pancreatic tissue with two labeled components.

- A pale-staining, rounded cluster of cells is labeled pancreatic islet (islet of Langerhans). It appears as a lighter region compared with surrounding tissue.
- The darker-staining tissue surrounding the islet is labeled pancreatic acini, which are tightly packed clusters of exocrine cells.
- A bracket marks the boundary between the pancreatic islet and the surrounding pancreatic acini, emphasizing the contrast between the lighter endocrine islet and the darker exocrine tissue.

Hormone Imbalances and Their Impact on Health

Hormone imbalances occur when there is too much or too little of a hormone in the bloodstream, disrupting the delicate control the endocrine system has over bodily processes. Even small hormonal fluctuations can have significant health consequences, as each hormone has a specific role and target in the body.

Common health conditions associated with hormone imbalance include acromegaly, Addison's disease, Cushing's syndrome, diabetes (insulin imbalance), thyroid disorders (such as hypothyroidism or hyperthyroidism), Grave's disease, Goiter, polycystic ovary syndrome (PCOS), and menopause.

- Acromegaly is caused by chronic hypersecretion of growth hormone (GH) in adults, almost always due to a benign pituitary adenoma. Because the epiphyseal growth plates are already closed, excess GH does not cause increased height; instead, it leads to enlargement of bones and soft tissues, especially in the hands, feet, jaw, and facial features. Patients often develop joint pain, insulin resistance, and cardiovascular complications if untreated.
- Addison's disease is primary adrenal cortical failure, most commonly due to autoimmune destruction of the adrenal cortex. Production of glucocorticoids (cortisol) and mineralocorticoids (aldosterone) is decreased. Clinical features include fatigue, weight loss, hypotension, hyperpigmentation, hyponatremia, hyperkalemia, and craving for salt. Without treatment, patients are at risk for an acute adrenal crisis, characterized by severe hypotension, confusion, electrolyte disturbances, and shock, which is a medical emergency.
- Cushing's syndrome refers to the clinical state of chronic exposure to excess glucocorticoids (usually cortisol), from either endogenous overproduction (for example, ACTH-secreting pituitary adenoma or adrenal tumor) or exogenous glucocorticoid therapy. Classic features include central (truncal) obesity, "moon face," "buffalo hump," muscle wasting, thin skin with easy bruising and striae, hypertension, glucose intolerance or diabetes, osteoporosis, and mood or cognitive changes. Untreated, it increases cardiovascular and metabolic morbidity.
- Type 1 diabetes mellitus is an autoimmune destruction of pancreatic β -cells, leading to an absolute deficiency of insulin. As a result, blood glucose levels become markedly elevated (hyperglycemia), and patients are dependent on exogenous insulin for

survival. It often presents in childhood or adolescence with polyuria, polydipsia, weight loss, and risk of diabetic ketoacidosis.

- Type 2 diabetes mellitus is characterized primarily by insulin resistance, often accompanied by a relative insulin secretory defect. It is strongly associated with obesity, physical inactivity, and genetic predisposition. Hyperglycemia develops gradually. Common symptoms include polydipsia, polyuria, fatigue, and blurred vision, though many patients are initially asymptomatic. Chronic hyperglycemia can damage blood vessels and nerves, leading to cardiovascular disease, nephropathy, retinopathy, and peripheral neuropathy.
- A goiter is an abnormal enlargement of the thyroid gland. It may occur in the setting of iodine deficiency, autoimmune thyroid disease (such as Graves' disease or Hashimoto thyroiditis), or nodular thyroid disease. Goiters can be associated with normal, decreased, or increased thyroid hormone production. Clinically, patients may have visible or palpable neck swelling; large goiters can cause dysphagia, dyspnea, or a sensation of neck tightness.
- Graves' disease is an autoimmune cause of hyperthyroidism. Thyroid-stimulating immunoglobulins (TSIs) bind to and activate the TSH receptor, driving excess thyroid hormone synthesis and gland enlargement. In addition to typical hyperthyroid symptoms (weight loss, heat intolerance, palpitations, tremor, anxiety), Graves' disease can present with Graves' ophthalmopathy (exophthalmos, eye irritation, lid lag) and, less commonly, pretibial myxedema. Management may include antithyroid drugs, radioactive iodine, or thyroid surgery.
- Hyperthyroidism refers to excessive circulating thyroid hormones (T3 and T4) from any cause (e.g., Graves' disease, toxic multinodular goiter, thyroiditis). Increased thyroid hormones elevate basal metabolic rate and sympathetic nervous system activity. Clinical manifestations include unexplained weight loss despite normal or increased appetite, tachycardia or palpitations, heat intolerance, sweating, nervousness, insomnia, and sometimes muscle weakness and osteoporosis if prolonged.
- Hypothyroidism is a state of deficient thyroid hormone production. Common causes include Hashimoto thyroiditis, iodine deficiency, or iatrogenic causes (thyroid surgery, radioactive iodine). Reduced thyroid hormone slows metabolic processes. Patients often present with fatigue, weight gain, cold intolerance, constipation, dry skin, bradycardia, depression, and menstrual irregularities. Long-standing or severe hypothyroidism can result in myxedema and significant cardiovascular effects.
- PCOS is a common endocrine disorder of reproductive-aged women, affecting roughly 6–13%, with many cases undiagnosed. It is characterized by a combination of:
 - Hyperandrogenism (clinical and/or biochemical), often with elevated testosterone
 - Ovulatory dysfunction (oligo-ovulation or anovulation), leading to irregular menstrual cycles and subfertility or infertility
 - Polycystic ovarian morphology on ultrasound in many, but not all, patients

Clinical features can include hirsutism, acne, androgenic alopecia, central weight gain, acanthosis nigricans (dark, velvety skin patches associated with insulin resistance), skin tags, mood changes, and sleep disturbances. PCOS is strongly associated with insulin resistance, impaired glucose tolerance or type 2 diabetes, dyslipidemia, and increased cardiovascular risk over time.

3.2: Activity 1

Word Scramble Challenge

This approach is designed to help practice spelling and learn new words. In this activity, the definition of selected endocrine related terms are given. Your job is to unscramble the scrambled form by rearranging the letters to reveal the correct term related to the definitions.

Table 3.2.1: Scrambled and unscrambled endocrine-related terms with their definitions

Definition of terms	Scrambled term	Unscrambled
Enlarged thyroid gland	REIGTO	
Nerve irritability and muscle cramps from hypocalcemia	E N A T T Y	
Measures levels of hormones in blood plasma	A M I D R I O M O A N S A U S Y	
Results from hyposecretion of thyroid hormones in an adult	Y M D E A M X E	
A hormone regulating sodium balance	LDOSTERONA	
Protruding eyeballs	H P X H O T A E L O S M	
Sugar in the urine	Y C R L O I S G U A	
A hormone increasing blood glucose	LUGAGCON	
A stress hormone	LORITCSOL	
Hormones regulating reproductive function	NTOGDOAROPINS	
Protruding eyeballs	HPXHOTAELOSM	

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3.3: Activity 2

Endocrine Gland Hormone Matching

Identify the endocrine glands indicated by letters A - J in the figure and then match them with the hormone(s) they produce. This activity will strengthen your understanding of the relationship between the anatomical location of endocrine glands and the hormones they secrete.

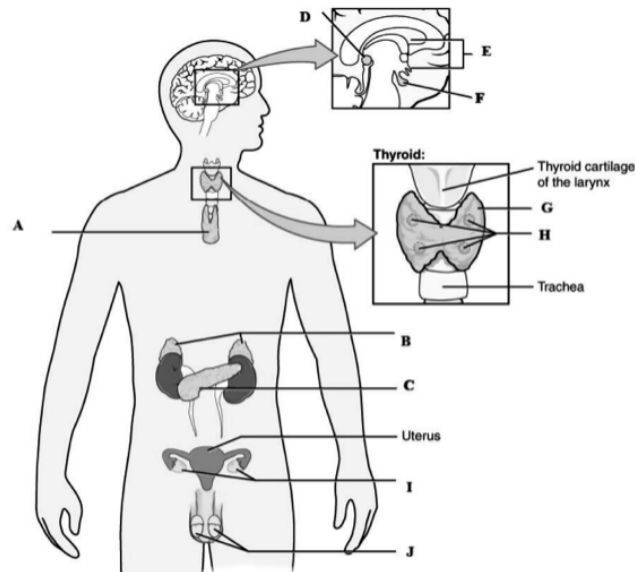


Figure 3.3.1: Overview of endocrine glands and their anatomical positions, including detailed views of pituitary and thyroid structures. (CC BY-SA 4.0; via Endocrine System).

Figure 3.3.1 shows the human endocrine system with labeled glands such as pituitary in the brain, thyroid in the neck, adrenal glands above the kidneys, pancreas, and reproductive organs. Insets provide detailed views of the brain showing hypothalamus and pituitary, and the thyroid gland near the trachea.

Identifying Letter	Gland/Hormone Secreting Organ	Hormone Secreted
A		
B		
C		
D		
E		
F		
G		
H		
I		
J		

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3.4: Activity 3

Functional Connections: Hypothalamic Control of the Anterior Pituitary

Purpose/Rationale

The hypothalamus and anterior pituitary form a central control hub for the endocrine system. Understanding how hypothalamic hormones regulate anterior pituitary hormones, and how feedback loops maintain homeostasis, is essential for interpreting clinical endocrine disorders. This lab will guide you step-by-step to:

- Trace regulatory pathways from hypothalamus → anterior pituitary → target gland/tissue
- Explain feedback mechanisms
- Connect pathway disruptions to real clinical signs and diseases

Step-by-Step Instructions

Step 1 – Choose Your Hormones

Select two of the following anterior pituitary hormones:

- Growth hormone (GH)
- Thyroid-stimulating hormone (TSH)
- Adrenocorticotrophic hormone (ACTH)
- Prolactin (PRL)
- Luteinizing hormone (LH)
- Follicle-stimulating hormone (FSH)

You may not choose the same hormone twice, and you should avoid selecting two hormones with identical target tissues unless you plan to highlight their differences clearly.

Step 2 – Create a Functional Pathway Diagram for Each Hormone

For each chosen hormone, draw a flow diagram or concept map that includes:

- Hypothalamus: specific releasing/inhibiting hormone name(s)
 - Example: GHRH, somatostatin, TRH, CRH, GnRH, dopamine (PIH), etc.
- Anterior pituitary: the hormone you selected (GH, TSH, etc.)
- Target organ(s) and target hormone(s) (if any)
 - Example: TSH → thyroid gland → T_3/T_4
 - ACTH → adrenal cortex → cortisol
- Feedback arrows: show negative (and positive, if applicable) feedback to hypothalamus and/or anterior pituitary

Your diagram must:

- Be clearly labeled (structures, hormones, direction of effect)
- Use arrows to indicate direction of regulation (stimulation vs inhibition)
- Distinguish feedback (e.g., dashed arrows, different color, or clear labels)

You may hand-draw and photograph/scan your diagram or create it digitally, as long as it is readable and professional.

Step 3 – Written Explanation for Each Hormone

For each of your two hormones, write a short explanation (250–350 words) that includes:

A. Hypothalamic Regulation

1. Name the specific hypothalamic hormone(s) that regulate your chosen hormone.
2. Describe how they act (stimulate or inhibit secretion).
3. Explain the anatomical/functional pathway briefly (e.g., hypothalamic hormone → hypophyseal portal system → anterior pituitary cells).
4. Example elements (do not just copy):
 - GH: GHRH stimulates, somatostatin inhibits somatotrophs.
 - TSH: TRH stimulates thyrotrophs.
 - Prolactin: primarily inhibited by dopamine (PIH), stimulated by TRH and suckling.

B. Feedback Mechanisms

- Describe the negative feedback loop(s) (and positive, if applicable):
- Identify which target hormone(s) or physiological changes feed back to:
 - the hypothalamus
 - the anterior pituitary
- Explain how these feedback loops help maintain homeostasis (e.g., prevent excessive hormone levels, stabilize metabolism, fluid balance, growth, reproduction).
- Example (TSH):
 - Rising T_3/T_4 levels inhibit TRH release from hypothalamus and TSH release from pituitary, preventing overproduction of thyroid hormone.

C. Clinical Significance

- Briefly describe what can happen if the hormone level is:
 - Too high (hypersecretion) OR
 - Too low (hyposecretion)
- Include at least one named clinical condition associated with dysregulation of this axis, and 2–3 key signs/symptoms.
- Connect one symptom back to mechanism when possible (e.g., “excess cortisol from ACTH-producing tumor → protein breakdown → muscle wasting, thin skin”).
- Examples:
 - GH: gigantism, acromegaly, dwarfism
 - TSH: hyperthyroidism, hypothyroidism
 - ACTH: Cushing disease, adrenal insufficiency
 - Prolactin: galactorrhea, infertility, amenorrhea
 - LH/FSH: infertility, delayed puberty, menstrual irregularities, hypogonadism

Expectations for Quality

Your work should:

- Use correct terminology (e.g., “adenohypophysis” for anterior pituitary is acceptable but optional).
- Be organized and logically structured (each hormone clearly separated).
- Be your own work; paraphrase and synthesize, do not copy/paste.
- Cite any external sources you use (e.g., textbook, reputable websites) in a simple reference list.

Suggested Structure for Submission

1. Hormone 1:
 - Diagram 1 (insert image)
 - Hypothalamic Regulation
 - Feedback Mechanisms ◦ Clinical Significance
2. Hormone 2:

- Diagram 2 (insert image)
- Hypothalamic Regulation
- Feedback Mechanism

3.5: Activity 4

A Microscopic Journey Through the Endocrine Glands

Materials

- Compound microscope
- Microscope lens paper
- Microscope lens cleaning solution
- Prepared slides
 - Pituitary gland (Hypophysis)
 - Thyroid and Parathyroid Glands
 - Pancreas
 - Adrenal gland

Pituitary gland (Hypophysis)

1. Obtain a prepared slide of the pituitary gland.
2. Using low power (10 times), identify the two main parts: the anterior pituitary (adenohypophysis) and the posterior pituitary (neurohypophysis). Note their distinct staining characteristics.
3. Increase magnification to high power (40 times).
4. In the anterior pituitary - Locate the irregular clusters or cords of cells.
5. In the posterior pituitary - Observe the unmyelinated nerve fibers and pituicytes (glial cells). The tissue has a lighter, more fibrous appearance than the anterior lobe.
6. Record observations: Drawing or microphotograph (10 times lens and 40 time lens) in the space.

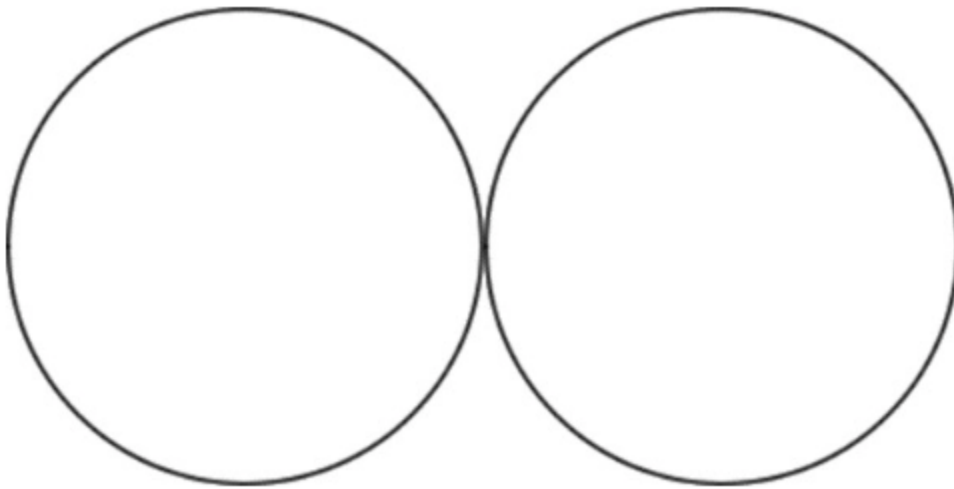


Figure 3.5.1: Observations of histology of pituitary glands drawing or microphotograph (10 times lens and 40 times lens) (Public Domain; Lakshmikanta Sengupta).

Thyroid gland

1. Obtain a prepared slide of the thyroid gland.
2. Using low power (10 times), locate the characteristic spherical structures called thyroid follicles. Note the substance inside the follicles, which is the colloid.
3. Switch to high power (40 times) to identify the different cells surrounding the follicles:
 - Follicular cells: Simple cuboidal epithelial cells that form the walls of the follicles.

- Parafollicular cells (C cells): Look for these cells in clusters between the follicles. They are pale-staining and secrete calcitonin.
4. Record observations: Drawing or microphotograph (10 times lens and 40 times lens) in the space.
 5. Label the follicles, follicular cells, parafollicular cells, and colloid.

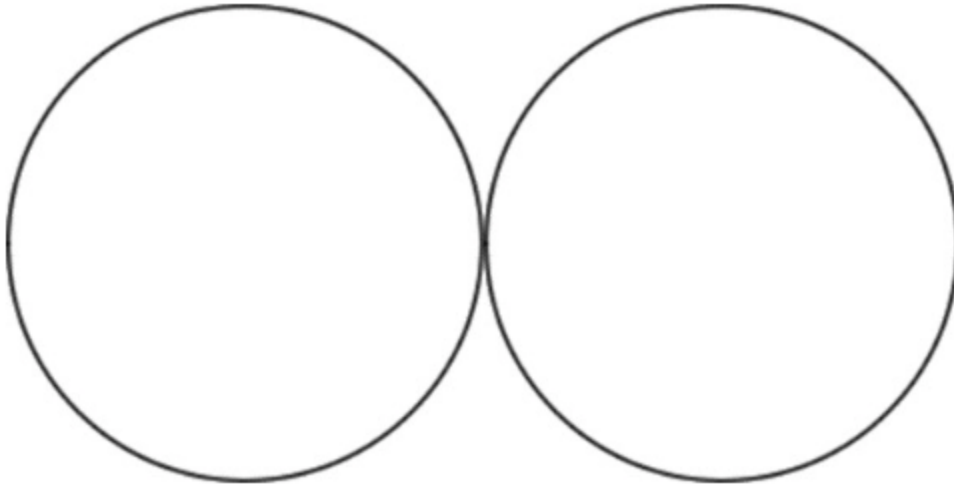


Figure 3.5.2: Observations of histology of thyroid glands drawing or microphotograph (10 times lens and 40 times lens) ([Public Domain](#); Lakshmikanta Sengupta).

Pancreas

1. Obtain a prepared slide of the pancreas.
2. Use low power to differentiate between the darkly stained exocrine acini and the lightly stained, rounded pancreatic islets (of Langerhans) - the endocrine portion of the pancreas.
3. Notice the high density of capillaries within and surrounding the islets, which facilitates the quick diffusion of hormones into the bloodstream.
4. Record observations: Drawing or microphotograph (10 times lens) in the space.
5. Label the exocrine acini and the islet of Langerhans.

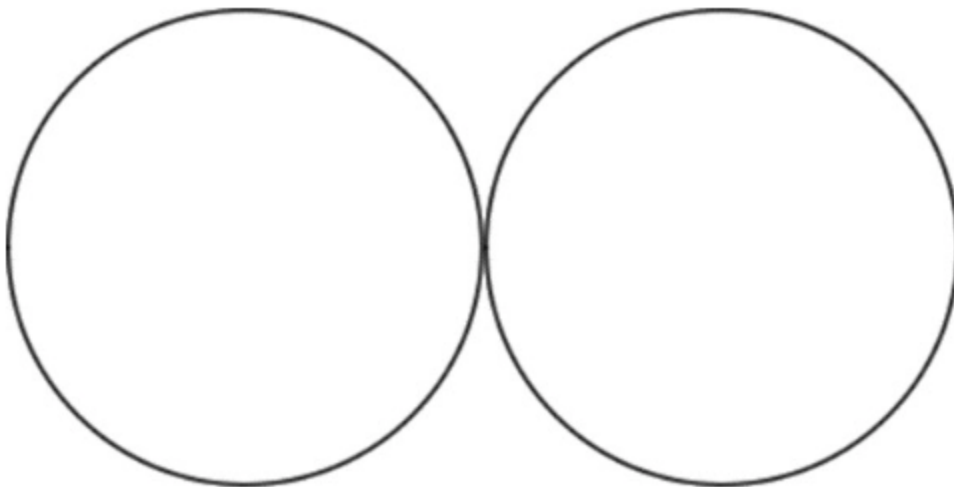


Figure 3.5.3: Observations of histology of pancreas drawing or microphotograph 10 times. ([Public Domain](#); Lakshmikanta Sengupta).

Adrenal gland

1. Obtain a prepared slide of the adrenal gland. Use low power to identify the outer capsule, the cortex, and the inner medulla.
2. Move to a higher magnification to observe the three distinct zones of the adrenal cortex (from outside to inside):

- Zona glomerulosa - Identify the small, rounded clusters of cells located just beneath the capsule. These cells produce mineralocorticoids like aldosterone.
 - Zona fasciculata - Locate the broad, middle layer consisting of cells arranged in long cords. Note the pale, foamy or vacuolated appearance of these cells, which is characteristic of steroid-secreting cells. These cells produce glucocorticoids like cortisol.
 - Zona reticularis - Find the innermost cortical layer, where the cells are arranged in a netlike or anastomosing pattern. This zone produces sex hormones.
3. In the adrenal medulla: Observe the large, polygonal chromaffin cells, which are arranged in clusters around blood vessels and have a basophilic cytoplasm. These cells secrete catecholamines (epinephrine and norepinephrine).
 4. Record observations: Drawing or microphotograph (10 times lens and 40 times lens) in the space.
 5. Label the capsule, cortex (with all three zones), and medulla.

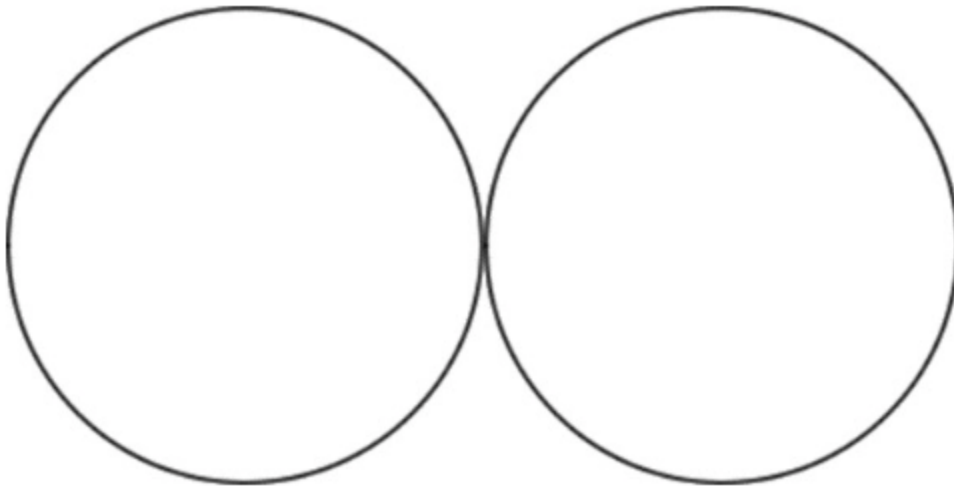


Figure 3.5.4: Observations of histology of thyroid glands drawing or microphotograph (10 times lens and 40 time lens). (Public Domain; Lakshmikanta Sengupta).

3.6: Activity 5

Case studies

By presenting real-world clinical scenarios, case studies encourage active learning, critical thinking, and the application of theoretical knowledge to practical situations.

Case 1

A 28-year-old postpartum woman has fatigue, weight gain, dry skin, constipation, and feels cold. Labs later show high TSH and low free T4.

- Anatomy anchor: Thyroid in the front of the neck; follicles store hormone precursor
- Physiology keys:
 - Hypothalamus (TRH) → Pituitary (TSH) → Thyroid (T4/T3).
 - T4 converts to T3 in tissues; T3 sets metabolic pace.
 - Low T4 removes negative feedback, so TSH rises.
- Quick tasks:
 - Sketch the TRH-TSH-T4/T3 loop and label “negative feedback.”

Discussion points

1. Based on her symptoms and lab results (high TSH, low free T4), what is the most likely diagnosis? Is the problem primarily at the level of the hypothalamus, anterior pituitary, or thyroid gland? Explain your reasoning using the TRH-TSH-T4/T3 axis.
2. Using the TRH-TSH-T4/T3 negative feedback loop you sketched, explain why TSH is elevated when free T4 is low. What does this tell you about how the pituitary and hypothalamus are functioning in this patient?
3. How does low T3/T4 affect basal metabolic rate, GI motility, skin/hair, and thermoregulation?

Case 2

Sebastian, a 34-year-old business executive, comes to the doctor complaining of feeling jittery and anxious. He also reports experiencing heart palpitations, heat intolerance, and unexplained weight loss despite an increased appetite. Upon examination, the doctor notices John's eyes appear to be bulging slightly.

Initial lab work:

- Thyroid-stimulating hormone (TSH): Very low.
- Thyroxine (T4) and Triiodothyronine (T3): Elevated.

Discussion points

- What is the likely cause of John's bulging eyes (exophthalmos) and other symptoms?
- Based on the lab results, what is the most likely diagnosis?

Case 3

Sarah, a 19-year-old college student, visits the campus health clinic complaining of constant fatigue, persistent weight gain despite no change in diet, and feeling cold even in warm rooms. She reports that her once regular menstrual cycles have become irregular.

Initial assessment

- Weight: Increased by 15 pounds over six months.
- Physical examination: Reveals a slightly puffy face, dry skin, and a hoarse voice.
- Vital signs: Blood pressure and heart rate are normal, but her body temperature is slightly low.

Initial lab work

- Thyroid-stimulating hormone (TSH): Elevated.
- Thyroxine (T4): Low.

Discussion points

1. Which endocrine gland is most likely malfunctioning?
2. What is the probable diagnosis?
3. Explain the negative feedback loop involving the hypothalamus, pituitary, and thyroid gland in this case.
4. What treatment is typically prescribed for this condition, and what is its mechanism of action?

Case 4

Timothy, a 16-year-old high school student, begins a rapid and disproportionate growth spurt, causing joint pain and unusual shoe size increases. He also experiences difficulty with concentration and becomes more introverted. Family members initially dismiss his symptoms as "growing pains".

Initial assessment

- Medical history: Records show Timothy was an average height and weight for his age until recently.
- Physical examination: Reveals large hands and feet and coarse facial features.
- Diagnostic imaging: An MRI shows a pituitary tumor.

Initial lab work

- Growth hormone (GH): Elevated.
- Insulin-like growth factor 1 (IGF-1): Elevated.

Discussion points

1. What is the condition affecting Timothy, and what is the underlying cause?
2. Explain the typical feedback loop for growth hormone secretion. How is this loop disrupted in this case?
3. How does this condition differ when it occurs in adults versus during adolescence?
4. How could a tumor on the pituitary gland explain Timothy's symptoms?

Key Terms and Definitions

- **Acromegaly:** Disorder in adults caused when abnormally high levels of growth hormone (GH) trigger growth of bones in the face, hands, and feet.
- **Adrenal cortex:** Outer region of the adrenal glands consisting of multiple layers of epithelial cells and capillary networks that produces mineralocorticoids and glucocorticoids.
- **Adrenal glands:** Endocrine glands located at the top of each kidney that are important for the regulation of the stress response, blood pressure and blood volume, water homeostasis, and electrolyte levels.
- **Adrenal medulla:** Inner portion of adrenal glands that produces epinephrine and norepinephrine.
- **Adrenocorticotropic Hormone (ACTH):** Anterior pituitary hormone that stimulates the adrenal cortex to secrete corticosteroid hormones (also called Corticotropin).
- **Aldosterone:** Hormone produced and secreted by the adrenal cortex that stimulates sodium and fluid retention and increases blood volume and blood pressure.
- **Alpha cell:** Endocrine cell of the pancreatic islets that produces the hormone glucagon.
- **Anterior Pituitary:** Portion of the pituitary gland that produces six hormones; also called adenohypophysis.
- **Antidiuretic Hormone (ADH):** Hypothalamic hormone that is stored by the posterior pituitary and signals the kidneys to reabsorb water.
- **Atrial Natriuretic Peptide (ANP):** Hormone produced by the heart to reduce blood volume, pressure, and Na⁺ concentration.
- **Autocrine:** Chemical signal that elicits a response in the same cell that secreted it.
- **Beta cell:** Endocrine cell of the pancreatic islets that produces the hormone insulin.
- **Calcitonin:** Peptide hormone produced and secreted by the parafollicular cells (C cells) of the thyroid gland that functions to decrease blood calcium levels.
- **Colloid:** Fluid inside the thyroid follicle that contains the glycoprotein thyroglobulin.
- **Diabetes Mellitus:** Condition caused by destruction or dysfunction of the beta cells of the pancreas or cellular resistance to insulin that results in abnormally high blood glucose levels.
- **Endocrine gland:** Gland that secretes hormones into the surrounding interstitial fluid, which then diffuse into blood and are carried to various organs and tissues within the body.
- **Epinephrine:** Primary and most potent catecholamine hormone secreted by the adrenal medulla in response to short-term stress; also called adrenaline.
- **Erythropoietin (EPO):** Hormone produced by the kidneys to stimulate red blood cell production in the bone marrow.
- **Gigantism:** Disorder in children caused when abnormally high levels of GH prompt excessive growth.
- **Glucagon:** Pancreatic hormone that stimulates the catabolism of glycogen to glucose, thereby increasing blood glucose levels.
- **Glucocorticoids:** Hormones produced by the zona fasciculata of the adrenal cortex that influence glucose metabolism.
- **Growth hormone (GH):** Anterior pituitary hormone that promotes tissue building and influences nutrient metabolism (also called somatotropin).
- **Hashimoto's thyroiditis:** The most common form of thyroid inflammation and the most common reason people develop hypothyroidism; it is an autoimmune disorder that causes antibodies to attack the thyroid cells.
- **Hyperglycemia:** High blood sugar, sometimes a sign that diabetes is not well-controlled.
- **Hyperparathyroidism:** A condition in which one or more of the parathyroid glands become overactive and produce too much parathyroid hormone (PTH). This excess PTH raises calcium levels in the blood, which can lead to bone loss, kidney stones, fatigue, and abdominal pain.
- **Hyperthyroidism:** A condition in which the thyroid gland produces too much thyroxine (T4) and sometimes triiodothyronine (T3), leading to overactive metabolism.
- **Hypoglycemia:** Low blood sugar, sometimes called an insulin reaction.
- **Hypoparathyroidism:** Underactive parathyroid glands result in reduced calcium levels, causing muscle spasms (tetany), nerve excitability, and heart rhythm disturbances.
- **Hypophyseal portal system:** Network of blood vessels that enables hypothalamic hormones to travel into the anterior lobe of the pituitary without entering systemic circulation.
- **Hypopituitarism:** A rare disorder resulting from the pituitary gland's inability to produce sufficient amounts of one or more crucial hormones, impacting various bodily systems.
- **Hypothyroidism:** A condition in which the thyroid gland does not produce enough thyroid hormones (primarily thyroxine, or T4, and sometimes triiodothyronine (T3)) to meet the body's needs.
- **Insulin:** Pancreatic hormone that enhances the cellular uptake and utilization of glucose, thereby decreasing blood glucose levels.

- **Islets of Langerhans (Pancreatic islets):** Clusters of endocrine cells in the pancreas that produce insulin, glucagon, and other hormones.
- **Isthmus:** Tissue mass that connects the two lobes of the thyroid gland.
- **Leptin:** Hormone produced by adipose tissue that promotes feelings of satiety and reduces hunger.
- **Mineralocorticoids:** Hormones produced by the zona glomerulosa cells of the adrenal cortex that influence fluid and electrolyte balance.
- **Myxedema:** Severe form of hypothyroidism characterized by swelling of the skin and tissues.
- **Norepinephrine:** Secondary catecholamine hormone secreted by the adrenal medulla in response to short-term stress; also called noradrenaline.
- **Oxytocin:** Hypothalamic hormone stored in the posterior pituitary gland; important in stimulating uterine contractions during labor, milk ejection during breastfeeding, and feelings of attachment (also produced in males).
- **Pancreas:** Organ located between the stomach and the small intestine that contains exocrine and endocrine cells.
- **Paracrine:** Chemical signal that elicits a response in neighboring cells; also called paracrine factor.
- **Parafollicular cell:** Thyroid cell that produces the hormone calcitonin.
- **Parathyroid gland:** Gland located on the posterior surface of the thyroid that produces parathyroid hormone (PTH).
- **Pineal gland:** Endocrine gland that secretes melatonin, which is important in regulating the sleep-wake cycle.
- **Pituitary gland:** Bean-sized organ suspended from the hypothalamus that produces, stores, and secretes hormones in response to hypothalamic stimulation (also called hypophysis).
- **Pituitary stalk (Infundibulum):** Stalk that connects the pituitary gland to the hypothalamus.
- **Posterior pituitary:** Extension of the brain that releases hormones produced by the hypothalamus; along with the infundibulum, it is also referred to as the neurohypophysis.
- **Progesterone:** Predominantly female sex hormone important in regulating the female reproductive cycle and the maintenance of pregnancy.
- **Prolactin (PRL):** Anterior pituitary hormone that promotes development of the mammary glands and the production of breast milk.
- **Testosterone:** Steroid hormone secreted by the male testes; important in sperm maturation, male reproductive system development, and male secondary sex characteristics.
- **Thymus:** Gland located deep to the sternum that produces thymosin hormones contributing to immune system development.
- **Thyroid gland:** Endocrine gland located in the neck that produces thyroid hormones thyroxine (T4) and triiodothyronine (T3).
- **Thyroidectomy:** Surgical removal of the thyroid gland.
- **Thyroiditis:** Causes temporary hyperthyroidism, usually followed by hypothyroidism.
- **Thyroxine (T4):** The most commonly prescribed synthetic thyroid replacement.
- **Thyroid-Stimulating Hormone (TSH):** Anterior pituitary hormone that triggers secretion of thyroid hormones by the thyroid gland (also called thyrotropin).
- **Up-regulation:** An increase in the number of hormone receptors in response to increased hormone levels.

4: LYMPHATIC SYSTEM DYNAMICS

Introduction

In this lab, you'll delve into the structures and functions of the lymphatic system, understanding how it plays a crucial role for transporting lymph—a fluid rich in immune cells, helping to filter out pathogens and initiate immune responses.

We will also explore how the viral pathogens are transmitted in a population based on role-playing, develop skills to culture microbes from diverse surfaces, evaluate antimicrobial effectiveness and work on resistance of bacteria to antibiotics.

Learning Objectives

- Identify and describe key lymphatic structures and their functions in fluid balance and immunity.
- Differentiate between primary and secondary lymphoid organs and analyze their roles in immune responses.
- Examine lymphatic circulation's contribution to fluid homeostasis and immune support.
- Conduct microbial culture experiments, observe bacterial growth, and evaluate antimicrobial effectiveness using aseptic techniques.
- Discuss the implications of environmental bacteria and the importance of hygiene in preventing infections.

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: Glossary

4.1: Background Information

Overview

The lymphatic system is a series of vessels, ducts, and trunks that remove interstitial fluid from the tissues and return it to the blood. The lymphatic vessels are also used to transport dietary lipids and cells of the immune system. Cells of the immune system, lymphocytes, all come from the hematopoietic system of the bone marrow. Primary lymphoid organs, the bone marrow and thymus gland, are the locations where lymphocytes proliferate and mature. Secondary lymphoid organs are the site in which mature lymphocytes congregate to mount immune responses. Many immune system cells use the lymphatic and circulatory systems for transport throughout the body to search for and then protect against pathogens.

The lymphatic vessels begin as open-ended capillaries, which feed into larger and larger lymphatic vessels, and eventually empty into the bloodstream. Along the way, the lymph travels through the lymph nodes, which are commonly found near the groin, armpits, neck, chest, and abdomen. Humans have about 500 to 600 lymph nodes throughout the body Figure 4.1.1. Several organs and tissues that participate in immunity are also part of the lymphatic system.

An important function of the lymphatic system is to return the fluid (lymph) to the blood. Lymph may be thought of as recycled blood plasma. Blood pressure causes leakage of fluid from the blood capillaries, resulting in the accumulation of fluid in the interstitial space. In humans, 20 liters of plasma is released into the interstitial space of the tissues each day due to capillary leakage. The blood vessels reabsorb 17 liters of this interstitial fluid, leaving three liters in the tissues for the lymphatic system to transport back to the circulation. If the lymphatic system is damaged in some way, such as by being blocked by cancer cells or destroyed by injury, interstitial fluid accumulates in the tissue spaces, causing a condition called lymphedema.

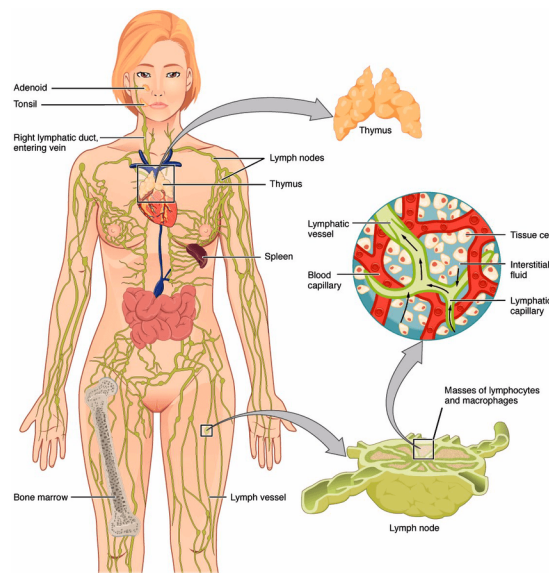


Figure 4.1.1: Anatomy of the lymphatic system lymphatic vessels in the arms and legs convey lymph to the larger lymphatic vessels in the torso. (CC BY 4.0; via [Structure of the Lymphatic System](#)).

Figure 4.1.1 summarizes major parts of the lymphatic system and includes close-up views of a lymph node and lymphatic capillaries.

- The body-wide network of lymph vessels is shown throughout the limbs and trunk.
- Lymphatic tissues in the throat are labeled adenoid and tonsil.
- A large vessel in the upper chest is labeled right lymphatic duct, entering vein, showing where lymph returns to the bloodstream.
- Clusters of lymph nodes are labeled in the upper body, and a larger lymph node is shown as a separate close-up.
- The thymus is labeled in the upper chest, and an enlarged inset shows the thymus gland by itself.
- The spleen is labeled in the upper abdomen.

- Bone marrow is labeled within a long bone in the leg.

Lymph node close-up:

- The lymph node diagram labels internal areas as masses of lymphocytes and macrophages, indicating immune cells concentrated inside the node.

Lymphatic capillary close-up:

- The circular inset labels a blood capillary, tissue cells, and interstitial fluid.
- It also labels a lymphatic capillary leading into a lymphatic vessel, illustrating how interstitial fluid enters lymphatic capillaries and becomes lymph.

Lymphatic capillaries, also called the terminal lymphatics, are vessels where interstitial fluid enters the lymphatic system to become lymph. Located in almost every tissue in the body, these vessels are interlaced among the arterioles and venules of the circulatory system in the soft connective tissues of the body Figure 4.1.2. Exceptions are the central nervous system, bone marrow, bones, teeth, and the cornea of the eye, which do not contain lymph vessels.

Lymph capillaries in the tissue spaces

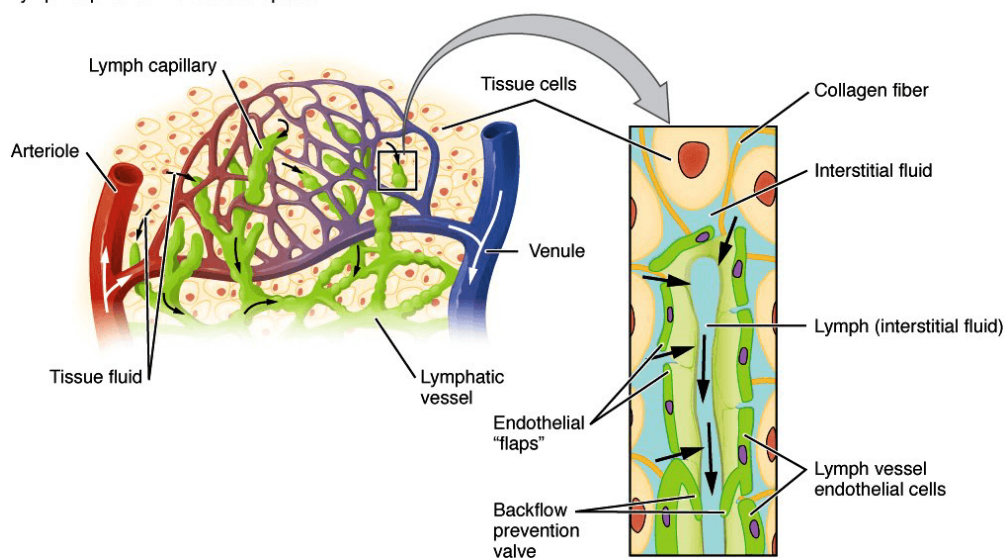


Figure 4.1.2: Lymphatic capillaries are interlaced with the arterioles and venules of the cardiovascular system. Collagen fibers anchor a lymphatic capillary in the tissue (inset). Interstitial fluid slips through spaces between the overlapping endothelial cells that compose the lymphatic capillary. (CC BY 4.0; via [Structure of the Lymphatic System](#)).

Figure 4.1.2 explains how interstitial (tissue) fluid enters lymph capillaries and becomes lymph.

- The main view shows a small blood vessel network with an arteriole feeding a capillary bed and a venule draining it. Surrounding the blood capillaries are tissue cells and tissue fluid in the spaces between cells.
- A lymph capillary begins within these tissue spaces and connects to a larger lymphatic vessel, showing where excess tissue fluid is collected.

Magnified inset (structure of a lymph capillary):

- Collagen fibers and tissue cells surround the lymph capillary.
- The fluid outside the capillary is labeled interstitial fluid; once inside the lymph capillary it is labeled lymph (interstitial fluid).
- The wall of the lymph capillary is made of lymph vessel endothelial cells.
- Overlapping edges of these cells form one-way openings labeled endothelial “flaps”, which allow interstitial fluid to enter the lymph capillary.
- A backflow prevention valve is shown, indicating that once fluid enters, it is prevented from flowing back out.

Larger Lymphatic Vessels, Trunks, and Ducts

The lymphatic capillaries empty into larger lymphatic vessels, which are similar to veins in terms of their three-tunic structure and the presence of valves. These one-way valves are located fairly close to one another, and each one causes a bulge in the lymphatic vessel, giving the vessels a beaded appearance.

In general, superficial lymphatics, follow the same routes as veins, whereas deep lymphatic vessels, of the viscera generally follow the paths of arteries. The superficial and deep lymphatics eventually merge to form larger lymphatic structures known as lymphatic trunks. On the right side of the body, the right sides of the head, thorax, and right upper limb trunks drain lymph fluid into the right subclavian vein via the right lymphatic duct Figure 4.1.3. On the left side of the body, the trunks from the remaining portions of the body drain into the larger thoracic duct, which drains into the left subclavian vein. The thoracic duct itself begins just beneath the diaphragm in the Cisterna chyli.

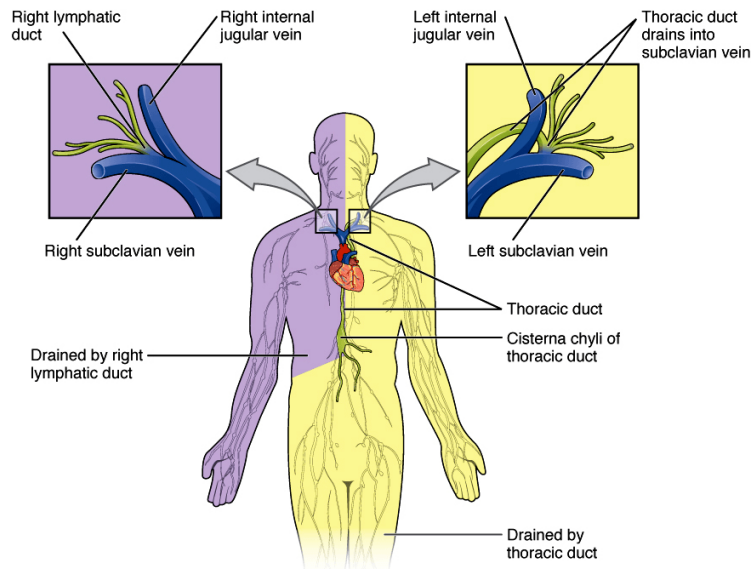


Figure 4.1.3: Major Trunks and Ducts of the Lymphatic System. The thoracic duct drains a much larger portion of the body than does the right lymphatic duct. (CC BY 4.0; via [Structure of the Lymphatic System](#)).

Figure 4.1.3 shows how lymph returns to the bloodstream through two major lymphatic ducts and where each duct drains.

- The body is divided into two drainage regions. As described earlier, a portion of the right side of the body is drained by the right lymphatic duct, while all remaining areas of the body are drained by the thoracic duct.
- The right lymphatic duct and left lymphatic ducts are located in the cervical region, at the base of the neck.

Right lymphatic duct drainage (inset at the top left):

- The right lymphatic duct is shown emptying into the venous system at the junction of the right internal jugular vein and the right subclavian vein.

Thoracic duct drainage (inset at the top right):

- The thoracic duct is shown draining into a subclavian vein on the left side, at the junction of the left internal jugular vein and the left subclavian vein.

Main thoracic duct pathway (center labels):

- The thoracic duct runs upward through the trunk.
- Its enlarged lower portion is labeled “cisterna chyli of thoracic duct,” indicating a collecting area at the base of the thoracic duct before lymph travels upward to enter the bloodstream.

Primary Lymphoid Organs

The primary lymphoid organs are the bone marrow and thymus gland. The lymphoid organs are where lymphocytes mature, proliferate, and are selected, which enables them to attack pathogens without harming the cells of the body.

- Bone Marrow - All immune cells, or leukocytes, including B cells originate from hematopoietic stem cells in the bone marrow. B cells also mature and in learn to recognize specific antigens.
- Thymus - T lymphocytes, migrate from the bone marrow to the thymus to mature. Here, they also undergo a process called thymic selection, where they learn to distinguish between the body's own (self) and non-self invaders.

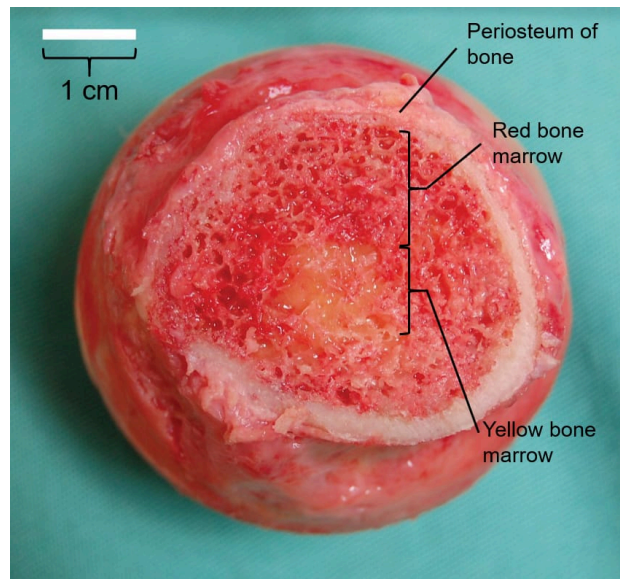


Figure 4.1.4: A layer of spongy bone over 1 cm thick with red bone marrow filling the spaces around its trabeculae forms the majority of the head of the femur, covered in periosteum and surrounding a spot of yellow bone marrow at the center slightly less than 1 cm in diameter. (CC BY 4.0; via [Anatomy of Lymphatic Organs and Tissues](#)).

Figure 4.1.4 shows a cut surface of a bone with labeled layers and marrow types.

- A scale bar indicates 1 cm.
- The outer covering is labeled periosteum of bone.
- Inside the bone, a region is labeled red bone marrow.
- A central region is labeled yellow bone marrow.

Secondary Lymphatic Organs

Secondary lymphatic organs are sites where mature lymphocytes become activated and carry out their immune functions. Lymph nodes are small, bean-shaped organs distributed throughout the body that filter lymph fluid for pathogens and foreign materials, and they are densely packed with lymphocytes capable of mounting immune responses against antigens found in the filtered lymph.

The spleen, located in the upper left quadrant of the abdomen beneath the diaphragm and next to the stomach, is encapsulated by a fibrous outer layer and divided internally into white pulp and red pulp; the white pulp is rich in lymphocytes and supports immune responses, while the red pulp contains blood-filled sinusoids that filter and recycle old red blood cells and platelets. Through these functions, the spleen acts as a blood filter, supports immunity by producing antibodies and lymphocytes, and stores blood components, making it essential for circulatory and immune health.

Mucosa-associated lymphoid tissue (MALT) consists of lymphoid tissues located in various mucous membrane layers, including the respiratory and digestive tracts, with Peyer's patches serving as a specific example found in the walls of the small intestine where they help defend against pathogens entering through the digestive system.

Tonsils and adenoids also form part of the lymphatic system and contribute significantly to immune defense; the tonsils are

located at the back of the throat and include the palatine tonsils on either side, the lingual tonsils at the base of the tongue, and the pharyngeal tonsils—commonly called adenoids—in the nasopharynx. These tissues are made of lymphoid structures containing lymphocytes that trap and destroy pathogens entering through the mouth and nose, while the adenoids, positioned high behind the nose, similarly capture airborne pathogens. Together, tonsils and adenoids provide a first line of defense that helps prevent respiratory infections.

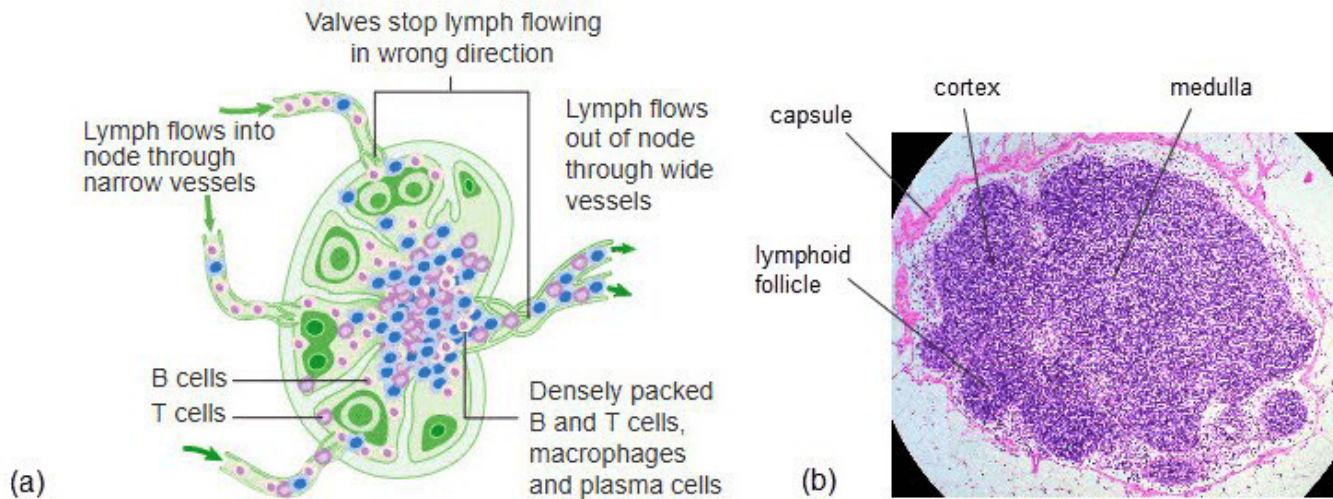


Figure 4.1.5: Lymph node structure: (a) Diagram of lymph flow and immune cells; (b) Histology showing capsule, cortex, and medulla. (CC BY 4.0; via [Anatomy of Lymphatic Organs and Tissues](#)).

Figure 4.1.5 shows two views of a lymph node.

- Part (a) is a diagram illustrating lymph flow. Lymph enters the node through afferent vessels with one-way valves that prevent backflow. Inside the node, lymph passes through regions densely packed with immune cells, including B cells, T cells, macrophages, and plasma cells, which filter debris and pathogens. Lymph exits through efferent vessels, also equipped with valves to maintain one-way flow.
- Part (b) is a histological cross-section of a lymph node stained in purple. It shows the outer capsule, cortex containing lymphoid follicles, and the medulla, which is densely packed with dark-staining immune cells.

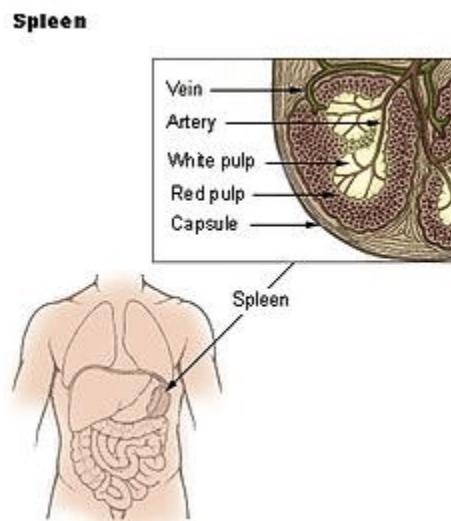


Figure 4.1.6: Highlights the spleen's key components: the vein, artery, white pulp, red pulp, and capsule. These structures filter blood and support immune functions effectively. (CC BY 4.0; via [Spleen](#)).

Figure 4.1.6 shows the spleen and a simplified diagram of its internal structure.

- A small body outline indicates the location of the spleen in the upper abdomen.
- A larger inset shows a cross-section of the spleen labeled with major features:
 - Capsule (outer covering)
 - White pulp (lymphatic tissue regions)
 - Red pulp (blood-filled tissue regions)
 - Artery and vein (blood vessels entering and leaving the spleen)

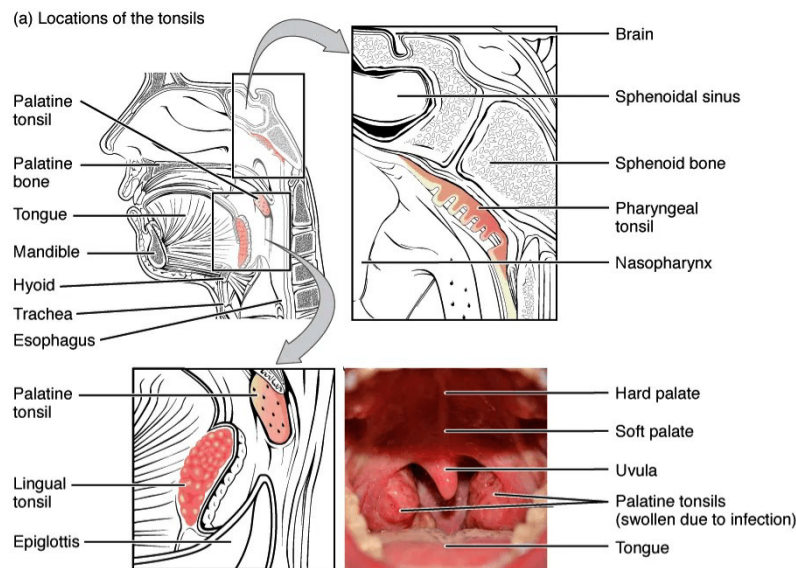


Figure 4.1.7: Diagrams and a labeled throat image identify the palatine tonsils in the oropharynx, the lingual tonsils at the base of the tongue, and the pharyngeal tonsil (adenoids) in the nasopharynx, with nearby structures labeled (hard palate, soft palate, uvula, epiglottis, and related head-and-neck anatomy). (CC BY 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, Peter DeSaix via [Anatomy of the Lymphatic and Immune Systems](#)).

Figure 4.1.7 “Locations of the tonsils,” describes the palatine, pharyngeal, and lingual tonsils.

Upper-left diagram (side view of head and neck)

- The palatine tonsil is on the back of the throat, behind the tongue.
- The palatine bone is just above and behind the palatine tonsil.
- Below the tongue we see the mandible, with the hyoid in the upper neck.
- The trachea and esophagus are shown below the hyoid.

Upper-right diagram (detail of upper throat and nasal region)

- The pharyngeal tonsil is in the nasopharynx, in the upper throat behind the nasal cavity.
- Directly behind the pharyngeal tonsil is the sphenoid bone, and above that is the sphenoidal sinus and then the brain.

Lower-left diagram (detail of lower throat region)

- The lingual tonsil lies at the base of the tongue, slightly below the palatine tonsil. It is just above the epiglottis, and lies parallel to the mandible.

Lower-right photo

- This photo of an open mouth shows the hard palate with the soft palate behind it, leading to the uvula.
- The palatine tonsils are shown just behind the soft palate on either sides of the uvula, and they are swollen due to infection.

Microbes in the Environment

Microbes are essential to human health but can also cause disease when their balance is disrupted. Microbes found in the environment include bacteria, viruses, fungi, protozoa, and algae, each playing different ecological and health-related roles.

A. Bacteria is found in soil, water, air, and surfaces.

- Beneficial: Gut bacteria help break down food, absorb nutrients, and prevent harmful bacteria from growing. They also help train the immune system to identify helpful microbes.
- Penicillin: This antibiotic is produced by a type of mold.
- Disease causing: Clostridium botulinum bacteria produces toxins that cause botulism, a severe form of food poisoning. Mycobacterium tuberculosis causes tuberculosis (airborne transmission); Salmonella contamination results in food-borne illness.
- Treatment: Antibiotics, though antibiotic resistance is a growing challenge.

B. Viruses

- Influenza virus → Flu (airborne droplets).
- SARS-CoV-2 → COVID-19 (respiratory transmission).
- HIV → AIDS (blood-borne and sexual transmission).
- Treatment: Antiviral drugs, vaccines for prevention.

C. Fungi

- Includes molds and yeasts, found in soil, water, and air.
- Can be decomposers, pathogens, or beneficial (fermentation).
- Candida albicans (yeast infections), Aspergillus (respiratory infections).
- Treatment: Antifungal medications.

D. Protozoa

- Found in freshwater, soil, and moist environments.
- Many are harmless, but some are pathogenic.
- Examples:
 - Giardia lamblia (waterborne parasite, causes gastrointestinal illness).
 - Plasmodium falciparum (causes malaria, transmitted by mosquitoes).
- Treatment: Antiprotozoal drugs.

Learning about microbes is essential for understanding the importance of the lymphatic system, as the two are inseparably linked through the body's immune defenses. The lymphatic system functions as the "transport network" and "headquarters" for the immune system, where immune cells monitor, filter, and respond to invading microorganisms.

Human body is constantly exposed to microbes, both harmful (pathogens) and helpful (commensals). These microorganisms and their byproducts are routinely collected from tissues into the lymphatic fluid (lymph) and transported to lymph nodes for surveillance. This continuous transport demonstrates how the lymphatic system acts as a central hub for reporting microbial activity.

Antimicrobial resistance is not a new phenomenon. In nature, microbes are constantly evolving in order to overcome the antimicrobial compounds produced by other microorganisms. Human development of antimicrobial drugs and their widespread clinical use has simply provided another selective pressure that promotes further evolution. Several important factors can accelerate the evolution of drug resistance. These include the overuse and misuse of antimicrobials, inappropriate use of antimicrobials, sub-therapeutic dosing, and patient noncompliance with the recommended course of treatment.

For example, Staphylococcus aureus, often called "staph," is a common bacterium that can live in the human body and is usually easily treated with antibiotics. A very dangerous strain, however, methicillin-resistant Staphylococcus aureus (MRSA) has made the news over the past few years. This strain is resistant to many commonly used antibiotics, including methicillin, amoxicillin, penicillin, and oxacillin. MRSA can cause infections of the skin, but it can also infect the bloodstream, lungs, urinary tract, or sites of injury. While MRSA infections are common among people in healthcare facilities, they have also appeared in healthy people who haven't been hospitalized but who live or work in tight populations (like military personnel and prisoners). Researchers have expressed concern about the way this latter source of MRSA targets a much younger population than those residing in care facilities.

Hands-On Microbial Culture

Understanding the types of microbes present in different environments, methods of detection, and control strategies is crucial for

maintaining public health and environmental safety. Culturing microbes allows observing their growth and behavior in real-time, providing insights into their relationships with the lymphatic system. Microbial cultures can reveal how various strains interact with lymphatic cells and influence immune responses.

By analyzing antibiotic resistance patterns, we can protect ourselves against harmful bacteria and ensure effective treatment options remain available. This analysis helps healthcare providers choose the most effective antibiotic for treating infections. Understanding resistance patterns allows public health officials to implement strategies to reduce the spread of resistant bacteria.

Infectious Disease Transmission

Infectious diseases can spread through various modes of transmission, significantly impacting public health.

- Airborne (coughing, sneezing) - involves pathogens being carried through the air in droplets or dust particles, allowing them to be inhaled by others over distances; examples: Tuberculosis, Influenza.
- Direct contact, where pathogens are transferred from an infected individual to a susceptible host through physical contact, such as touching, kissing, or sexual intercourse; examples: HIV, MRSA.
- Food-borne and waterborne illnesses may be caused by toxins created by microbes. Many cases of food poisoning happen when someone eats food that has harmful bacteria in it. The bacteria or the toxins produced by them can then make the person sick. Bacteria also can get into the water supply and make someone sick. The U.S. Centers for Disease Control and Prevention define the greatest threats of food- and waterborne illnesses to be from among the following bacteria: Salmonella species, Shigella dysenteriae, Escherichia coli O157:H7 (E. coli), Vibrio cholerae.
- Vector-borne disease is a disease that results from an infection transmitted to humans and other animals by blood-feeding arthropods, such as mosquitoes, ticks, and fleas. Examples of vector-borne diseases include Dengue fever, West Nile Virus, Lyme disease, and malaria.

Most microorganisms do not cause disease. In order to indicate that a disease is infectious, it must be demonstrated that the disease-causing pathogen is present in people diagnosed with a disease but not in healthy people and that healthy people who contract the pathogen develop disease. The severity of the disease depends on the ability of the pathogen to damage the host as well as the ability of the host to resist the pathogen. Diagnostic methods used to identify disease include clinical presentation, microscopy, biochemical test, such as Enzyme-Linked Immunosorbent Assay (ELISA), growth culture, and molecular diagnostics.

Prevention Strategies

- Vaccination - Prevents viral and bacterial infections (e.g., flu, COVID-19, measles).
- Hand Hygiene - Reduces transmission of microbes.
- Safe Food Handling - Prevents food-borne illnesses.
- Vector Control - Insect repellents and mosquito nets for malaria prevention.

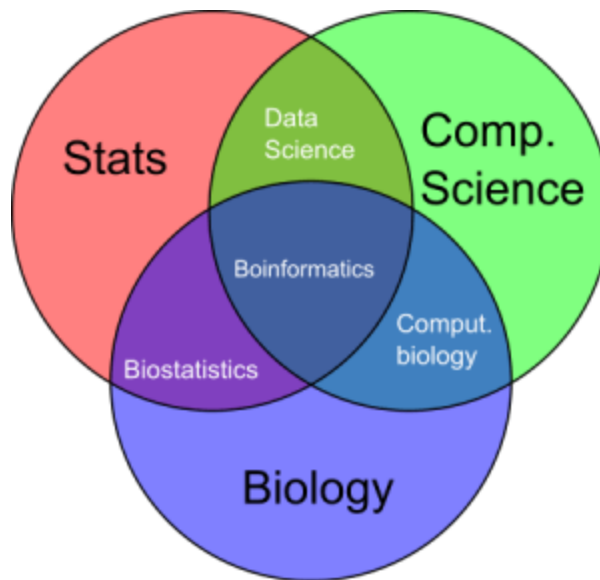


Figure 4.1.8: A Venn diagram showing what you might find at the intersections of statistics, computer science and biology. (CC BY-NC-SA 4.0; author via [What is Epidemiology](#)).

Figure 4.1.8 is a three-circle Venn diagram illustrating interdisciplinary fields.

- The red circle represents Statistics, the green circle represents Computer Science, and the blue circle represents Biology.
- Overlapping areas show combined disciplines:
 - Statistics + Computer Science: Data Science
 - Statistics + Biology: Biostatistics
 - Computer Science + Biology: Computational Biology
 - All three: Bioinformatics

4.2: Activity 1

Mapping the Lymphatic System

In this engaging lab activity, students will explore the lymphatic system by identifying various regions, organs, and structures indicated by numbered arrows (1 to 9) on the Figure 4.2.1. Participants will also collaborate with peers to describe the role each identified structure plays in the immune system and fluid regulation.

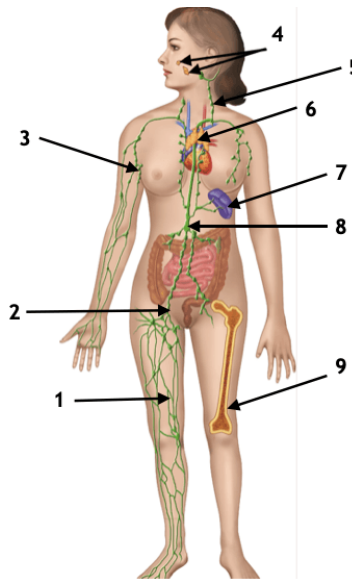


Figure 4.2.1: Human laboratory model image showing the lymphatic and other organs. (CC BY-NC-SA 4.0; via [Lymphatic System](#)).

Table 4.2.1: Identification and Functions of Lymphatic System Structures

Identifying Number	Organ/Structure	Function
	Spleen	
	Inguinal lymph node	
	Bone marrow	
	Lymphatic capillaries/	
	vessels	
	Tonsils	
	Axillary lymph node	
	Thymus	
	Cervical lymph node	
	Cisterna chili	

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4.3: Activity 2

Compare Lymphatic and Cardiovascular Systems

Instructions

1. Review the table headings and categories.
2. Compare the lymphatic and cardiovascular systems based on organization, circulation, flow pressure, mechanism of flow, and filtration.
3. Fill in each column with accurate information for both systems.
4. Use complete phrases or bullet points for clarity.

Table 4.3.1: Key Differences Between Lymphatic and Cardiovascular Systems

	Lymphatic System	Cardiovascular System
Organization		
What circulates (include all circulating components)		
Relative Flow Pressure		
Mechanism of Flow		
Filtration Blood		Blood is filtered by the kidneys.

4.4: Activity 3

Mapping Lymph Node Anatomy

In this engaging lab activity, students will explore the various parts of a lymph node, including the cortex, medulla, germinal centers, and hilum to gain insights into their specific roles in immune response and lymphatic function indicated by numbered arrows (1 to 8) on the Figure 4.4.1. Participants will also collaborate with peers to describe the role each identified structure plays in the immune system and fluid regulation.

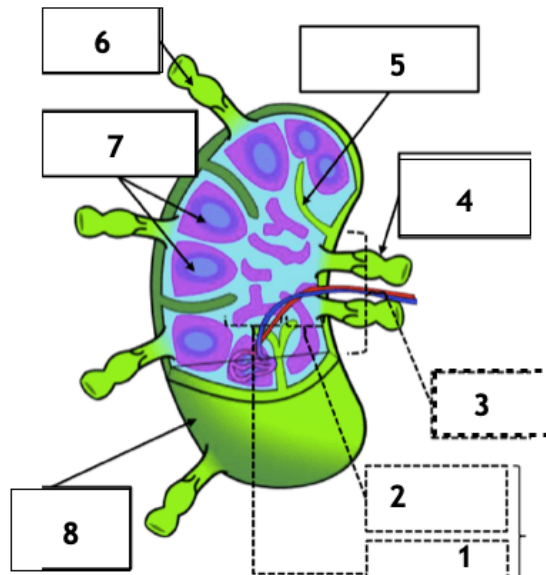


Figure 4.4.1: Lymph node image highlights key components with numbers (1 - 8) for identification. (CC BY-NC-SA 4.0; via Lymphatic System).

Table 4.4.1: Identification and Functions of Lymph Node Structures

Identifying Number	Organ/Structure	Function
	Capsule	
	Afferent lymph vessel	
	Efferent lymph vessel	
	Hilus	
	Cortex	
	Medulla	
	Nodules	
	Trabeculae	

Promoting Critical Thinking

- What happens if the lymphatic system fails to drain excess interstitial fluid? Elaborate.

4.5: Activity 4

Simulation of Transmission of Viral Infection

This simulation activity allows participants to model the spread of a sexually transmitted infection (STI) without using hazardous materials, using starch and iodine to represent the infection and detection process.

Procedure

Each student gets a numbered test tube filled with a small amount of fluid that simulate body fluids (for, example, blood, semen, or vaginal secretions). One of the test tube (patient zero) contains diluted starch solution (representing the virus) and the rest contain uninfected body fluids (water). Starch solution (representing the "virus"). Lugol's Iodine solution will be used for the "diagnostic test". There will be Trial 1 (exchange of fluids with random partners) and Trial 2 (can only exchange fluids keeping with your behavioral role, as stated on the CARD).

Trial 1 - Exchanging Fluids with Random Partners

1. Pick up simulated body fluid and a blank test tube from the front desk. Note the number of your original tube and use the blue tape to create the duplicate (blank tube).
2. Transfer 1 ml of simulated body fluid into the blank tube. Keep this tube separate on the test tube rack. The original test tube will be used to simulate direct contact with fluids of other students in the class.
3. You must ask the other person for permission to exchange fluids before proceeding with the exchange!
4. Exchange Round 1: All participants find a consenting partner and exchange a small amount of fluid. Pour a small amount of your fluid into the vial of another person. You should receive an equal amount of their fluid. This is the simulation of having shared body fluids.
5. Each participant should record the test tube number of the person they exchanged with on their index card.
6. Exchange Round 2 through Round 3: Participants then find new partners and repeat the exchange, again recording the partner(s)' test tube numbers on the index card.
7. After completion of Round 3, it will be time to get tested for the virus. The Instructor will administer the virus detection test by adding a drop (0.05 ml) Lugol's iodine solution to each student's test tube.
8. The fluid with starch will turn a dark blue or black color. If the fluid is uncontaminated, the iodine will not change color and your solution will be brown.
9. To detect the index case number, use a drop of Iodine in your blank tube.

Data Recording

A shared spreadsheet can help organize the information for contact tracing.

Table 4.5.1: Test Tube Exchanges and Results

Tube #	Exchanges Round 1	Exchanges Round 2	Exchanges Round 3	Test Result (Positive/Negative)
1	Tube #	Tube #	Tube #	
2	Tube #	Tube #	Tube #	
3	Tube #	Tube #	Tube #	

Determining the Prevalence of the Disease/Infections

To determine the prevalence of a disease at the start of an experiment, the total number of existing cases of the disease is divided by the total population at that specific point in time. The formula is:

$$\text{Prevalence} = \frac{\text{Number of cases}}{\text{Total population}}$$

For example, if an experiment begins with a population of 1,000 people and 50 of them have the disease, the prevalence would be $50 \div 1,000 = 0.05$ or 5%.

It is important not to confuse prevalence with incidence.

- Prevalence: Measures the proportion of a population that already has a disease at a specific point in time.
- Incidence: Measures the rate of new cases of a disease that develop over a specific period.
- Calculate and Record prevalence in Trial 1

Trial 2 - Exchanging Fluids Following Behavioral Role Play

Assigning Roles:

- The participants will play role based on relationship scenarios (e.g., monogamous, polygamous, promiscuous, one-night stand).
- Each student will pick up a relationship card from the front desk. You should keep your role secret throughout the activity.
- Role Card is in the following table:

Table 4.5.2: Role Cards and Test Tube Exchange Results

Roles
Monogamous - May "exchange/trade fluid" with the same person as many times as they want – it does NOT have to be another monogamous person
Polygamous- May "exchange/trade fluid" with 3 different people
Promiscuous - May "exchange/trade fluid" with as many people as they want
One night stand - May "exchange/trade fluid" with one person one time

Hypothesis

- General Hypothesis: The initial infection will spread through the population, and the number of infected individuals will increase with each round of fluid exchange.
- Specific Hypothesis: The pattern and rate of spread will be influenced by the type of contact. Groups with higher-risk contact scenarios (e.g., "polygamous") will have a higher number of infected individuals and a more complex spread pattern than groups with lower-risk contact (e.g., "monogamous").

Procedure

1. Pick up simulated body fluid (Trial 2) and a blank test tube from the front desk. Note the number of your original tube and use the blue tape to create the duplicate (blank tube).
2. Transfer 1 ml of simulated body fluid into the blank tube. Keep this tube separate on the test tube rack. The original test tube will be used to simulate direct contact with fluids of other students in the class.
3. Also pick up a randomly chosen role card that identifies a behavioral role (monogamous, polygamous, promiscuous, one-night stand). This tells you when and with whom you can exchange your fluid. You should keep your role secret throughout the activity.
4. You must ask the other person for permission to exchange fluids before proceeding with the exchange!
5. You cannot act out of character. If you are playing the role as monogamous, after you complete exchange with a partner, you can politely refuse a new partner by saying, "Sorry, not interested". However, monogamous role will all exchanging fluids with the same person as many times one wishes, even after the partner has exchanged fluids with other partners.
6. Exchange Round 1: All participants find a consenting partner and exchange a small amount of fluid. Pour a small amount of your fluid into the vial of another person. You should receive an equal amount of their fluid. This is the simulation of having shared body fluids.
7. Carry on the exchange of fluids for three (3) rounds. You cannot act out of character.
8. After completion of Round 3, it will be time to get tested for the virus. The Instructor will administer the virus detection test

by adding a drop (0.05 ml) Lugol's iodine solution to each student's test tube.

9. The fluid with starch will turn a dark blue or black color. If the fluid is uncontaminated, the iodine will not change color and your solution will be brown.
10. To detect the index case number, use a drop of Iodine in your blank tube.

Data Table for Role Playing

This table will help organize the data collected during the role-playing simulation of disease transmission among different relationship types: monogamous, polygamous, promiscuous, and one night stand.

Table 4.5.3: Relationship Types and Associated Fluid Exchange Patterns

Relationship Type	Number of Partners	Fluid Exchanges	Number in category	Number tested positive
Monogamous	1	Low		
Polygamous	Multiple	Moderate to High		
Promiscuous	Many	High		
One-Night Stand	Varies	Moderate		

Calculate and Record Prevalence in Trial 2

- Total Population: Determine the total number of individuals in your study.
- Identify Infected Individuals: Count how many individuals tested positive for the infection in each group.
- Calculate Prevalence for Each Group: Use the formula above to calculate the prevalence for each relationship type.

Example Scenario

- Total Population - 100 individuals
- Monogamous Group - 20 individuals (2 infected)
- Polygamous Group - 30 individuals (6 infected)
- Promiscuous Group - 25 individuals (10 infected)
- One-Night Stand Group - 25 individuals (5 infected)

Table 4.5.4: Population Prevalence by Relationship Type

TRIAL 2	
Population	Prevalence
Total	
Relationship type	Prevalence
Monogamous	
Polygamous	
Promiscuous	
One Night Stand	

Post lab Critical Thinking Question

1. What was the specific mode of transmission in this simulation (e.g., direct contact, aerosol)? How does this compare to how viruses spread in the real world?
2. What percent of the class became infected after exchanging the fluids in Trial 1 and Trial 2? What percent of the class was infected originally, before exchanging the fluids? How would you explain the results?

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4.6: Activity 5

Detecting Bacteria

This lab investigates the presence of bacteria in the environment by culturing samples on Nutrient Agar (NA) or Luria-Bertani (LB) agar or Tryptic Soy Agar (TSA).

The objectives of this lab are to:

- Develop skills in sample collection.
- Streak samples onto LB or TSA agar plates to ensure effective isolation and growth of colonies.
- Understand the principles of aseptic techniques and their crucial role in microbiology.
- Differentiate bacterial colony morphology based on color, size, and texture.
- Discuss the implications of bacterial presence in the environment and emphasize the importance of hygiene

Materials

- LB or TSA agar plates (one per sampling site)
- Sterile cotton swabs
- Sterile saline or distilled water (for moistening swabs)
- Permanent markers (for labeling plates)
- Incubator (37°C) or room temperature for growth
- Parafilm or tape (to seal plates)
- Gloves & lab coats (for safety)
- Disinfectant wipes (for cleaning workspaces)

Lab Procedure

Step 1: Labeling the Plates

Using a permanent marker, label the bottom of each agar plate (not the lid) with:

- Your group name, Date, Sample source (e.g., "Phone screen," "Doorknob," "Dollar bill")
- Nutrient Agar (NA), LB or TSA (indicating which medium is used)
- Each group will work on two different surfaces. Draw lines on the bottom of the group's agar plate (the side with the agar on it) to mark 2 equal sized regions 'A' and 'B'.

Step 2: Collecting Environmental Samples

NOTE: For health and safety reasons, please do not swab any living organisms or part thereof.

1. Sterilize hands and wear gloves to prevent contamination.
2. You will investigate places/things you normally TOUCH like your cell phone or table top. You will compare the environment before (B) and after (A) treatment (for example the desk before and after you clean it with alcohol swab). Record a description of the 2 environments on the assignment sheet.
3. Moisten a sterile cotton swab with sterile water or saline to improve bacterial collection.
4. Swipe the swab over the selected surface (e.g., lab bench, phone, faucet, dollar bill) using a consistent motion.
5. Rotate the swab gently to maximize bacterial transfer onto the agar.

Step 3: Streaking the Agar Plate

The streak plate method is used to isolate individual bacterial colonies from a mixed sample. By spreading bacteria in a

systematic pattern, the density of microbial growth is reduced in successive streaks, leading to isolated colonies across the plate.

1. Gently roll the swab with sample across the surface of the agar plate in a zigzag motion to transfer bacteria turning the plate 90 degree each time.
2. Replace the lid immediately to prevent contamination.
3. Discard the swab in the Biohazard container.

Step 4: Incubation

1. Invert the plates (agar side up) to prevent condensation from dripping onto the agar.
2. The instructor will incubate the plates at 37 degree C for 24–48 hours. The next laboratory period you will observe the results and record your observations.
3. Ensure plates are sealed with parafilm or tape to prevent accidental exposure.
4. Clean up: Disinfect all work surfaces with 70% ethanol or bleach solution.

Step 5: Observing and Recording Results (next week or next lab day - continuation)

1. After incubation, carefully observe bacterial colony growth. Record colony characteristics:
 - Color (white, yellow, cream, red, etc.)
 - Size (small, medium, large)
 - Shape (circular, irregular, filamentous)
 - Texture (smooth, rough, dry, mucoid)
2. Compare bacterial diversity across different environmental surfaces.

Table 4.6.1: Comparison of Bacterial Growth Characteristics from Different Surfaces Before and After Cleaning

Description of source	Description of growth on plate: approximate # of colonies	Colony Colors (white, yellow, cream, red etc.)	Colony Size (small, medium, large)	Colony Shape (circular, irregular, filamentous)
Cell Phone surface (Before)				
Cell Phone surface (After)				
Table Top (Before)				
Table Top (After)				

Key Questions to Consider next week (Post observation)

1. Which surface had the most bacterial growth?
2. Were certain colony types more common on specific surfaces?
3. What factors might influence microbial presence (moisture, human contact, cleanliness)?
4. How does proper hygiene impact microbial contamination in everyday environments?

4.7: Activity 6

Testing Antimicrobial Products

In order for a microorganism to cause disease, it must first reach the potential host. Microorganisms can move around an environment in various but typically passive ways, including via aerosols (inside droplets of water), direct contact between two animated objects, and fomites (a contaminated inanimate object). Some microorganisms can retain their pathogenic potential whilst outside their host for extended periods of time, with studies suggesting survival for days and even weeks on inanimate surfaces such as plastics and metals (door handles, lift buttons, light switches which are often considered to be 'hygienic surfaces'. Many of these materials are used to construct frequently touched surfaces (FTS) such as door handles, lift buttons, light switches and digital locks. There is evidence of transfer of potentially harmful microorganisms from the FTS to a biological surface (e.g., human skin) via touch. This experiment/activity evaluates the effectiveness of antimicrobial products (e.g., disinfectants, antiseptics, hand sanitizers) against two bacterial species:

- *Escherichia coli* (*E. coli*) – a Gram-negative bacterium.
- *Staphylococcus epidermidis* (*S. epidermidis*) – a Gram-positive bacterium.

By measuring zones of inhibition, we will determine which antimicrobial agents are most effective against each bacterial species.

Materials:

1. NA agar plates per group: 2 (Plate 1: synthetic antimicrobial; Plate 2 natural antimicrobial).
2. Sterile cotton swabs: 2
3. Bacterial culture: 2 types
4. Marker: 1; Ruler or caliper (for measuring zones of inhibition): 1
5. Sterile filter paper circles: 8
6. Tubes with antibacterial products (see lab cart for various choices)*
7. Forceps (1 pair)
8. Alcohol wipes (8-12)

Procedure

Preparation of Bacterial Lawn

1. Label agar plates (at the bottom part)
 - Divide each plate into two halves (one for *E. coli*, one for *S. epidermidis*).
 - Label with the bacterial species name and tested antimicrobial product.
2. Inoculate the Plates
 - Using a sterile swab, dip into the *E. coli* broth culture, remove excess liquid, and streak the entire half of the plate in three directions to create a uniform lawn.
 - Repeat with a new sterile swab for *S. epidermidis* on the other half.
3. Allow the plate to dry (approximately 5 minutes) with the lid partially open to prevent excess moisture.

Application of Antimicrobial Agents

1. Prepare Antimicrobial Discs
 - If using filter paper discs, soak each disc in an antimicrobial product (check with the instructor) for 30 seconds, then place them on the plate.
2. Apply Control Discs
 - Place a sterile water disc as a negative control to ensure that inhibition zones are due to antimicrobial activity, not paper absorption.
3. Gently press down on each disc using forceps to ensure good contact with the agar.

Incubation

- Invert the plates (agar side up) and incubate at 37°C for 24 to 48 hours.

Measuring and recording the Results

1. After incubation, measure the zones of inhibition
 - Use a ruler or caliper to measure the diameter (in mm) of the clear zone around each disc.
 - If no clear zone appears, record as 0 mm (indicating resistance).
2. Compare results between *E. coli* and *S. epidermidis*

Table 4.7.1: Antimicrobial Products and Zones of Inhibition

Antimicrobial Product	Zone of Inhibition (mm) in <i>E. coli</i>	Zone of Inhibition (mm) in <i>S. epidermidis</i>	Interpretation (Resistant, Intermediate, Susceptible)
Sterile Water (Control)			

- Larger zones = greater bacterial susceptibility.
- Smaller or no zones = bacterial resistance to the product.

Discussion & Analysis

1. Which antimicrobial agent was most effective?
2. Did *E. coli* and *S. epidermidis* respond differently to the antimicrobial products? Why?
3. How do differences in cell wall structure (Gram-positive vs. Gram-negative) influence susceptibility?
4. Why is a control disc important in this experiment?

Safety and Disposal

1. Do not open incubated plates to prevent exposure to potential pathogens.
2. Dispose of plates and used swabs in biohazard waste.
3. Sterilize work areas and wash hands after completing the experiment.

4.8: Activity 7

Antibiotic Resistance and Public Health

Antibiotic resistance is a major global public health threat that occurs when bacteria evolve mechanisms to survive antibiotic treatment. This reduces the effectiveness of antibiotics, making infections harder to treat and leading to increased morbidity, mortality, and healthcare costs. The overuse and misuse of antibiotics in medicine, agriculture, and animal husbandry accelerate this problem, leading to the emergence of drug resistant bacterial strains.

Mode of Action of Antibiotics

Depending on the effect they have on bacteria, antibiotics are classified as bactericidal or bacteriostatic. Bactericidal antibiotics kill the bacteria, while bacteriostatic antibiotics stop the bacteria from growing. Antibiotics have multiple modes of action, including:

- Cell wall synthesis inhibition - Ampicillin, Bacitracin, Penicillins (e.g., amoxicillin), Vancomycin
- Protein synthesis inhibition - Chloramphenicol, Erythromycin, Gentamicin, Streptomycin
- Causes leakage of ions and metabolites - Daptomycin - Cell membrane disruption
- Nucleic acid synthesis inhibition - Ciprofloxacin
- Antimetabolite activity - Sulfonamides (Folic Acid Synthesis Inhibitors)

Conventional Antibiotic Susceptibility Testing (AST)

Traditional AST procedures, such as disk diffusion, broth micro-dilution, gradient tests, breakpoint tests, and agar dilution, rely on exposing bacterial isolates to a series of antimicrobials and visually detecting growth.

The Kirby-Bauer antibiotic disc diffusion test is a standardized method used in microbiology to determine the susceptibility of bacteria to various antibiotics. It helps clinicians and researchers assess which antibiotics are effective against a bacterial strain.

- A Mueller-Hinton agar plate is uniformly inoculated with a bacterial culture/swab.
- A 6-mm filter discs impregnated with known concentration of different antibiotics are placed on the surface.
- As bacteria grow, antibiotics diffuse outward from the discs, creating zones of inhibition where bacterial growth is prevented.

The rate of diffusion of the antimicrobial through the agar is dependent on the diffusion and solubility properties of the drug in MH agar and the molecular weight of the antimicrobial compound. Larger molecules will diffuse at a slower rate than lower molecular weight compounds. These factors, in combination, result in each antimicrobial having a unique break-point zone size indicating susceptibility to that antimicrobial compound. The antibiotics kill bacteria by interfering with their cell wall formation, replication, protein synthesis, both in transcription and translation.

The diameter of the inhibition zone is measured and compared to a standard chart to classify bacteria as susceptible, intermediate, or resistant to each antibiotic.

Experiment (Day 1)

1. Setting up experiment
 - Clean the table with Sanisol and wash your hands with soap.
 - Label the Petri plates with the name of the organism, your group and date at the side with the agar, around the periphery.
2. Inoculation
 - To inoculate, put 4 drops of bacterial suspension on the agar plate.
 - Make sure you put the plastic pipettes back in your bacterial cultures.
3. Use the sterile cotton swab into the bacteria culture and gently spread bacteria all over the two agar plates. Try to completely cover the agar surface with bacteria. Dispose of the cotton swab in the biohazard waste container.
4. Note the abbreviation of each antibiotic in your worksheet.
5. Sterilize forceps on alcohol to place the antibiotic discs to the agar surface at the center of each quadrant, at least 5 mm

from the edges of the plate.

6. Gently tap on each disc with the forceps to ensure contact. Cover the Petri plates.
7. Repeat the same procedure for both the cultures.
8. Invert the plates (agar side up) and incubate at 37°C for 24–48 hours (stacking them together with a tape).

Observation (Day 2)

- After incubation, measure the diameter of the zones of inhibition around each disc (in mm) and record in the worksheet.
- Compare results with standardized reference charts provided by the Clinical and Laboratory Standards Institute (CLSI) to determine susceptibility:

Table 4.8.1: CLSI Standards for Antibiotic Susceptibility Based on Zone of Inhibition

Antibiotic	Resistant (R)	Intermediate (I)	Susceptible (S)
Chloramphenicol	≤ 12 mm	13–17 mm	≥ 18 mm
Ampicillin	≤ 13 mm	14–16 mm	≥ 17 mm
Gentamicin	≤ 12 mm	13–14 mm	≥ 15 mm
Bacitracin	≤ 8 mm	9–13 mm	≥ 14 mm

Observations and Interpretation

- Susceptible (S): Effective antibiotic, bacteria inhibited.
- Intermediate (I): Some bacterial resistance, may require higher doses.
- Resistant (R): Bacteria grow despite the antibiotic, indicating ineffectiveness.

Table 4.8.2: Antibiotic Zones of Inhibition and Susceptibility Interpretation

Antibiotic	Zone of Inhibition (mm)	Interpretation (insert a check mark)		
		Susceptible	Intermediate	Resistant
Gentamicin				
Chloramphenicol				
Bacitracin				
Ampicillin				

- **Adaptive immune response** – Relatively slow but very specific and effective immune response controlled by lymphocytes.
- **Afferent lymphatic vessels** – Lead into a lymph node.
- **Agar** – A gel-like product added to culture medium when bacteria are grown on plates.
- **Antibody** – Antigen-specific protein secreted by plasma cells; immunoglobulin.
- **Antigen** – Molecule recognized by the receptors of B and T lymphocytes.
- **Antibiotic** – A drug that kills or stops the growth of bacteria. Antibiotics are a type of antimicrobial. Examples: penicillin, ciprofloxacin.
- **Antibiotic resistance** – Antimicrobial resistance of bacteria.
- **Antimicrobial** – A substance that kills or stops the growth of microbes, including bacteria, fungi, or viruses.
- **Antimicrobial susceptibility testing (AST)** – Laboratory testing performed on microbes to determine if they are susceptible or resistant to one or more drugs. Results indicate if bacteria are susceptible (can be treated), intermediate (may require adjusted dosage), or resistant (cannot be treated).
- **Bacteria** – Single-celled organisms that live in and around us with a distinct structure from other microbes. They can be helpful or cause illnesses such as diarrhea, strep throat, ear infections, and pneumonia.
- **B cells** – Lymphocytes that act by differentiating into an antibody-secreting plasma cell.
- **Bone marrow** – Tissue inside bones; site of all blood cell differentiation and maturation of B lymphocytes.
- **Bronchus-associated lymphoid tissue (BALT)** – Lymphoid nodule associated with the respiratory tract.
- **Cisterna chyli** – A dilated sac in the lymphatic system that collects lymph from the lower body and marks the beginning of the thoracic duct.
- **Efferent lymphatic vessels** – Lead out of a lymph node.
- **Germinal centers** – Clusters of rapidly proliferating B cells found in secondary lymphoid tissues.
- **Immune system** – Series of barriers, cells, and soluble mediators that combine to respond to infections by pathogenic organisms.
- **Incidence (of infection)** – The number of newly infected persons in a population during a defined period.
- **Innate immune response** – Rapid but relatively nonspecific immune response.
- **Lymph** – Fluid contained within the lymphatic system.
- **Lymph node** – Bean-shaped organs associated with lymphatic vessels.
- **Lymphatic capillaries** – Smallest lymphatic vessels; origin of lymph flow.
- **Lymphatic system** – Network of lymphatic vessels, lymph nodes, and ducts that carries lymph from tissues back to the bloodstream.
- **Lymphatic trunks** – Large lymphatics that collect lymph from smaller vessels and empty into the blood via lymphatic ducts.
- **Lymphocytes** – Agranular leukocytes of the lymphoid lineage characterized by a large nucleus and small rim of cytoplasm; many function in specific immunity.
- **Lymphoid nodules** – Unencapsulated patches of lymphoid tissue found throughout the body.
- **Mucosa-associated lymphoid tissue (MALT)** – Lymphoid nodule associated with mucosa.
- **Naïve lymphocyte** – Mature B or T cell that has not yet encountered antigen.
- **Natural killer cell (NK)** – Cytotoxic lymphocyte of innate immune response.
- **Pathogen** – A microorganism capable of causing disease.
- **Pathogenic** – Capable of causing disease.
- **Plasma cell** – Differentiated B cell actively secreting antibody.
- **Primary lymphoid organ** – Site where lymphocytes mature and proliferate; includes red bone marrow and thymus gland.
- **Right lymphatic duct** – Drains lymph fluid from the upper right side of the body into the right subclavian vein.
- **Secondary lymphoid organs** – Sites where lymphocytes mount adaptive immune responses; examples include lymph nodes and spleen.
- **Spleen** – Secondary lymphoid organ that filters pathogens from blood (white pulp) and removes damaged blood cells (red pulp).
- **T cell** – Lymphocyte that acts by secreting molecules that regulate the immune system or by destroying foreign cells, viruses, and cancer cells.
- **Thoracic duct** – Large duct that drains lymph from the lower limbs, left thorax, left upper limb, and left side of the head.
- **Thymocyte** – Immature T cell found in the thymus.
- **Thymus** – Primary lymphoid organ involved in development and maturation of T cells; active during infancy and childhood.
- **Tonsils** – Lymphoid nodules associated with the nasopharynx.

5: URINARY SYSTEM ANATOMY AND PHYSIOLOGY

Introduction

In this lab, we will explore the anatomy and physiology of the urinary system, focusing on the structure and function of the kidneys, ureters, bladder, and urethra, by examining laboratory models, preserved specimens, microscopic slides of renal tissue.

Learning Objectives

- Identify and describe the location-structure-function relationships of the urinary system organs including kidneys, ureter, urinary bladder, urethra.
- Relate anatomy of nephron, the functional unit of the kidney to the process of urine formation.
- Trace the flow of blood through the kidney and relate this to elements of urine formation.
- Compare and contrast glomerular filtration, tubular reabsorption, tubular secretion.
- Explain urinary incontinence

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: Activity 8

5.10: Activity 9

5.11: Activity 10

5.12: Glossary

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5.1: Background Information

Overview

The urinary, or renal system is responsible for maintaining the homeostatic composition of the blood. It regulates the concentrations of nutrients, waste products, electrolytes, hormones, drugs, and literally hundreds of other types of molecules. one of excretion, elimination and reabsorption. Nephrons, the smallest functional unit of the kidneys, are found in numbers of one to two million within the kidney and can filter out large amounts of both water and the solutes (up to 180 L of filtrate per day), then reabsorbing the things the body needs to retain. The fluid that remains becomes urine (1 to 2 Liters/day) and consists of excess water and solutes that were not reabsorbed from the filtrate. The remaining three organs (ureters, urinary bladder, and urethra) facilitate urine storage and secretion. Of these organs, only the urethra is anatomically distinct between males and females.

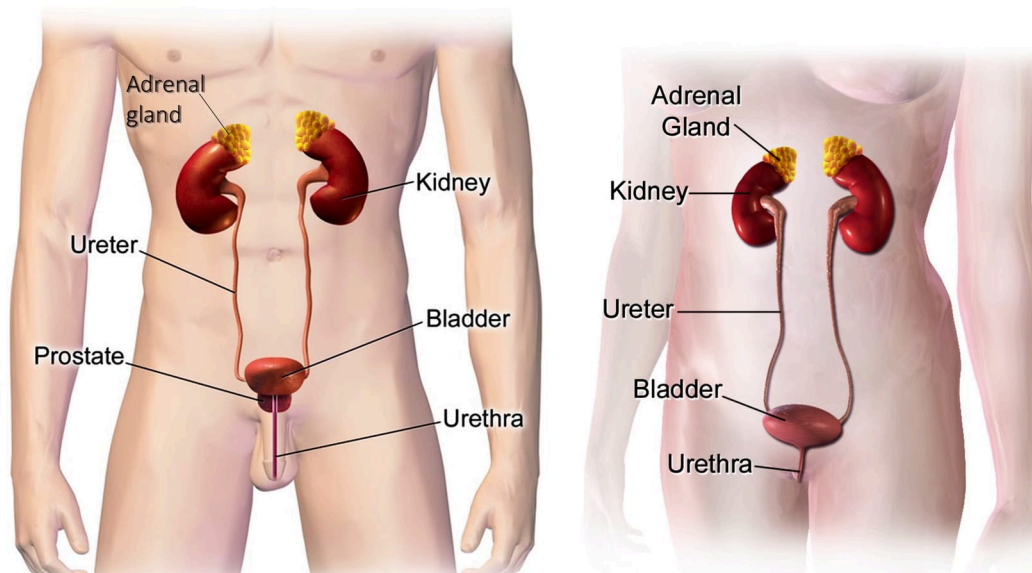


Figure 5.1.1: Overview of the anatomy of the urinary system (left) male and (right) female. Both show kidneys draining urine via ureters into the urinary bladder, then out through the urethra. The male urethra is longer and passes through the prostate and penis; the female urethra is shorter and opens anterior to the vaginal canal, with the uterus and ovaries shown in relation to the bladder. (CC BY-NC-SA 4.0; Rosanna Hartline via [Urinary System-Introduction](#)).

Figure 5.1.1 is a side-by-side labeled diagram comparing two versions of the urinary system anatomy. In both diagrams, the following structures are labeled:

- Adrenal gland
- Kidney
- Ureter
- Bladder
- Urethra

The kidneys are shown as a pair of bean-shaped organs positioned in the upper abdomen. An adrenal gland sits on top of each kidney. A ureter extends downward from each kidney to the bladder. The bladder is shown as a rounded storage organ in the lower pelvis. The urethra extends from the bladder to the outside of the body. In the left diagram, the prostate is also labeled. It is positioned below the bladder and surrounds the upper portion of the urethra.

Kidneys

There are two kidneys, one right and one left. They are retroperitoneal (posterior to peritoneum) and encased in protective layers of adipose tissue along the posterior body wall of the abdomen.

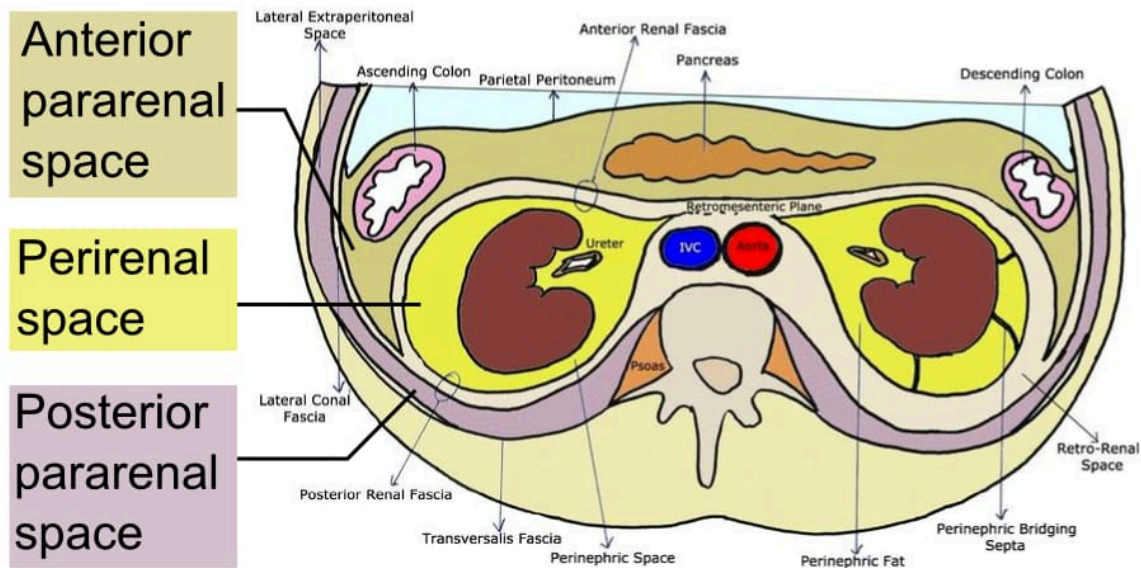


Figure 5.1.2: Position of the kidneys. The kidneys are surrounded by perinephric fat and surrounded by an anterior renal fascia and posterior renal fascia. (CC BY-NC-SA 4.0; Rosanna Hartline via Kidneys).

Figure 5.1.2 is a cross-sectional anatomical diagram of the abdominal cavity at the level of the kidneys. It shows the position of the kidneys and surrounding retroperitoneal spaces and fascia. The main instructional purpose is to identify the anterior pararenal space, perirenal space, and posterior pararenal space, and to show how these spaces relate to nearby organs, blood vessels, and connective tissue layers.

- **Anterior pararenal space:** This space is located in front of the kidneys and in front of the anterior renal fascia. It is part of the retroperitoneum and contains structures such as the pancreas and portions of the colon. In the diagram, this space is shown as the area anterior to the kidney-containing compartment.
- **Perirenal space:** This space surrounds each kidney directly. It is enclosed by the anterior renal fascia and posterior renal fascia. It contains the kidney, ureter, and perinephric fat. In the diagram, this is the compartment immediately around each kidney.
- **Posterior pararenal space:** This space lies behind the kidneys and behind the posterior renal fascia. It is located between the posterior renal fascia and the transversalis fascia. In the diagram, it is shown posterior to the kidney-containing compartment.

Fascia and connective tissue illustrated in Figure 5.1.2:

- **Anterior renal fascia:** This is the connective tissue layer that forms the front boundary of the perirenal space. It separates the perirenal space from the anterior pararenal space.
- **Posterior renal fascia:** This is the connective tissue layer that forms the back boundary of the perirenal space. It separates the perirenal space from the posterior pararenal space.
- **Lateral conal fascia:** This fascia is shown along the lateral side of the kidney region. It represents a lateral extension of the renal fascia that helps define the boundaries of these retroperitoneal spaces.
- **Transversalis fascia:** This fascia is located more posteriorly and forms an outer boundary behind the posterior pararenal space.
- **Perinephric bridging septa:** These are thin connective tissue bands within the perinephric fat that help organize and support the fat surrounding the kidney.

Fat and kidney region illustrated in Figure 5.1.2:

- **Perinephric space:** This label refers to the region immediately surrounding the kidney within the renal fascia. It corresponds closely to the perirenal compartment.
- **Perinephric fat:** This is the fat surrounding the kidney inside the perirenal space. It cushions and supports the kidney.
- **Retro-renal space:** This is a smaller space located behind the kidney within the broader retroperitoneal arrangement.

Organs and structures illustrated in Figure 5.1.2:

- **Kidneys:** The two kidneys are shown as paired bean-shaped organs, one on each side of the diagram. They lie within the perirenal spaces.
- **Ureter:** A ureter is labeled as a tube emerging from the kidney and descending inferiorly to carry urine away from the kidney.
- **Pancreas:** The pancreas is shown in the anterior part of the diagram, positioned within the anterior pararenal space.
- **Ascending colon:** The ascending colon is labeled on one side of the diagram and is positioned laterally in the anterior pararenal region.
- **Descending colon:** The descending colon is labeled on the opposite side and is also positioned laterally in the anterior pararenal region.
- **Parietal peritoneum:** This thin lining is shown anterior to the retroperitoneal structures. It separates the peritoneal cavity from the retroperitoneal spaces.
- **Lateral extraperitoneal space:** This is the space along the outer lateral abdominal wall, outside the peritoneal cavity.
- **Retro mesenteric plane:** This is a fascial plane shown centrally and anteriorly, helping define the organization of retroperitoneal compartments.
- **Psoas:** The psoas muscle is labeled posterior and medial to the kidneys. It lies near the vertebral column and forms part of the posterior abdominal wall.

Major blood vessels illustrated in Figure 5.1.2:

- **IVC:** The inferior vena cava is labeled near the center of the diagram. It is the large vein that returns blood from the lower body to the heart.
- **Aorta:** The aorta is labeled next to the inferior vena cava. It is the large artery that carries oxygenated blood from the heart to the body.

The kidneys filter dissolved materials from the blood, including metabolic wastes, regulate electrolytes, regulate fluid volume (thereby influencing blood pressure), concentrates and stores waste products in the form of urine, and reabsorbs metabolically important substances back into the circulatory system. The following are specific functions of the kidneys:

- **Remove waste:** The kidneys filter waste products and excess fluid out of the blood and remove them from the body in the form of urine. (nitrogenous wastes such as urea and ammonium). Urine also helps remove potentially harmful nitrogenous wastes such as urea and uric acid as well as many other products of cellular metabolism. One of these, called creatinine, is a waste product created in muscle cells from an energy-storage molecule called creatine phosphate, and its clearance from the kidney is often used to evaluate kidney function and potential kidney diseases. Urine passes out of the kidneys into the ureters, which transport it to the bladder where it is stored until it can be voided through the urethra.
- **Maintain the right balance of chemicals in the body:** The kidneys keep the right balance of chemicals, such as sodium, potassium, calcium, magnesium, and other substances your body needs to function properly. They filter excess amounts of these chemicals from the blood and get rid of them in the urine.
- **Synthesize several regulatory chemicals:** The kidneys produce and secrete three important chemicals: renin, erythropoietin, and the active form of vitamin D (Calcitriol).

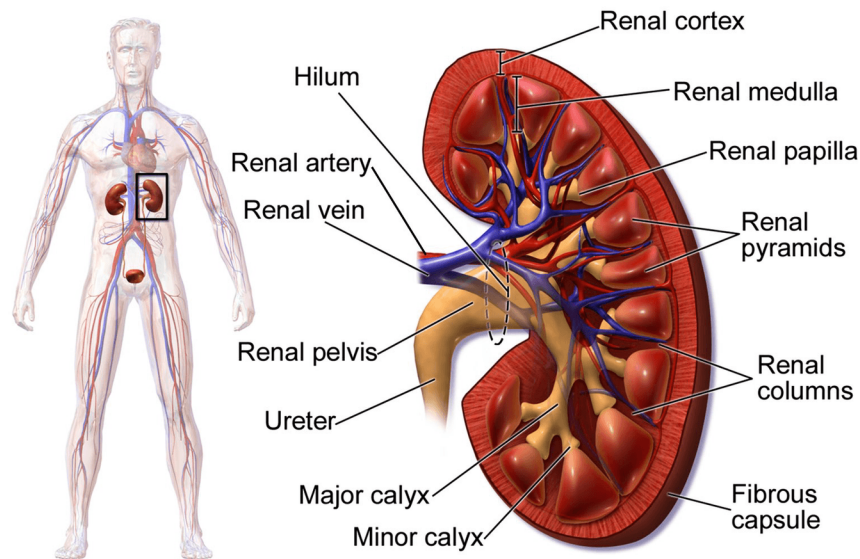


Figure 5.1.3: Frontal section of the left kidney showing cortex, medulla, renal pyramids, columns, papillae, calyces, and fibrous capsule. (CC BY-NC-SA 4.0; Rosanna Hartline via Kidneys).

Figure 5.1.3 is an anatomical diagram of a kidney shown in longitudinal section, with labeled internal and external structures. The instructional purpose is to identify the major anatomical parts of the kidney and show how blood enters and leaves the kidney and how urine is collected and drained. A small inset at the left indicates the location of the kidneys within the body. The main image on the right shows one kidney cut open so the internal organization can be seen.

- **Fibrous capsule:** The fibrous capsule is the thin outer covering of the kidney. It surrounds the organ and helps protect it while maintaining its shape.
- **Renal cortex:** The renal cortex is the outer region of the kidney located just deep to the fibrous capsule. It forms the outer layer of kidney tissue and contains structures involved in filtration, including renal corpuscles and portions of the tubules.
- **Renal medulla:** The renal medulla is the inner region of the kidney. It lies beneath the cortex and is organized into cone-shaped sections called renal pyramids. It contains loops of Henle and collecting ducts that help concentrate urine.
- **Renal pyramids:** The renal pyramids are triangular or cone-shaped structures within the renal medulla. Their broad bases face outward toward the cortex, and their narrow tips point inward toward the renal pelvis. They contain tubules and collecting ducts that transport urine.
- **Renal papilla:** The renal papilla is the pointed tip of each renal pyramid. It projects into a minor calyx and is the site where urine drains from the collecting ducts into the calyx.
- **Renal columns:** The renal columns are extensions of cortical tissue that project inward between the renal pyramids. They separate the pyramids and provide space for blood vessels to pass through the kidney.
- **Hilum:** The hilum is the indented medial opening of the kidney. It is the entry and exit point for the renal artery, renal vein, ureter, nerves, and other structures connected to the kidney.
- **Renal artery:** The renal artery is the large blood vessel that carries oxygenated blood into the kidney. It enters through the hilum and branches throughout the kidney to supply blood for filtration.
- **Renal vein:** The renal vein is the large blood vessel that carries filtered blood away from the kidney. It exits through the hilum and returns blood to the systemic circulation.
- **Renal pelvis:** The renal pelvis is the central, funnel-shaped collecting region inside the kidney. It receives urine from the major calyces and narrows as it continues into the ureter.
- **Major calyx:** A major calyx is one of the larger chambers that receives urine from two or more minor calyces. The major calyces channel urine into the renal pelvis.
- **Minor calyx:** A minor calyx is a small cup-like chamber that surrounds the renal papilla of a pyramid. It collects urine directly from the papilla before draining into a major calyx.
- **Ureter:** The ureter is the tube that carries urine away from the kidney. It begins at the renal pelvis and extends downward toward the urinary bladder.

Renal Blood Supply

The renal blood supply encompasses a complex network of arteries, arterioles, capillaries, and veins, which enables the kidneys to

filter and maintain blood homeostasis. Blood enters the kidney through a large renal artery, which branches into smaller arteries while transporting blood toward the renal cortex. Within the cortex, these arteries penetrate the renal lobes and divide into arterioles. These arterioles lead to the glomerular capillaries, where blood filtration occurs. After filtration, blood flows through a network of capillaries that allow substances to be exchanged with nearby kidney tubules. Finally, smaller veins collect blood from the capillaries. These veins converge to form larger veins that transport the blood away from the renal lobes and cortex. They lead to the renal vein, which returns the filtered blood to systemic circulation.

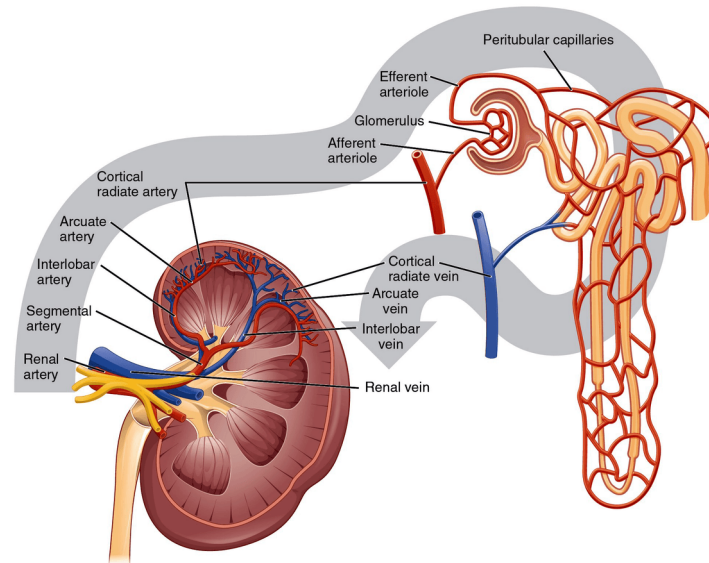


Figure 5.1.4: Blood flow in the kidney. Gross anatomy (left) and microscopic anatomy (nephron, right). (CC BY 4.0; via [The Urinary System](#)).

Figure 5.1.4 shows the path of blood flow through the kidney and how kidney blood vessels connect to a nephron's capillary beds.

Blood flow into the kidney (arteries)

- Blood enters through the renal artery.
- The renal artery branches into the segmental arteries.
- Segmental arteries branch into interlobar arteries.
- Interlobar arteries branch into arcuate arteries.
- Arcuate arteries branch into cortical radiate arteries.

Blood flow through the nephron (glomerulus and capillaries)

- From a cortical radiate artery, blood flows into an afferent arteriole.
- The afferent arteriole delivers blood to the glomerulus (a capillary network where filtration begins).
- Blood leaves the glomerulus through an efferent arteriole.
- The efferent arteriole leads to the peritubular capillaries, which surround the nephron tubules and are involved in reabsorption and secretion.

Blood returning from the kidney (veins)

- Blood drains from capillaries into the cortical radiate vein.
- Cortical radiate veins drain into the arcuate vein.
- Arcuate veins drain into the interlobar vein.
- Interlobar veins merge to form the renal vein, which carries blood out of the kidney.

A Nephron

A nephron is the basic structural and functional unit of the kidneys that regulates water and soluble substances in the blood by filtering the blood, reabsorbing what is needed, and excreting the rest as urine. Its function is vital for homeostasis of blood volume, blood pressure, and plasma osmolarity. It is regulated by the neuroendocrine system by hormones such as antidiuretic

hormone, aldosterone, and parathyroid hormone. A nephron consists of a cup-like Bowman's capsule in the renal cortex and a coiled renal tubule that extends from the capsule. The renal tubule consists of three sections. The first section, the proximal convoluted tubule (PCT), and the last section, the distal convoluted tubule (DCT), are located in the renal cortex. Connecting the PCT and DCT is the loop of Henle, which curves in and out of the renal medulla.

The Bowman's capsule surrounds a tuft of capillaries called a glomerulus. Together, these structures form the renal corpuscle. As the blood flows through the glomerular capillaries, it is filtered, allowing water and specific soluble substances to enter the capsular space, which drains into the renal tubule.

As the filtrate courses through the renal tubules, most substances return to the bloodstream by reabsorption. However, many substances remain in the tubules, and additional substances enter from nearby capillaries through secretion. The filtrate eventually flows from the distal convoluted tubule into one or more collecting ducts. These elongated passageways carry the filtrate from the renal cortex to the apical tips of the renal pyramids, where the filtrate drains into the renal calyces and out of the kidney (excretion).

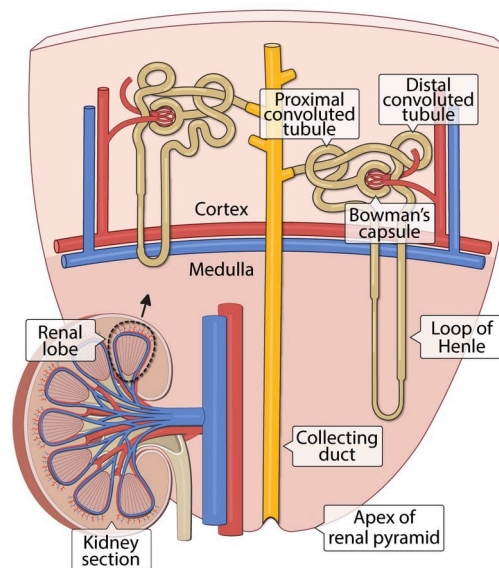


Figure 5.1.5: Section of kidney. The Bowman's capsule filters blood which then goes through the proximal convoluted tubule through the Loop of Henle to the distal convoluted tubule and drained into the collecting duct which opens up in the apex of the renal pyramid. (CC BY 4.0; via Human Bio Media).

Figure 5.1.5 is a schematic diagram showing the organization of nephrons within a section of the kidney. It highlights the relationship between the renal cortex, renal medulla, renal lobe, renal pyramid, and the parts of individual nephrons. The main educational purpose is to show where nephron structures are located in the kidney and how filtrate moves through the nephron and into the collecting duct.

- **Kidney section:** The kidney section is the cutaway view of the organ shown in the lower left corner and expanded into the larger diagram. It provides the overall anatomical context for the nephron structures and shows how the cortex and medulla are arranged.
- **Renal lobe:** The renal lobe is a portion of kidney tissue that includes one renal pyramid and the overlying cortical tissue associated with that pyramid. In the inset, one lobe is outlined to show the anatomical region represented in the enlarged diagram.
- **Cortex:** The cortex is the outer region of the kidney. In this diagram, it contains the renal corpuscles and the convoluted tubules. It is where filtration begins and where much of reabsorption and secretion occur.
- **Medulla:** The medulla is the inner region of the kidney, located beneath the cortex. It contains the deeper portions of the nephron, including the loops of Henle and collecting ducts, which are important for concentrating urine.
- **Bowman's capsule:** Bowman's capsule is the cup-shaped structure that surrounds the glomerulus at the beginning of the nephron. It collects the filtrate that passes out of the glomerular capillaries during filtration.
- **Proximal convoluted tubule:** The proximal convoluted tubule is the first coiled segment of the renal tubule after Bowman's capsule. It lies in the cortex and is the major site where filtered water, ions, and nutrients are reabsorbed back into the blood.
- **Loop of Henle:** The loop of Henle is the U-shaped portion of the nephron that descends from the cortex into the medulla and then returns toward the cortex. It plays a key role in establishing the concentration gradient that allows the kidney to

conserve water and concentrate urine.

- **Distal convoluted tubule:** The distal convoluted tubule is the coiled tubular segment that follows the loop of Henle. It lies in the cortex and is involved in additional regulation of electrolytes, pH, and fluid balance before filtrate enters the collecting duct.
- **Collecting duct:** The collecting duct is the straight tube that receives filtrate from multiple distal convoluted tubules. It extends from the cortex through the medulla and carries urine toward the apex of the renal pyramid. It is also a site where final water reabsorption can occur.
- **Apex of renal pyramid:** The apex of the renal pyramid, also called the papillary region, is the pointed tip of a renal pyramid in the medulla. It is the area toward which collecting ducts drain as urine moves toward the calyces.

There are two types of nephrons in the kidneys, which are categorized based on the location of their renal corpuscles. Most kidney nephrons (about 85%) are categorized as cortical (superficial) nephrons because their renal corpuscles arise in the superficial (outer) renal cortex. Cortical nephrons also have relatively short loops of Henle that do not extend beyond the outer renal medulla. The other 15% of nephrons are classified as juxtamedullary nephrons because their renal corpuscles occur near (juxta-) the renal medulla. Additionally, the loops of Henle in these nephrons are longer, extending deep into the medulla. The cortical nephrons carry out most of the kidneys' regulatory and excretory functions, and the juxtamedullary nephrons provide additional support in regulating urine concentration.

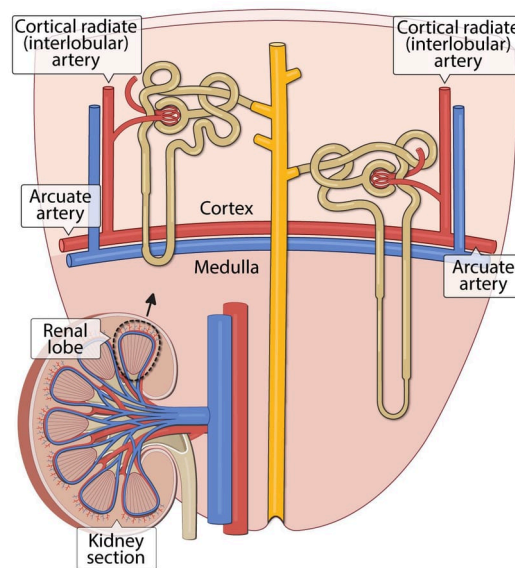


Figure 5.1.6: Comparison of nephron types: cortical (outer cortex, short loop of Henle, peritubular capillaries) vs juxtamedullary (near corticomedullary junction, long loop of Henle, vasa recta for urine concentration). (CC BY 4.0; via Human Bio Media).

Figure 5.1.6 is a simplified anatomical diagram of kidney organization showing the relationship between a renal lobe, the cortex, the medulla, and selected blood vessels that supply the nephron region. The figure includes an inset of a kidney section and an enlarged view of a single renal lobe. The instructional purpose is to show where cortical radiate arteries and arcuate arteries are located in relation to the cortex, medulla, and renal lobe.

- **Kidney section:** The kidney section is the smaller inset image at the lower left. It shows a cutaway view of the kidney with multiple renal pyramids and branching blood vessels, providing the larger anatomical context for the enlarged lobe shown above.
- **Renal lobe:** The renal lobe is the outlined region in the inset kidney section. A renal lobe consists of one renal pyramid in the medulla together with the overlying cortical tissue. The enlarged main figure represents this one lobe.
- **Cortex:** The cortex is the outer region of the kidney shown in the enlarged figure above the boundary line with the medulla. It contains the renal corpuscles and convoluted tubules of nephrons and receives blood from cortical radiate vessels.
- **Medulla:** The medulla is the inner region of the kidney shown below the cortex in the enlarged figure. It contains deeper nephron segments, including loops of Henle and collecting ducts, and is associated with urine concentration.
- **Arcuate artery:** The arcuate artery is shown running horizontally along the boundary between the cortex and medulla. Its position at this junction is important because it gives rise to smaller vessels that extend upward into the cortex. The diagram labels this vessel on both the left and right sides of the enlarged figure.
- **Cortical radiate, or interlobular, artery:** The cortical radiate artery, also called the interlobular artery, is shown as a vertical artery extending upward from the arcuate artery into the cortex. These arteries carry blood from the arcuate arteries into

the cortical tissue, where they supply nephrons. The diagram labels this structure on both the left and right sides to show repeated branching within the cortex.

Nephron Blood Supply Review

About 20% to 25% of the cardiac output passes through the kidneys each time the blood circulates through the body. Most blood entering the kidney (about 94%) goes to the renal cortices, where nephrons exchange substances (filtration, reabsorption, and secretion) with nearby capillaries to form urine. Blood travels into the kidney from the descending aorta by the renal artery. Branches of the renal artery distribute the blood inside the kidney, eventually delivering it to the renal lobes.

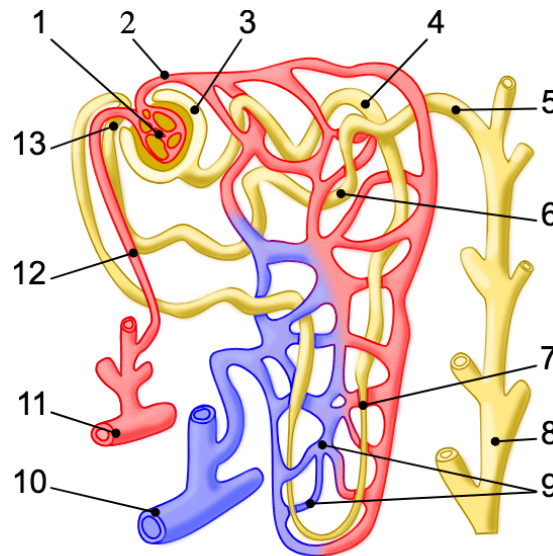


Figure 5.1.7: Detailed view of nephron structure with labeled components, including renal corpuscle, tubules, loop of Henle, collecting duct, and associated blood vessels. (CC BY-SA 4.0; via [Nephron, Parts, and Histology](#)).

Figure 5.1.7 is a simplified nephron diagram showing the renal corpuscle, renal tubules, surrounding blood vessels, and the collecting duct system. Structures are labeled with the numbers 1 through 13 rather than text. The educational purpose is to show how filtrate moves through the nephron and how blood flows through the associated vascular system. Below is a description of each numbered label:

- 1 — Bowman's capsule: Bowman's capsule is the structure that receives fluid filtered from the blood. It surrounds the glomerulus and marks the beginning of the nephron.
- 2 — Glomerulus: The glomerulus is a network of capillaries where blood filtration occurs. Water and small dissolved substances move out of the blood here and enter Bowman's capsule.
- 3 — Proximal convoluted tubule: The proximal convoluted tubule is the first tubule segment after Bowman's capsule. It reabsorbs most of the filtered water, nutrients, and ions back into the blood.
- 4 — Distal convoluted tubule: The distal convoluted tubule is a later segment of the nephron tubule. It helps regulate electrolyte balance, acid-base balance, and additional water movement before filtrate enters the collecting system.
- 5 — Collecting duct: The collecting duct receives fluid from distal convoluted tubules of one or more nephrons. It carries the fluid onward as it becomes urine and also participates in final water reabsorption.
- 6 — Peritubular capillaries: The peritubular capillaries are blood vessels associated with the nephron tubules. They are the site where substances move between the blood and the tubules during reabsorption and secretion.
- 7 — Collecting duct branch: This numbered label identifies a branch of the collecting duct system that contributes fluid to the larger collecting pathway.
- 8 — Collecting duct trunk: This label identifies a larger continuation of the collecting duct system that carries urine from smaller branches toward its exit from the nephron region.
- 9 — Vasa recta: The vasa recta are specialized capillaries associated with deeper nephron segments. They help maintain the concentration gradient needed for urine concentration and participate in exchange with the loop of Henle.
- 10 — Venous drainage vessel: This vessel carries blood away from the nephron-associated capillary networks and returns it toward larger renal veins.
- 11 — Arterial supply vessel: This vessel carries blood toward the nephron and contributes to the arterial supply leading to

filtration.

- 12 — Loop of Henle: The loop of Henle is the nephron segment between the proximal and distal convoluted tubules. It is responsible for establishing the concentration gradient that allows the kidney to regulate water balance and urine concentration.
- 13 — Afferent arteriole: The afferent arteriole carries blood into the glomerulus. It is the direct blood supply to the filtration site.

The Ureter

As urine is formed, it drains into the calyces of the kidney, which merge to form the funnel shaped renal pelvis within each hilum. As the renal pelvis extends out of the hilum, it narrows to become the ureter of each kidney. The ureters go downwards, turn medially and pierce the bladder wall obliquely. This is important because it creates a one-way valve (a physiological sphincter rather than an anatomical sphincter) that allows urine into the bladder, but prevents the reflux of urine from the bladder back into the ureter.

The ureters are approximately 30 cm long and consist of three tissue layers. The inner mucosa is lined with transitional epithelium and scattered goblet cells that secrete protective mucus. The thick muscular layer of the ureter consists of both longitudinal and circular smooth muscles that create the peristaltic contractions to move the urine into the bladder without the aid of gravity. Finally, a loose, outer adventitial layer composed of collagen and fat anchors the ureters between the parietal peritoneum and the posterior abdominal wall.

The Urinary Bladder

The urinary bladder is the primary organ that collects urine from both ureters. In females, the bladder lies anterior to the uterus, posterior to the pubic bone and anterior to the rectum. During late pregnancy, its capacity is reduced due to compression by the enlarging uterus, resulting in increased frequency of urination. In males, the anatomy is similar, minus the uterus, and with the addition of the prostate inferior to the bladder. The bladder is partially retroperitoneal (outside the peritoneal cavity) with its peritoneal-covered “dome” projecting into the abdomen when the bladder is distended with urine.

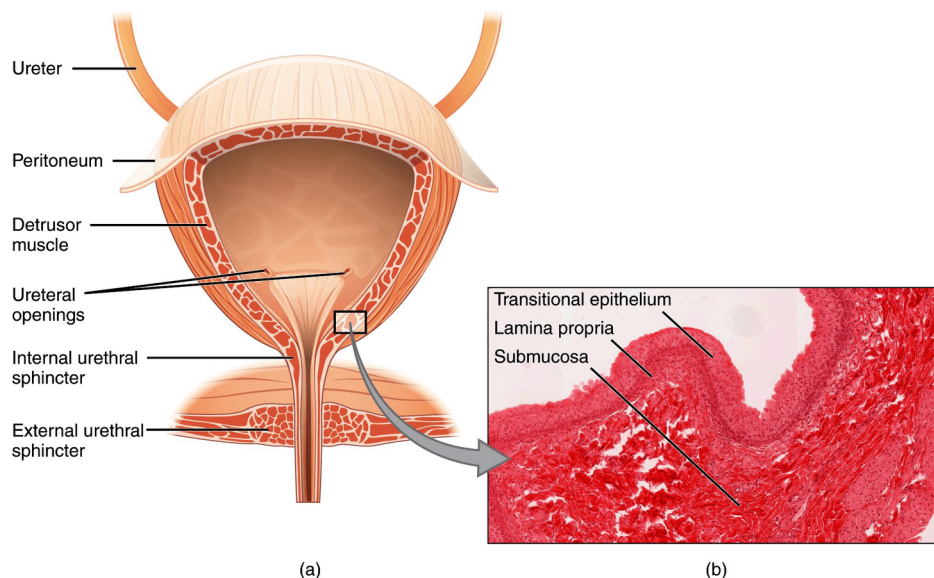


Figure 5.1.8: Urinary bladder diagram and histology showing ureter entry, sphincters, detrusor muscle, and transitional epithelium. (CC BY-SA 4.0; via [The Urinary System](#)).

Figure 5.1.8 has two panels showing urinary bladder anatomy at two scales.

Panel (a): bladder structure (cross-section)

- A ureter enters the bladder at the top.
- The outer covering is labeled peritoneum.
- The thick muscular wall is labeled detrusor muscle.
- Inside the bladder, two ureteral openings are labeled where urine enters the bladder.

- At the bladder outlet, the internal urethral sphincter is labeled.
- Below it, the external urethral sphincter is labeled around the urethra.

Panel (b): bladder wall histology (microscope view)

- The lining is labeled transitional epithelium.
- Beneath the lining are layers labeled lamina propria and submucosa

The Urethra

The terminal organ of the urinary system is the urethra, which transports urine from the bladder to the outside of the body for disposal. The urethra is the only urologic organ that shows any significant anatomic difference between males and females; all other urine transport structures are identical. The urethra in both males and females begins inferior and central to the two ureteric openings in the bladder. Together, these structures form the three points of a triangular-shaped area at the base of the bladder, known as the trigone. In both males and females, the proximal urethra is lined by transitional epithelium, whereas the terminal portion is a non-keratinized, stratified squamous epithelium. In the male, pseudostratified columnar epithelium lines the urethra between these two cell types. Voiding is regulated by an involuntary autonomic nervous system-controlled internal urinary sphincter, which consists of smooth muscle, and a second voluntary external urinary sphincter that is made of skeletal muscle.

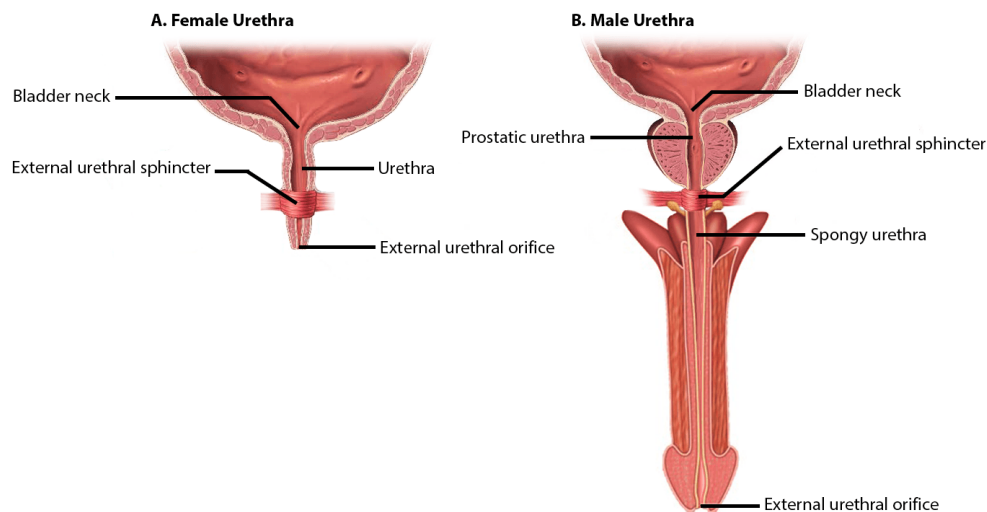


Figure 5.1.9: Comparison of the Female and Male Urethra. The urethra transports urine from the urinary bladder to the outside of the body. The female urethra (A) is short, as it only passes through the pelvic floor before reaching the external surface. The majority of the male urethra (B) is shared by the urinary and reproductive systems and, thus, is longer because it passes through both the prostate gland and the penis. (CC BY-NC-SA 4.0; via [Urinary Tract](#)).

Figure 5.1.9 compares the female urethra and the male urethra and labels key parts involved in urine flow and urinary control.

Shared features (both):

- The urethra begins at the bladder neck, where urine exits the bladder.
- The urethra ends at the external urethral orifice, where urine leaves the body.
- The external urethral sphincter surrounds the urethra and helps control urine release.

Female urethra:

- The urethra is shorter and relatively straight from the bladder neck to the external urethral orifice.
- The external urethral sphincter is shown around the lower portion of the urethra.

Male urethra:

- The urethra is longer and is divided into labeled regions.

- The prostatic urethra is the segment that passes through the prostate gland.
- The urethra then passes through the external urethral sphincter.
- The spongy urethra is the segment that continues to the external urethral orifice.

5.2: Activity 1

Warming up - Connecting Prior Knowledge About Urinary System

Learning about the urinary system in a lab helps you understand its anatomy and function, which is crucial for diagnosing and treating related health issues like kidney disease, diabetes, and urinary tract infections (UTIs). Hands-on experience with models, diagrams, and urine samples allows you to identify the parts of the system, comprehend how it filters blood and regulates bodily fluids, and perform tests like urinalysis.

Hemodialysis is one of three renal replacement therapies (the other two being kidney transplant and peritoneal dialysis). Hemodialysis achieves the extracorporeal removal of waste products such as creatinine and urea and free water from the blood when the kidneys are in a state of failure. Hemodialysis can be an outpatient or inpatient therapy. Less frequently hemodialysis is done at home. Dialysis treatments in a clinic are initiated and managed by specialized staff made up of nurses and technicians; dialysis treatments at home can be self-initiated and managed or done jointly with the assistance of a trained helper who is usually a family member.



Figure 5.2.1: The hemodialyzer machine shown here is 33.5 inches tall, 19 inches deep and 17.5 inches wide. The kidney is much smaller than this machine and is the size of our fist. (CC BY 4.0; via [The Urinary System](#)).

Activate your prior knowledge, review relevant textbook chapters and your lab manual to respond to the following prompts.

Prompts for Student Reflection

1. The kidneys are often described as the "filtration factories" of the body. Based on your prior knowledge, what specific anatomical features (for example, the extensive blood vessel network or the nephron's structure) would be essential for this filtering process?
2. Hemodialysis requires accessing a patient's bloodstream. Why is it impossible to simply draw blood from a standard vein in the arm for this procedure.
3. Consider the perspective of a patient undergoing hemodialysis treatment. How does understanding the underlying anatomy and physiology of their condition and treatment empower them to manage their health more effectively?

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5.3: Activity 2

Identify Anatomical Structures of the Urinary System

Pick up the urinary system model from the lab desk in the class and identify the components indicated by letters (A - I) using anatomical terms.

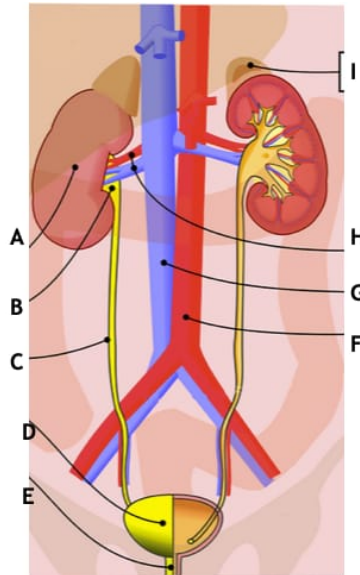


Figure 5.3.1: Illustration of the urinary system with labeled structures A–I, including kidneys, ureters, bladder, and major blood vessels. (CC BY-NC-SA 4.0;

Identification of the Urinary System

Match the following structures to the Figure 5.3.1 labeled with letters A-I and fill in the Table 5.3.1 below.

- Abdominal aorta
- Adrenal gland
- Inferior vena cava
- Renal pelvis
- Right kidney
- Renal artery
- Renal vein
- Urinary bladder
- Ureter, urethra

Table 5.3.1: Table showing letters A–I from the urinary system diagram with corresponding anatomical terms for identification.

The letter indicated on the image	Structures
A	
B	
C	
D	
E	
F	

The letter indicated on the image	Structures
G	
H	
I	

5.4: Activity 3

Apply Anatomical Terms to Identify Urinary System Structures

Fill in the missing words in the Table 5.4.1 to identify the structures/parts of the urinary system indicated by numbers on the image. Apply anatomical terms.

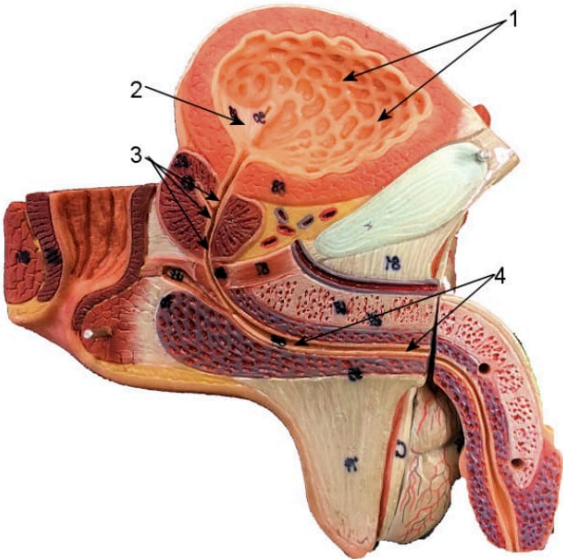


Figure 5.4.1: Detailed anatomical illustration of the male pelvic region indicating internal structures such as the bladder, prostate, and urethral pathway with numbered labels for identification. (CC BY-NC-SA 4.0; via [Urinary System](#)).

Table 5.4.1: Table showing components of a dialysis setup, including patient arm position, tubing, and dialysis machine parts.

Prompt	Student Response (Fill in the Blank)
1 is pointing to the _____ (1 word) which are folds in the bladder and stomach.	
2 is pointing to the _____ (1 word)	
3 is pointing to the _____ (2 words)	
4 is pointing to the _____ (2 words)	

5.5: Activity 4

Identify Urinary System Structures Using Anatomical Terms

Fill in the missing words in the Table 5.5.1 to identify the structures/parts of the urinary system indicated by numbers on the image. Apply anatomical terms.

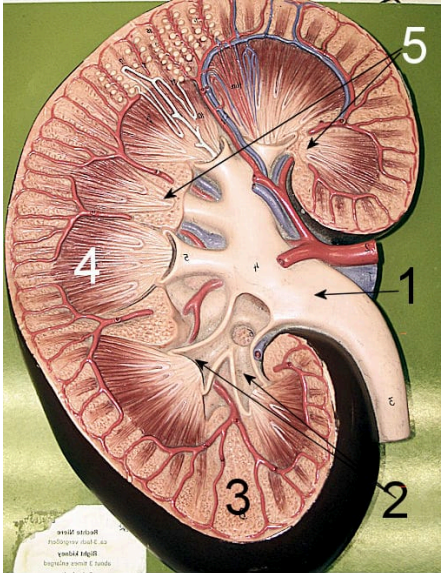


Figure 5.5.1: Detailed anatomical model of the kidney illustrating internal regions such as cortex, medulla, renal pelvis, and major vessels with numbered labels for identification. (CC BY-NC-SA 4.0; via [Urinary System](#)).

Table 5.5.1: Table listing numbered kidney structures (1–4) with prompts for students to fill in correct anatomical terms.

Prompt	Student Response (Fill in the Blanks)
1 would best described as the ____ _____. (2 words)	
2 is pointing to the minor _____. (1 word)	
3 is the _____. (2 words)	
4 is the renal _____ (1 word). It can also be called a medullary _____ (1 word, singular)	

5.6: Activity 5

Identify Urinary System Structures

Fill in the missing words in the Table 5.6.1 to identify the structures/parts of the urinary system indicated by numbers on the image. Apply anatomical terms.



Figure 5.6.1: Detailed illustration of nephron anatomy highlighting filtration and reabsorption pathways, with numbered labels for key components such as glomerulus, proximal tubule, and loop of Henle. (CC BY-NC-SA 4.0; via [Urinary System](#)).

Table 5.6.1: Prompts for five numbered nephron structures to complete with correct anatomical terms.

Prompt	Student Response (Fill in the Blank)
1 would best described as the ____ ____ _____. (3 words)	
2 is pointing to the _____. (1 word)	
3 is the _____. (3 words)	
4 is the _____ nephron loop/loop of Henle. (1 word)	
5 is the _____ nephron loop/loop of Henle. (1 word)	

5.7: Activity 6

Identify Structures of the Urinary System

Fill in the missing words to identify in the Table 5.7.1 the structures/parts of the urinary system indicated by numbers on the image. Apply anatomical terms.

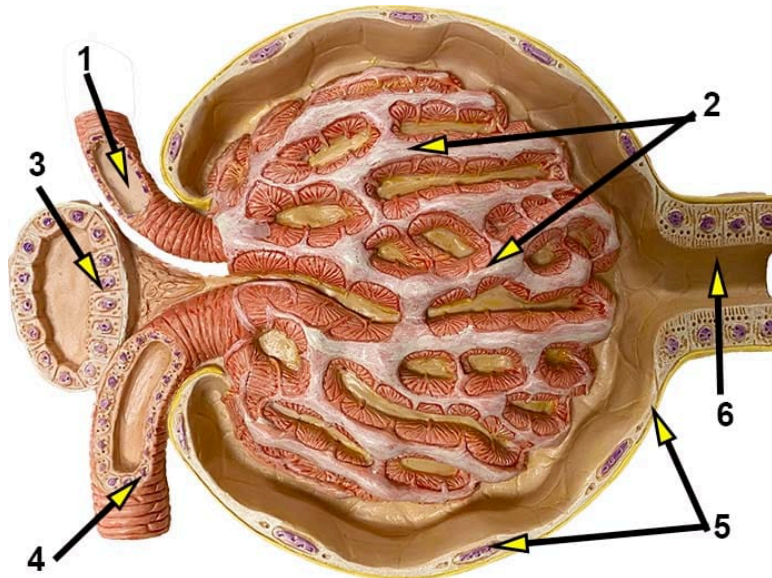


Figure 5.7.1: Anatomical model of the kidney interior highlighting renal pyramids, major and minor calyces, and associated passageways with numbered labels for identification. (CC BY-NC-SA 4.0; via [Urinary System](#)).

Table 5.7.1: Prompts for six numbered nephron structures to complete with correct anatomical terms.

Prompt	Student Response (Fill in the Blanks)
1 would best described as the _____ arteriole. (1 word)	
2 is pointing to the _____ around _____ capillaries. (2 words)	
3 is pointing to the _____ . (2 words)	
4 is pointing to the _____ arteriole. (1 word)	
5 is pointing to the the _____ capsule. (1 word)	
6 is pointing to the _____ convoluted tubule. (1 word)	

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5.8: Activity 7

Identify Urinary System Structures

Fill in the missing words to identify the structures/parts of the urinary system indicated by letters on the image. Apply anatomical terms.

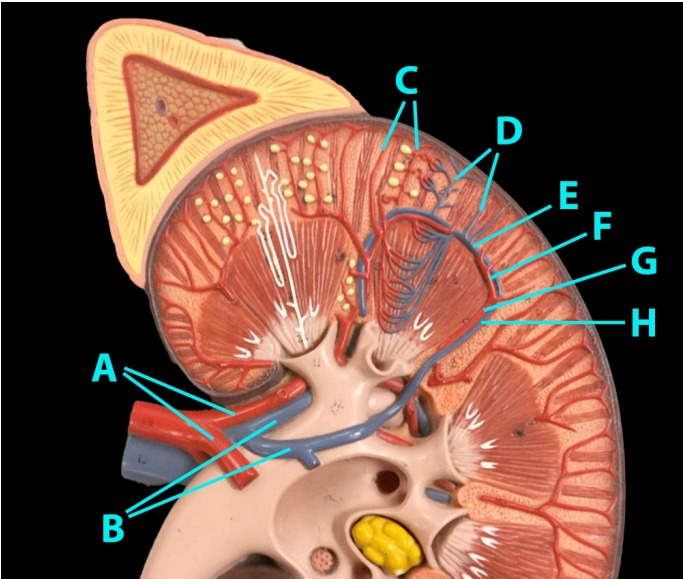


Figure 5.8.1: Anatomical model of kidney and adrenal gland highlighting internal regions, renal pyramids, and major vessels with labels A–H for identification. (CC BY-NC-SA 4.0; via [Urinary System](#)).

Table 5.8.1: Prompts for eight labeled kidney structures to complete with correct anatomical terms.

Prompt	Student Response (Missing word)
A would best described as the _____. (2 words)	
B is pointing to the _____. (2 words)	
C is the _____. (2 words)	
D is the _____. (2 words)	
E is the _____. (2 words)	
F is the _____. (2 words)	
G is the _____. (2 words)	
H is the _____. (2 words)	

5.9: Activity 8

Critical Thinking to Establish Structure–Function Relationships

For each item, answer both parts (name and explanation):

1. Which region is best designed to house most of the renal corpuscles (glomeruli + Bowman's capsules), and why is that anatomically logical?
 - a. Name the region.
 - b. Explain how its location relates to the need for high blood supply and easier access to large arteries.
2. Which region is arranged in pyramid-like structures with parallel tubules and collecting ducts, and how does this arrangement help with urine concentration and flow?
 - a. Name the structures and the region.
 - b. Explain how their shape and orientation support function.
3. The renal pelvis is a funnel-shaped structure. Why is this shape appropriate for its function?
 - a. Identify what it collects.
 - b. Explain why a funnel design is efficient here.

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5.10: Activity 9

Structure Function Analysis

Answer each question in 2 to 4 sentences. Don't just tell what happens; explain why the structure is appropriate.

1. Glomerulus and Capsule
 - The glomerular capillaries are fenestrated (full of pores), and Bowman's capsule wraps closely around them. Why is this combination of "leaky" capillaries and a surrounding capsule ideal for filtration, and what would go wrong if the capillaries were non-fenestrated?
2. Proximal Convoluted Tubule (PCT)
 - The PCT has a brush border (microvilli) and a very folded, convoluted path. How do these structural features support its role as the "workhorse" of reabsorption? Give at least two reasons.
3. Descending vs Ascending Limb of Loop of Henle
 - The descending limb is highly permeable to water but not to many solutes. The ascending limb is relatively impermeable to water but actively transports Na^+ , Cl^- . How does this structural difference between the two limbs allow the kidney to create a concentration gradient and produce concentrated or dilute urine?
4. Collecting Ducts and Hormones
 - Collecting ducts pass from the cortex to the medulla and can change their permeability to water in response to ADH (antidiuretic hormone). Why is it functionally important that collecting ducts run through a region with a high osmotic gradient (deep medulla), and how does their adjustable permeability support body water balance?
5. Filtration and Selective Reabsorption
 - Why doesn't protein (e.g., albumin) normally appear in significant amounts in the urine of a healthy person? Relate this to the structure of the filtration barrier in the renal corpuscle.
 - Why is the proximal convoluted tubule called the "workhorse" of the nephron? (Hint: Think about the percentage of water, glucose, amino acids, and ions that are reabsorbed here.)

5.11: Activity 10

Blood Pressure and the Kidneys

Hypertension and Kidney Function Case Study

A 55-year-old patient has long-standing high blood pressure (hypertension). Over time, this has damaged small blood vessels in the kidneys, including the afferent arterioles and glomeruli. Answer in 2–4 sentences each:

1. How can damage to the small renal blood vessels (afferent arterioles and glomeruli) affect the glomerular filtration rate (GFR)? (Think: less blood flow = ? filtration.)
2. If GFR decreases significantly, how might this affect:
 - Blood levels of urea and creatinine
 - The body's ability to regulate fluid volume and blood pressure?
3. From a real-life perspective, explain why controlling blood pressure is important for protecting kidney function.

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Key Terms and Definitions

- Absorption - passage of digested products from the intestinal
- Aminopeptidase: protease that breaks down peptides to single amino acids; secreted by the brush border of small intestine
- Amylase - secreted by both the salivary glands and the pancreas, breaks down starches into sugars
- Bile: digestive juice produced by the liver; important for digestion of lipids
- Bolus: mass of food resulting from chewing action and wetting by saliva
- Carboxypeptidase: protease that breaks down peptides to single amino acids; secreted by the brush border of the small intestine
- Chemical digestion - enzymatic breakdown of food
- Chylomicron: small lipid globule
- Chyme - soupy mixture of partially digested food and stomach juices
- Chymotrypsin: pancreatic protease, breaks down peptides into free amino acids that can be absorbed by the intestinal wall
- Defecation - elimination of undigested substances from the body in the form of feces
- Digestion: mechanical and chemical break down of food into small organic fragments
- Dipeptidase: protease that breaks down peptides to single amino acids; secreted by the brush border of small intestine
- Duodenum: first part of the small intestine where a large part of digestion of carbohydrates and fats occurs
- Elastase: pancreatic protease
- Esophagus: tubular organ that connects the mouth to the stomach
- Essential nutrient: nutrient that cannot be synthesized by the body; it must be obtained from food
- Gallbladder: organ that stores and concentrates bile
- Ingestion - taking food into the GI tract through the mouth
- Jejunum: second part of the small intestine
- Lactase: enzyme that breaks down lactose, a sugar found in dairy products, into glucose and galactose
- Large intestine: digestive system organ that reabsorbs water from undigested material and processes waste matter
- Lipase: an enzyme, produced in small amounts by mouth and stomach, and in larger amounts by pancreas; responsible for the breakdown of lipids (fats) into fatty acids and glycerol (simple sugar alcohol).
- Liver: organ that produces bile for digestion and processes vitamins and lipids
- Lumen - through mucosal cells and into the bloodstream or lacteals
- Maltase: enzyme that breaks down maltose into glucose
- Mastication - chewing
- Mechanical digestion - chewing, mixing, and segmentation that prepares food for chemical digestion
- Mineral: inorganic, elemental molecule that carries out important roles in the body
- Pancreas: gland that secretes digestive juices
- Pepsin: enzyme found in the stomach whose main role is protein digestion
- Small intestine: organ where digestion of protein, fats, and carbohydrates is completed
- Peristalsis - muscular contractions and relaxations that propel food through the GI tract
- Propulsion - voluntary process of swallowing and the involuntary process of peristalsis that moves food through the digestive tract
- Segmentation - alternating contractions and relaxations of non-adjacent segments of the intestine that move food forward and backward, breaking it apart and mixing it with digestive juices
- Stomach: sac-like organ containing acidic digestive juices
- Sucrase: enzyme that breaks down sucrose into glucose and fructose
- Trypsin: pancreatic protease that breaks down protein
- Vitamin: organic substance necessary in small amounts to sustain life

6: QUANTITATIVE AND QUALITATIVE ANALYSIS OF ARTIFICIAL URINE SAMPLES

Introduction

In this lab, we will delve into the fascinating world of urinalysis, a vital tool in clinical diagnostics that helps us understand various health conditions. Through hands-on activities, you will explore the components of urinalysis, including physical, chemical, and microscopic examinations of urine samples. You'll gain the skills to identify normal and abnormal characteristics, which are crucial for accurate diagnoses. Additionally, we will engage in case studies that allow you to apply your knowledge in real-world scenarios, enhancing your critical thinking and diagnostic abilities. By the end of this lab, you will have a comprehensive understanding of how urinalysis contributes to patient care and medical decision-making.

Learning Objectives

By the end of this chapter, you will be able to:

- Describe the key physical (color, clarity, and specific gravity) and chemical (Dipstick) components of a urinalysis and explain how each contributes to diagnosing common health conditions.
- Differentiate between normal and abnormal findings in simulated urine samples, demonstrating accurate observation and documentation skills.
- Relate lab findings to specific kidney diseases, urinary tract infections, and metabolic disorders (e.g., diabetes).
- Analyze and interpret urinalysis data from clinical case studies to formulate appropriate provisional diagnoses and rationales, strengthening critical thinking and clinical reasoning.
- Discuss the clinical implications of specific urinalysis findings in real-world healthcare settings, integrating theoretical knowledge with practical decision-making and patient care considerations.

6.1: Background Information

6.2: Activity 1

6.3: Activity 2

6.4: Activity 3

6.5: Activity 4

6.6: Glossary

6.1: Background Information

Overview

The kidneys continuously form urine, reabsorbing glucose, amino acids, water, and salts from the filtrate of blood plasma. Factors such as diet, physical activity, body metabolism, disease, time of day, and body position (standing, sitting, or lying down) can influence the chemical composition of urine. Typical daily normal volume of urine is 1-2 liters (adult), however, varies considerably.

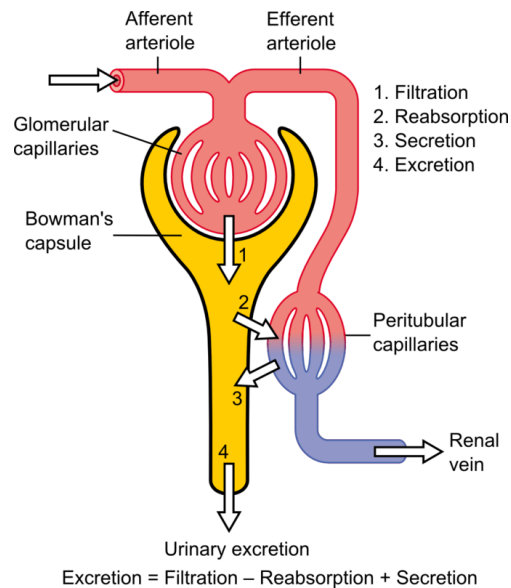


Figure 6.1.1: Physiological processes at the nephron in the formation of urine. (CC BY 4.0; via Boundless Anatomy and Physiology).

Figure 6.1.1 shows the main blood vessels and tubule pathway involved in urine formation, highlighting four processes: filtration, reabsorption, secretion, and excretion.

- Blood enters the kidney's filtering unit through the afferent arteriole and flows into the glomerular capillaries (a capillary tuft).
- The glomerular capillaries sit inside Bowman's capsule.
Step 1: Filtration occurs here—water and small dissolved substances move from the blood into Bowman's capsule, forming filtrate.
- Blood leaves the glomerulus through the efferent arteriole and then flows into the peritubular capillaries, which surround the kidney tubules.
- Along the tubule:
Step 2: Reabsorption moves needed substances from the tubule back into the blood in the peritubular capillaries.
Step 3: Secretion moves additional substances from the blood in the peritubular capillaries into the tubule.
- What remains in the tubule is eliminated as urine.
Step 4: Excretion is shown as fluid leaving the tubule as urinary excretion.
- The diagram also states the relationship: $\text{Excretion} = \text{Filtration} - \text{Reabsorption} + \text{Secretion}$

As filtrate passes through the nephron, its osmolarity (ion concentration) changes as ions and water are reabsorbed. The filtrate entering the proximal convoluted tubule is 300 mOsm/L, which is the same osmolarity as normal plasma osmolarity.

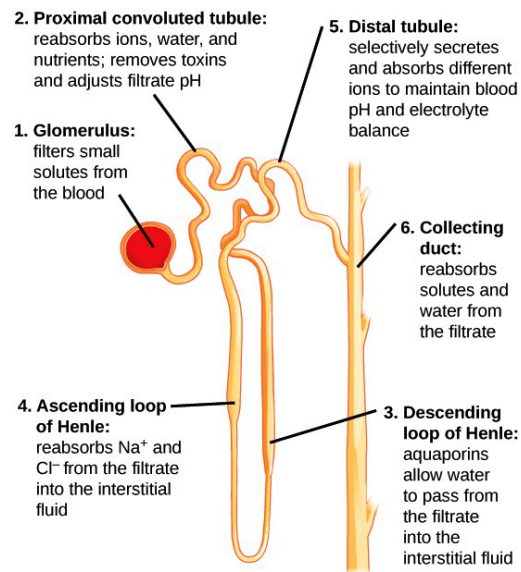


Figure 6.1.2: Nephron structure: Each part of the nephron performs a different function in filtering waste and maintaining homeostatic balance. (CC BY 4.0; via [Physiology of Kidneys](#)).

Figure 6.1.2 shows the nephron structure and its functional regions. It begins with the glomerulus, which filters small solutes from blood. Next is the proximal convoluted tubule, which reabsorbs ions, water, and nutrients, removes toxins, and adjusts filtrate pH. The descending loop of Henle allows water to pass into interstitial fluid via aquaporins. The ascending loop of Henle reabsorbs sodium and chloride ions. The distal tubule selectively secretes and absorbs ions to maintain blood pH and electrolyte balance. Finally, the collecting duct reabsorbs solutes and water from the filtrate before urine formation.

1. Glomerulus: filters small solutes and water from the blood to form filtrate.
2. Proximal convoluted tubule: reabsorbs ions, water, and nutrients; removes some toxins; and helps adjust filtrate pH.
3. Descending loop of Henle: aquaporins allow water to leave the tubule and move into the surrounding interstitial fluid.
4. Ascending loop of Henle: reabsorbs sodium (Na^+) and chloride (Cl^-) from the filtrate into the interstitial fluid.
5. Distal tubule: selectively reabsorbs and secretes ions to help maintain blood pH and electrolyte balance.
6. Collecting duct: reabsorbs additional water and solutes from the filtrate as urine concentration is finalized.

In general, urine consists of urea and other organic and inorganic chemicals dissolved in water. Urine is normally 95% water and 5% solutes, although considerable variations in the concentrations of these solutes can occur owing to the influence of factors such as dietary intake, physical activity, body metabolism, and endocrine functions. Primary components of normal urine are:

- Urea - Primary organic component. Product of protein and amino acid metabolism
- Creatinine - Product of nucleic acid breakdown in food and cells
- Uric acid - Product of creatine metabolism by muscles
- Chloride - Primary inorganic component. Found in combination with sodium (table salt) and many other inorganic substances
- Sodium - Primarily from salt, varies by intake
- Potassium - Combined with chloride and other salts
- Phosphate - Combines with sodium to buffer the blood
- Ammonium Regulates blood and tissue fluid acidity
- Calcium - Combines with chloride, sulfate, and phosphate

Two unique characteristics of a urine specimen account for continued popularity:

1. Urine is a readily available and easily collected specimen.
2. Urine contains a great deal of information about body's major metabolic functions which can be obtained by laboratory tests.

Urinalysis is a critical, non-invasive, and cost-effective diagnostic test that examines a sample of urine to detect potential health issues like urinary tract infections, kidney problems, diabetes, and liver disease. A complete urinalysis is a three-part urine examination (macroscopic, chemical, and microscopic) to detect various medical conditions like urinary tract infections, diabetes, and kidney problems.

Macroscopic (visual) Exam

- Color - Fluid balance, diet, medicines, and diseases can affect this (Vitamin B, consumption of blackberries and beets). Normal urine is pale to dark yellow; variations can indicate dehydration (darker), certain medications, or food dyes. Orange or reddish brown may indicate dehydration or blood in the urine.
- Clarity - Clear urine is normal; cloudy urine may indicate infection, blood cells, or crystals. Turbid urine suggests the presence of protein or excess cellular material, may indicate urinary tract infection.
- Odor - The smell ("odor") of urine may provide health information. For example, urine of diabetics may have a sweet or fruity odor due to the presence of ketones (organic molecules of a particular structure). Generally fresh urine has a mild smell but aged urine has a stronger odor, similar to that of ammonia [bacterial breakdown of urea to ammonia].
- Specific gravity - This is the ratio of the weight of a volume of a substance compared with the weight of the same volume of distilled water. Given that urine is mostly water, but also contains some other substances dissolved in the "water", its density is expected to be close to, but slightly greater than, 1.0.

Table 6.1.1: Hydration Status Classification Based on USG Values

USG value	Label of Hydration Status	USG value	Label of Hydration Status
< 1.004	Hyperhydrated (Overhydrated)	1.025-1.029	Mildly Dehydrate/Hypohydrated (just beyond limits for Euhydrated)
1.004-1.015	Euhydrated (Normal Hydrated)	1.030-1.034	Dehydrated/Hypohydrated
1.020-1.025	Mildly Dehydrate/Hypohydrated (still within limits for Euhydrated)	> 1.035	Severely Dehydrated

Chemical Exam - uses a dipstick to test for chemicals

- pH - The pH of normal urine is generally in the range 4.6 - 8, a typical average being around 6.0. Much of the variation is due to diet. Alkaline urine pH may indicate kidney failure or UTI or vomiting. An acidic pH may be caused by severe lung disease, uncontrolled diabetes, aspirin overdose, severe diarrhea, dehydration, starvation, or drinking too much alcohol.
- Protein (mostly albumin) - not normally present in the urine, but strenuous exercise, pregnancy, fever and some diseases (kidney disease and nephritis) may cause its appearance. The condition is called proteinuria.
- Glucose - normally there is very little or no glucose in urine. When the kidneys are damaged and/or blood sugar level is very high (uncontrolled diabetes), urinary level increases. The condition is called glycosuria.
- Nitrites - bacteria that cause a urinary tract infection (UTI) possess an enzyme that converts nitrates to nitrites. Thus, urinary nitrites indicate a UTI.
- Ketones - are produced by the liver when there are not enough carbohydrates consumed, or in diabetes mellitus, starvation, and severe vomiting and the when it breaks down fats as energy.
- Blood - indicates hemoglobin which usually indicates bleeding in the urinary tract, which could be caused by trauma, infection or kidney stones. Known as hematuria.

Reagent Strips

Routine chemical examination of urine has changed dramatically since the early days of urine testing, due to the development of the reagent strip method for chemical analysis. Reagent strips currently provide a simple, rapid means for performing medically significant chemical analysis of urine, including pH, protein, glucose, ketones, blood, bilirubin, urobilinogen, nitrite, leukocytes, and specific gravity.

Reagent strips consist of chemical-impregnated absorbent pads attached to a plastic strip. A color producing chemical reaction takes place when the absorbent pad comes in contact with urine. The reactions are interpreted by comparing the color produced on the pad within the required time frame with a chart supplied by the manufacturer. Several colors or intensities of a color for each substance being tested appear on the chart. By careful comparison of the colors on the chart and the strip, a semiquantitative value of trace, 1+, 2+, 3+, or 4+ can be reported. An estimate of the milligrams per deciliter present is available for appropriate testing areas. Reagent Strip Technique Testing methodology includes dipping the reagent strip completely, but briefly, into a well-mixed specimen, removing excess urine from the strip by running the edge of the strip on the container when withdrawing it from the specimen, blotting it horizontally on an absorbent medium, waiting the specified length of time for reactions to take place, and comparing the colored reactions against the manufacturer's chart using a good light source.

The timing for reactions to take place varies between tests and manufacturers, and ranges from an immediate reaction for pH to 120 seconds for leukocyte esterase. For the best semiquantitative results, the manufacturer's stated time should be followed; however, when precise timing cannot be achieved, manufacturers recommend that reactions be read between 60 and 120 seconds, with the leukocyte esterase reaction read at 120 seconds.

Microscopic Exam

Microscopic exam involves examining the urine sample under a microscope to identify cells, bacteria, crystals, and casts that may indicate an underlying health issue.

- Red or white blood cells - May be present in urine in disease, infection, or injury to the kidneys, ureters, bladder, or urethra.
- Casts - The formation of plugs of blood cells, proteins or other substances (casts) in the renal tubules that can occur in some renal diseases.
- Crystals - Few crystals are found in healthy urine and many crystals, or certain types, may indicate presence of kidney stones or metabolic dysfunction.
- Bacteria, yeast cells, or parasites - Presence in urine indicative of an infection.

How is the Sample Collected for Testing in Real Life Scenario?

- Urine for a urinalysis can be collected at any time. The first morning sample is considered the most valuable because it is more concentrated and more likely to yield abnormalities if present. It is important to clean the genitalia before collecting urine. Bacteria and cells from the surrounding skin can contaminate the sample and interfere with the interpretation of test results.
- With women, menstrual blood and vaginal secretions can also be a source of contamination. Women should spread the labia of the vagina and clean from front to back; men should wipe the tip of the penis. It is suggested to let some urine fall into the toilet, then 1 - 2 ounces of urine be collected in the container provided, then void the rest into the toilet. This type of collection is called a "midstream collection" or a "clean catch."

A urine sample will only be useful for a urinalysis if taken to the doctor's office or laboratory for processing within a short period of time. If it will be longer than an hour between collection and transport time, then the urine should be refrigerated or a preservative may be added.

6.2: Activity 1

Exploring Urinalysis

Simulated scenarios provide instant feedback on your performance, helping you identify areas for improvement in real-time. In this engaging activity, students will dive into the world of urinalysis through interactive simulations, allowing them to practice techniques, analyze results, and apply critical thinking in a safe and controlled environment. This hands-on approach fosters a deeper understanding of how urinalysis contributes to patient care and diagnosis.

Objectives of the Activity

- **Develop Practical Skills.** Gain confidence in performing urinalysis techniques through repeated simulation exercises.
- **Enhance Analytical Thinking.** Learn to interpret urinalysis results in the context of various medical conditions.
- **Collaborate and Discuss:** Work with peers to discuss findings and share insights, enriching the learning experience.

Steps to follow

1. Access the simulation platform on [Urinalysis Lab Simulation](#).
2. Select the link and follow prompts.
3. Read any background information or patient history included in the simulation. This context will help you interpret your findings later.
4. **Macroscopic (Physical) Analysis**
 - Use the virtual tools to examine urine color, clarity, and volume.
 - Record Observations. Note if the urine is clear, cloudy, or colored unusually. Pay attention to any prompts about odor or physical properties.
5. **Chemical Analysis (Dipstick Test)**
 - Drag and dip the digital urinalysis strip into the virtual urine sample.
 - Wait for Results. The simulation will display color changes on the strip's pads.
 - Interpret the Results. Compare the pad colors to the provided reference chart to determine levels of glucose, protein, blood, ketones, pH, and other markers.
 - Record Findings. Enter your results in the given data table.
6. **Microscopic Analysis**
 - Use the simulation tools to create a digital slide from the urine sample.
 - Zoom in to identify cells (RBCs, WBCs), crystals, casts, and bacteria.
 - Document Your Observations. Note quantities and types of microscopic elements seen.
7. **Interpretation and Diagnosis**
 - Review all data. Combine your macroscopic, chemical, and microscopic findings.

Table 6.2.1: Urinalysis Test Parameters and Normal Reference Ranges

Test Parameter		Normal	Observation in Virtual Strip	Predicted Issue
Macroscopic (Visual)				
Urine Color		Pale Yellow		
Urine Clarity		Clear		
Urine odor		Slight or none		
Chemical (Dipstick)				
Leukocytes (2 min)		Negative		
Nitrites (60 sec)		Negative		
Urobilinogen (60 sec)		0.5 - 1.0 mg/dL		

Test Parameter	Normal	Observation in Virtual Strip	Predicted Issue
Protein (60 sec)	<= 150 mg/day		
pH (60 sec)	4.5 - 8.0		
Blood (60 sec)	Negative		
Specific gravity (45 sec)	1.005 - 1.030		
Ketone (40 sec)	Negative		
Bilirubin (30 sec)	Negative		
Glucose (30 sec)	Negative		
Microscopic per HPF (High Power Field; 400x)			
Cells	Red Blood Cells (RBCs): 0-2		
	White Blood Cells (WBCs): 0-5		
	Squamous epithelial cells: few or none		
Casts (tube-shaped particles)	None		
Crystals	None, or very few, small crystals		
Microorganisms	Bacteria: None Yeast: None		

6.3: Activity 2

Analysis of Simulated Artificial Urine Samples

Objective: To perform a macroscopic (visual) and dipstick chemical analysis on four simulated artificial urine samples, including a control, to understand how different conditions can affect urine properties.

Materials Needed:

- Four simulated urine samples (labeled A, B, C, D)
- Urinalysis dipsticks
- Color chart for dipstick results
- Timer or stopwatch
- Gloves and Lab coat
- Paper towels

Safety Precautions:

- Wear gloves and a lab coat to prevent contact with the simulated urine.
- Handle all samples carefully to prevent contamination.
- Dispose used dipsticks and gloves in the designated waste container.

Procedure:

- Label each of the four 100 ml beakers as A, B, C and D
- Pour 50 ml simulated urine sample numbered A, B, C and D.

Part 1: Macroscopic (visual) Examination

1. Color
 - For each sample (A, B, C, D), hold the container up to a light source.
 - Observe and note the color of each sample. Record any differences in color, which may indicate variations in concentration or composition.
2. Clarity
 - Swirl each sample gently. Look through each sample against a light or white background.
 - Record whether each sample is clear, slightly cloudy, or cloudy.
3. Odor
 - Waft your hand over each sample to bring the odor towards your nose without directly smelling it.
 - Note any unusual odors for each sample.
4. Use pH paper to find out the pH of each sample. While the strip is still wet, compare the color with the color chart on the pH strip container to determine the pH.

Part 2: Dipstick Chemical Analysis

- Preparation:
 - Ensure all simulated urine samples are at room temperature.
 - Lay out a clean paper towel to work on.
 - Remove a dipstick from its container, ensuring you do not touch the reagent pads.
- Submerging the Dipstick:
 - For each sample, briefly dip the reagent end of the dipstick into the urine, ensuring all reagent pads are immersed.
 - Immediately remove the dipstick and gently tap it against the side of the container, holding horizontally, to remove excess liquid.

- Timing and Reading:
 - Start your timer or stopwatch as soon as you remove the dipstick from each sample.
 - Place the dipstick horizontally on the paper towel to prevent cross-contamination between pads.
 - Follow the manufacturer's guidelines for specific timing for each test pad.
- Record the results
 - Document/record the results for each test pad in the Table 3 for each sample.
- Analysis
 - Identify/predict any abnormalities or differences indicative of specific conditions.

Table 6.3.1: Urinalysis Observations and Reference Ranges for Macroscopic Examination

Test Parameter	Reference range	Observations				Predicted condition
		Sample A	Sample B	Sample C	Sample D	
Color pale yellow, dark yellow, orange, red						
Odor none, sweet or fruity, ammonia						
Clarity clear, slightly cloudy, cloudy, turbid						

Table 6.3.2: Urinalysis Observations and Reference Ranges for Chemical Parameters

Test Parameter	Reference range	Observations				Predicted condition
		Sample A	Sample B	Sample C	Sample D	
Leukocytes (2 min)	Negative					
Nitrites (60 sec)	Negative					
Protein (60 sec)	<= 150 mg/day					
pH (60 sec)	4.5 - 8.0					
Blood (60 sec)	Negative					
Ketone (40 sec)	Negative					
Glucose (30 sec)	Negative					
Specific gravity (45 sec)	1.005 - 1.030					

- Clean Up:
 - Dispose of the used dipsticks and gloves in the designated waste container.
 - Clean your work area with a disinfectant wipe.

6.4: Activity 3

Comparison of Urine and Other Liquids

Objective

To compare the physical and chemical properties of urine with various beverages, reinforcing understanding of urine composition and its implications for health.

Urine provides valuable insights into a person's health. By comparing its properties with common beverages, students will learn how different substances affect urine composition and understand the significance of specific urine characteristics. This activity emphasizes practical skills in measurement and analysis, as well as critical thinking regarding health implications.

Materials

- Simulated urine sample (control)
- Various beverages (e.g., distilled water, soda, juice, tea, sports drinks)
- pH test strips
- Urinalysis dipsticks (for protein, glucose, ketones, etc.)

Procedure

- Macroscopic (visual) Examination
- Observe and record the color, clarity, and odor of each sample (urine and beverages).

pH Testing

- Use pH test strips or a pH meter to measure the pH of each sample. Record the values.

Chemical Analysis

- Use urinalysis dipsticks to test for the following in the urine sample:
 - Protein
 - Glucose
 - Ketones
- Record the results based on the color changes.

Table 6.4.1: Physical properties of simulated urine and comparison liquids

Liquid	Color	Clarity	Odor	Specific Gravity
Simulated Urine				
Distilled Water				
Clear Soda				
Apple Juice				

Table 6.4.2: Chemical properties of simulated urine and comparison liquids

Chemical Parameter	Simulated Urine	Distilled Water	Clear Soda	Apple Juice
pH				

Chemical Parameter	Simulated Urine	Distilled Water	Clear Soda	Apple Juice
Glucose				
Protein				

Analysis questions

1. Compare your results for the simulated urine, distilled water, soda, and apple juice. How do their physical and chemical properties differ?
2. Relate the findings to kidney function. Based on your results, why can't a simple beverage like soda or water serve the same function as urine in the body?
3. Hypothesize what changes you would observe in a real urine sample after a person drinks a large glass of water. Which parameters would be most affected?

6.5: Activity 4

Case Study Analysis

Case studies in human anatomy and physiology play a crucial role in enhancing education and understanding for students and healthcare professionals. Analyzing case studies encourages critical thinking and problem-solving skills. Students must assess the situation, identify the relevant anatomical and physiological principles, and determine the best course of action. By working through case studies, students practice diagnostic reasoning, learning to identify symptoms, analyze data, and predict diagnosis. This is essential training for future clinical practice. Here are three detailed case studies based on urinalysis designed to promote comprehension of its importance, facilitate group discussions, enhance critical thinking, and connect with real-world scenarios.

Case Study 1

- Patient profile - A 45-year-old male experiencing frequent urination and abdominal pain.
- Macroscopic (visual) Examination - Urine is cloudy with a strong odor.
- Chemical Analysis (dipstick) - Positive for nitrites and leukocytes, pH 8.0.
- Microscopic Examination - Presence of white blood cells and bacteria.

What is predicted Diagnosis? Justify the basis of prediction.

Case Study 2

You are a pediatric physician. A child is brought to you who is suspected to be suffering abuse at home. You conduct urinalysis and find the following; pH 3.5, ketone levels are high, the urine sample has blood in it. You note that the child has bruises below his ribcage on his back. The child does not have diabetes. Answer the questions to demonstrate knowledge about urinalysis as a tool to predict diagnosis.

1. Is this urine sample acidic or alkaline?
2. What could be likely cause(es) of this pH level? Explain.
3. What is likely responsible for the elevated ketone levels?
4. What is likely causing the presence of blood in the child's urine?

Case Study 3

A 60-year-old woman is referred to the nephrology clinic for evaluation of her chronic edema and hypertension. She has a history of cardiovascular disease and is currently on medication.

- Urinalysis Results:
- Color - Pale yellow
- Clarity - Clear
- Leukocyte Esterase/Nitrite - Negative
- pH - 6.0
- Protein - 3+ (high)
- Glucose - Negative
- Ketones - Negative
- Blood - Negative
- Specific Gravity - 1.020
- Microscopic
- WBC - 1/hpf
- RBC - 1/hpf
- Casts - Many hyaline and granular
- Other - No crystals

Discussion Questions

1. What does the high level of proteinuria indicate about the patient's kidney function?
2. What clinical significance does the presence of high levels of proteinuria have for the patient's overall health, especially in relation to her existing cardiovascular disease?

Key Term and Definitions

- **24-Hour Urine Collection** - A method for collecting all urine produced in a 24-hour period to assess kidney function and metabolic processes.
- **Bilirubin and Urobilinogen** - Urine normally does not contain bilirubin. Elevated bilirubin suggests liver disease or biliary obstruction. Small amounts of urobilinogen are normal; high levels indicate hemolysis or liver disease. Obstructed bile ducts reduce urobilinogen in urine.
- **Casts** - Cylindrical structures formed in renal tubules, consisting of cells, proteins, or other substances. Types (e.g., hyaline, granular, RBC casts) can indicate specific kidney issues.
- **Crystals** - Solid particles in urine formed due to metabolic conditions or diet. Common types include calcium oxalate, uric acid, and struvite crystals.
- **Edema** - Swelling caused by excess fluid trapped in body tissues, often associated with kidney dysfunction or heart failure.
- **Glycosuria** - Glucose in urine occurs when blood glucose exceeds the kidney's reabsorption capacity (typically >180 mg/dL). Detected by dipstick.
- **Hematuria** - Presence of blood in urine, either visible (gross hematuria) or microscopic. Causes include infections, kidney stones, injuries, or serious conditions like cancer.
- **Ketones** - Byproducts of fat metabolism appearing in urine when the body uses fat for energy instead of carbohydrates. Elevated levels may indicate diabetic ketoacidosis or starvation.
- **Ketonuria** - Presence of ketones in urine, often seen in uncontrolled diabetes, starvation, or high-protein diets.
- **Leukocyte Esterase (LE)** - An enzyme from neutrophils, indicating pyuria often associated with UTI. Positive in infections and some non-infectious conditions.
- **Microscopic Examination** - A procedure where urine sediment is examined under a microscope to identify cells, crystals, casts, and bacteria.
- **Nitrites** - Produced when bacteria reduce urinary nitrates to nitrites. A positive test strongly suggests infection; a negative test does not rule out UTI.
- **pH** - A measure of urine acidity or alkalinity. Normal urine pH ranges from 4.5 to 8.0. Changes can indicate dietary habits, metabolic disturbances, or infections.
- **Proteinuria (Albuminuria)** - Elevated protein in urine, often caused by kidney damage. Healthy kidneys prevent protein loss, but damage allows protein to leak into urine. Dipstick results range from trace to 4+.
- **Pyuria** - Presence of white blood cells (pus cells) in urine, usually indicating infection or inflammation in the genitourinary tract.
- **Specific Gravity** - A measure of urine concentration, indicating the kidney's ability to concentrate or dilute urine. Normal values range from 1.005 to 1.030.
- **Urinalysis** - A laboratory test that examines urine to assess health status, diagnose diseases, and monitor medical conditions. It typically includes physical, chemical, and microscopic analyses.
- **Urine Culture** - A test that grows bacteria from a urine sample to identify the specific organism causing an infection and determine antibiotic sensitivity.
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INDEX

No index terms found.

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GLOSSARY

S

Sample Word 1 | Sample Definition 1

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DETAILED LICENSING

Overview

Title: Integrated Human Anatomy and Physiology Lab Manual III: Metabolism, Regulation, Defense, Excretion

Webpages: 70

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