Subject: Human Anatomy and Physiology-I Unit No: I

Definition and scope of anatomy and physiology, Levels of structural organization and body systems

Human **anatomy** is the scientific study of the body's structures. Some of these structures are very small and can only be observed and analyzed with the assistance of a microscope. Other larger structures can readily be seen, manipulated, measured, and weighed. The word "anatomy" comes from a Greek root that means "to cut apart." Human anatomy was first studied by observing the exterior of the body and observing the wounds of soldiers and other injuries. Later, physicians were allowed to dissect bodies of the dead to augment their knowledge. When a body is dissected, its structures are cut apart in order to observe their physical attributes and their relationships to one another. Dissection is still used in medical schools, anatomy courses, and in pathology labs. In order to observe structures in living people, however, a number of imaging techniques have been developed. These techniques allow clinicians to visualize structures inside the living body such as a cancerous tumor or a fractured bone.

Like most scientific disciplines, anatomy has areas of specialization. **Gross anatomy** is the study of the larger structures of the body, those visible without the aid of magnification (Figure 1**a**). Macro- means "large," thus, gross anatomy is also referred to as **macroscopic anatomy**. In contrast, micro- means "small," and microscopic anatomy is the study of structures that can be observed only with the use of a microscope or other magnification devices (Figure 1**b**). Microscopic anatomy includes cytology, the study of cells and histology, the study of tissues. As the technology of microscopes has advanced, anatomists have been able to observe smaller and smaller structures of the body, from slices of large structures like the heart, to the three-dimensional structures of large molecules in the body.

Anatomists take two general approaches to the study of the body's structures: regional and systemic. **Regional anatomy** is the study of the interrelationships of all of the structures in a specific body region, such as the abdomen. Studying regional anatomy helps us appreciate the interrelationships of body structures, such as how muscles, nerves, blood vessels, and other structures work together to serve a particular body region. In contrast, **systemic anatomy** is the study of the structures that make up a discrete body system—that is, a group of structures that work together to perform a unique body function. For example, a systemic anatomical study of the muscular system would consider all of the skeletal muscles of the body.

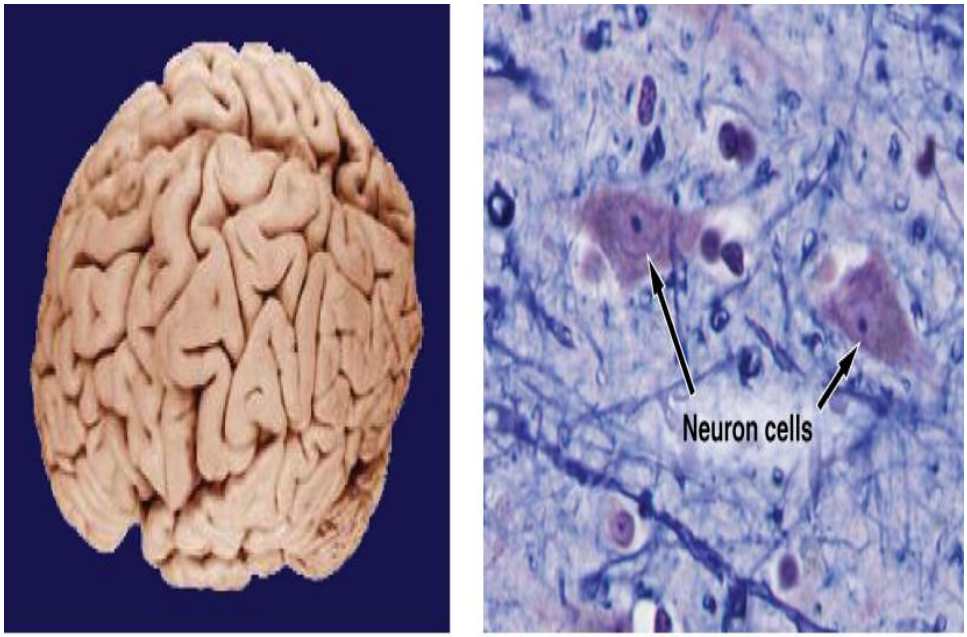


Figure 1. Gross and Microscopic Anatomy. (a) Gross anatomy considers large structures such as the brain. (b) Microscopic anatomy can deal with the same structures, though at a different scale.

Whereas anatomy is about structure, physiology is about function. Human **physiology** is the scientific study of the chemistry and physics of the structures of the body and the ways in which they work together to support the functions of life. Much of the study of physiology centers on the body's tendency toward homeostasis.

Homeostasis is the state of steady internal conditions maintained by living things. The study of physiology certainly includes observation, both with the naked eye and with microscopes, as well as manipulations and measurements. However, current advances in physiology usually depend on carefully designed laboratory experiments that reveal the functions of the many structures and chemical compounds that make up the human body.

Like anatomists, physiologists typically specialize in a particular branch of physiology. For example, neurophysiology is the study of the brain, spinal cord, and nerves and how these work together to perform functions as complex and diverse as vision, movement, and thinking. Physiologists may work from the organ level (exploring, for example, what different parts of the brain do) to the molecular level (such as exploring how an electrochemical signal travels along nerves).

Form is closely related to function in all living things. For example, the thin flap of your eyelid can snap down to clear away dust particles and almost instantaneously slide back up to allow you to see again. At the microscopic level, the arrangement and function of the nerves and muscles that serve the eyelid allow for its quick action and retreat. At a smaller level of analysis, the function of these nerves and muscles likewise relies on the interactions of specific molecules and ions. Even the three-dimensional structure of certain molecules is essential to their function.

Your study of anatomy and physiology will make more sense if you continually relate the form of the structures you are studying to their function. In fact, it can be somewhat frustrating to attempt to study anatomy without an understanding of the physiology that a

body structure supports. Imagine, for example, trying to appreciate the unique arrangement of the bones of the human hand if you had no conception of the function of the hand. Fortunately, your understanding of how the human hand manipulates tools—from pens to cell phones—helps you appreciate the unique alignment of the thumb in opposition to the four fingers, making your hand a structure that allows you to pinch and grasp objects and type text messages.

Levels of Structural Organization in the human body

The human body has 6 main levels of structural organization. We will begin this lesson with the simplest level within the structural hierarchy.

Chemical level– is the simplest level within the structural hierarchy. The chemical level includes the tiniest building blocks of matter, **atoms**, which combine to form **molecules**, like water. In turn, molecules combine to form **organelles**, the internal organs of a cell.

Cellular level– the cellular level is made up of the smallest unit of living matter, the **cell**. Individual cells may have some common functions but vary widely in size and shape. Each type of cells carries out a set of unique tasks within the human body.

Tissue level– Tissues are groups of similar cells that have a common function. A **tissue** must contain two different types of cells. The four basic tissue types in humans include **epithelium**, **connective**, **muscle**, and **nervous** tissue. Each tissue has a characteristic role within the human body which we will discuss later.

Organ level– an **organ** is a structure composed of at least two different tissue types that perform a specific function within the body. Examples include the brain, stomach, and liver. Complex functions begin to emerge at this level.

Organ system level– One or more organs work in unison to accomplish a common purpose. For instance, the heart and blood vessels work together and circulate blood

throughout the body to provide oxygen and nutrients to cells. Besides the cardiovascular system, the other organ systems of the body are the integumentary, skeletal, nervous, muscular, endocrine, respiratory, lymphatic, digestive, urinary, and reproductive systems.

Organismal level– The organismal level is the highest level of organization. It is the sum total of all structural levels working together. In short, it is the human being (or organism) as a whole.

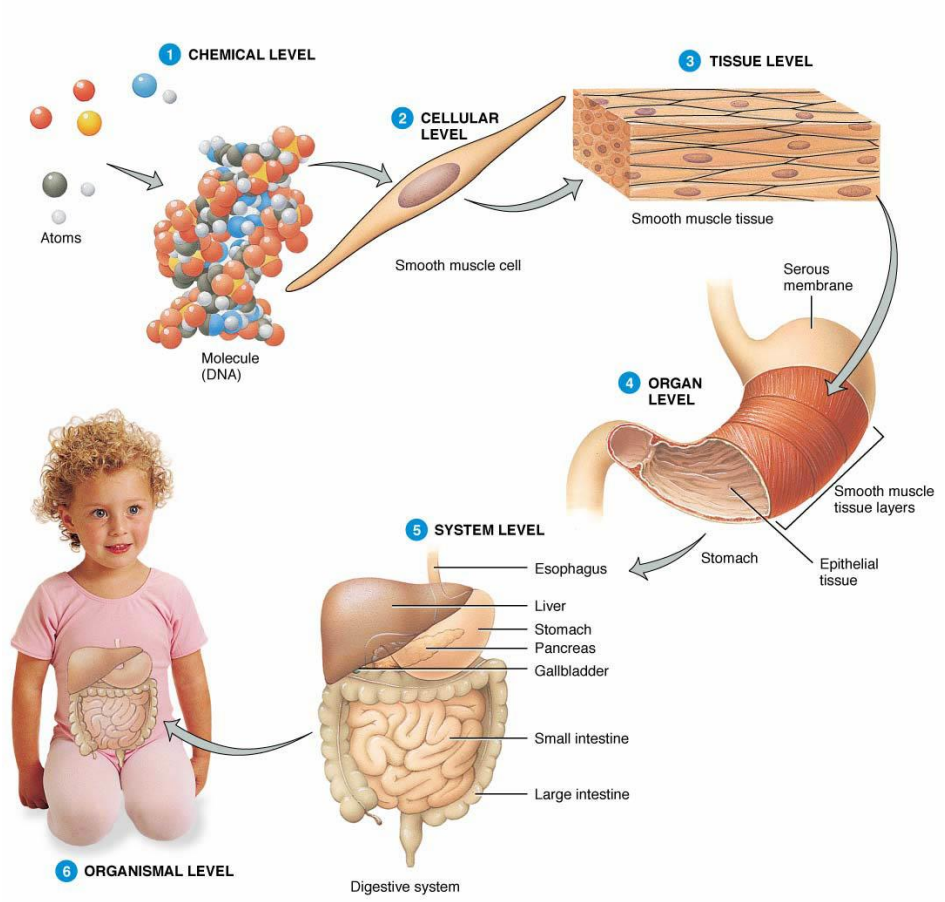


Figure 2: Levels of structural organization that make up the human body.

BODY SYSTEMS

A body system is a collection of parts able to work together to serve a common purpose – growth, reproduction and survival.

Each part of a system depends on the other parts to perform tasks that can't be achieved by single parts acting alone.

Each individual system works in conjunction with other systems to improve our chances of survival by maintaining a stable internal body environment. This stable environment is known as homeostasis.

An example of the way these systems are inter-related is the blood. It is part of the cardiovascular system and it carries products of digestion (digestive system) to body cells, excretory wastes (excretory system) to the kidneys and hormones (endocrine system) to target organs such as those forming part of the reproductive system.

Cardiovascular system: The heart and blood vessels make up this system. The heart is a pump forcing blood into a network of blood vessels allowing it to travel to organs and delivery sites requiring oxygen gas for respirationnutrients and the removal of waste substances.

Digestive system: This system resembles a long tube with attached organs. Ingested food is broken down into constituent nutrient molecules that are then absorbed into the bloodstream. Indigestible remains are then egested.

Endocrine system: Composed of a number of small organs distributed throughout the body, the endocrine system coordinates the metabolic activity of body cells by interacting

with the nervous system. Endocrine glands produce hormones (chemical messengers) released into the blood and transported to target sites around the body.

Excretory system: The excretory system is composed of the kidneys (urine-forming organs), the bladder (temporary storage for urine) and channels for moving this liquid waste around. Kidneys are blood purifiers filtering liquid from the bloodstream, removing undesirable substances (such as toxins) and returning those still required to the blood.

Immune system: The immune system is a protection mechanism composed of specialised cells, cell products, tissues, organs and processes within an organism that protect against pathogens.

Integumentary system

Commonly known as the skin, this system wraps the body in a protective covering with a number of functions such as UV protection and temperature regulation, taking it well beyond being just a mere covering.

Musculoskeletal system: The skeleton provides a framework on which the human body is arranged. It is articulated to allow free movement in conjunction with the skeletal muscles. They control movement, posture and assist the body with heat generation. Our bodies are held together by connective tissue.

Respiratory system: Our bodies are made up of countless cells all requiring oxygen to carry out the important process of respiration. In this process cells use oxygen gas and produce carbon dioxide gas – a waste product that must be removed from the body. The process of breathing allows these gases to be exchanged between the blood and lungs.

Reproductive system: The human body has a system of organs that work together for the purpose of reproduction. The biological purpose of this process is the continuation of life.

Nervous system: The nervous system is made up of a network of specialised cells, tissues and organs that coordinate and regulate the responses of the body to internal and external stimuli.

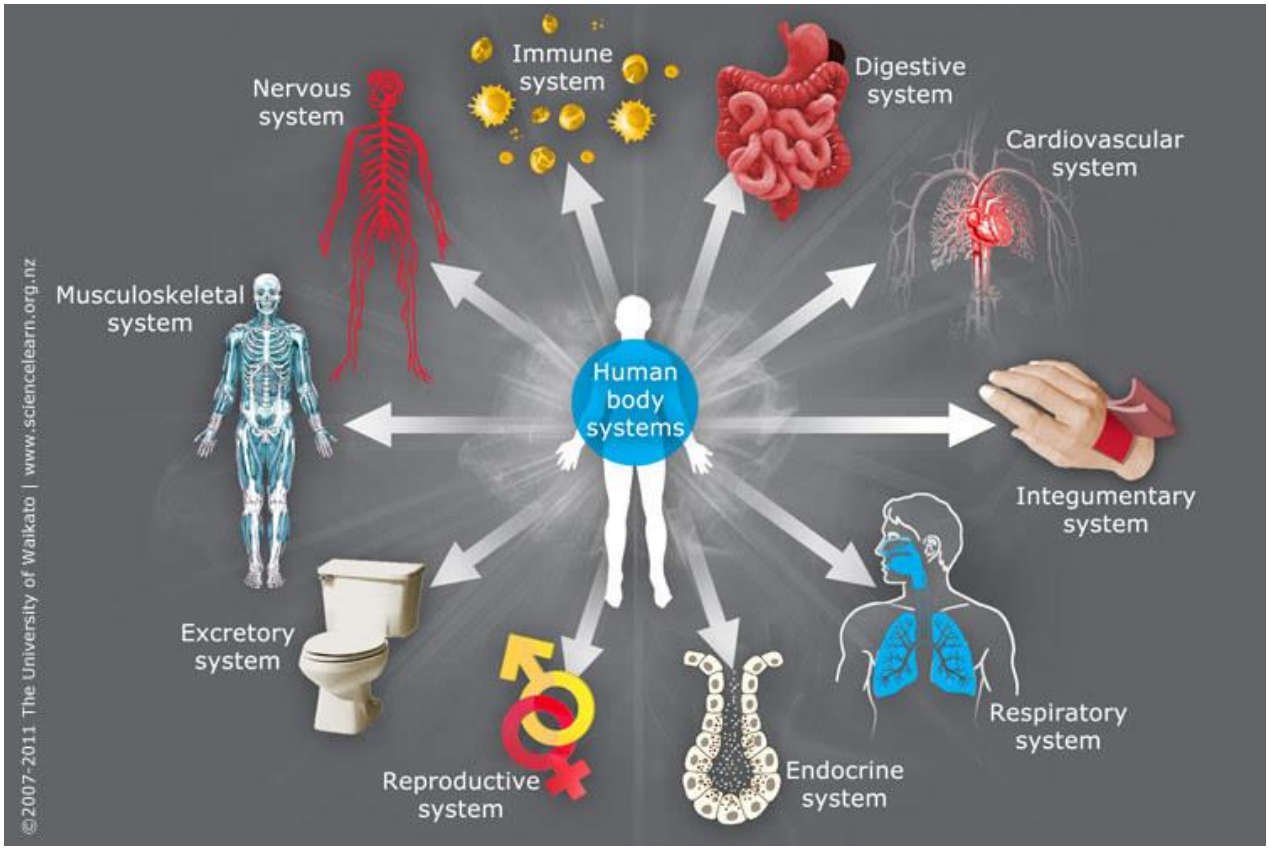


Figure 3: Human body system

BASIC LIFE PROCESSES

All living organisms have certain characteristics that distinguish them from non-living forms. The basic processes of life include organization, metabolism, responsiveness,

movements, and reproduction. In humans, who represent the most complex form of life, there are additional requirements such as growth, differentiation, respiration, digestion, and excretion. All of these processes are interrelated. No part of the body, from the smallest cell to a complete body system, works in isolation. All function together, in fine-tuned balance, for the wellbeing of the individual and to maintain life. Disease such as cancer and death represent a disruption of the balance in these processes.

The following are a brief description of the life process:

Organization

At all levels of the organizational scheme, there is a division of labor. Each component has its own job to perform in cooperation with others. Even a single cell, if it loses its integrity or organization, will die.

Metabolism

Metabolism is a broad term that includes all the chemical reactions that occur in the body. One phase of metabolism is catabolism in which complex substances are broken down into simpler building blocks and energy is released.

Responsiveness

Responsiveness or irritability is concerned with detecting changes in the internal or external environments and reacting to that change. It is the act of sensing a stimulus and responding to it.

Movement

There are many types of movement within the body. On the cellular level, molecules move from one place to another. Blood moves from one part of the body to another. The

diaphragm moves with every breath. The ability of muscle fibers to shorten and thus to produce movement is called contractility.

Reproduction

For most people, reproduction refers to the formation of a new person, the birth of a baby. In this way, life is transmitted from one generation to the next through reproduction of the organism. In a broader sense, reproduction also refers to the formation of new cells for the replacement and repair of old cells as well as for growth. This is cellular reproduction. Both are essential to the survival of the human race.

Growth

Growth refers to an increase in size either through an increase in the number of cells or through an increase in the size of each individual cell. In order for growth to occur, anabolic processes must occur at a faster rate than catabolic processes.

Differentiation

Differentiation is a developmental process by which unspecialized cells change into specialized cells with distinctive structural and functional characteristics. Through differentiation, cells develop into tissues and organs.

Respiration

Respiration refers to all the processes involved in the exchange of oxygen and carbon dioxide between the cells and the external environment. It includes ventilation, the diffusion of oxygen and carbon dioxide, and the transport of the gases in the blood. Cellular respiration deals with the cell's utilization of oxygen and release of carbon dioxide in its metabolism.

Digestion

Digestion is the process of breaking down complex ingested foods into simple molecules that can be absorbed into the blood and utilized by the body.

Excretion

Excretion is the process that removes the waste products of digestion and metabolism from the body. It gets rid of by-products that the body is unable to use, many of which are toxic and incompatible with life.

The ten life processes described above are not enough to ensure the survival of the individual. In addition to these processes, life depends on certain physical factors from the environment. These include water, oxygen, nutrients, heat, and pressure.

HOMEOSTASIS

Homeostasis refers to the body's ability to maintain a stable internal environment (regulating hormones, body temp., water balance, etc.). Maintaining homeostasis requires that the body continuously monitors its internal conditions. From body temperature to blood pressure to levels of certain nutrients, each physiological condition has a particular set point. A ***set point*** is the physiological value around which the normal range fluctuates. A ***normal range*** is the restricted set of values that is optimally healthful and stable. For example, the set point for normal human body temperature is approximately 37°C (98.6°F) Physiological parameters, such as body temperature and blood pressure, tend to fluctuate within a normal range a few degrees above and below that point. Control centers in the brain play roles in regulating physiological parameters and keeping them within the normal range. As the body works to maintain homeostasis, any significant deviation from the

normal range will be resisted and homeostasis restored through a process called a **feedback loop**.

A feedback loop has three basic components (Figure 1). A *sensor*, also known as a **receptor**, is a component of a feedback system that monitors a physiological value. It is responsible for detecting a change in the environment. This value is reported to the control center. The ***control center*** is the component in a feedback system that compares the value to the normal range. If the value deviates too much from the set point, then the control center activates an effector. An ***effector*** is the component in a feedback system that causes a change to reverse the situation and return the value to the normal range. Effectors are muscles and glands.

Two Types of Feedback Loops: Negative and Positive

Negative feedback is a mechanism in which the effect of the response to the stimulus is to shut off the original stimulus or reduce its intensity. Negative feedback loops are the body's most common mechanisms used to maintain homeostasis. The maintenance of homeostasis by negative feedback goes on throughout the body at all times, and an understanding of negative feedback is thus fundamental to an understanding of human physiology.

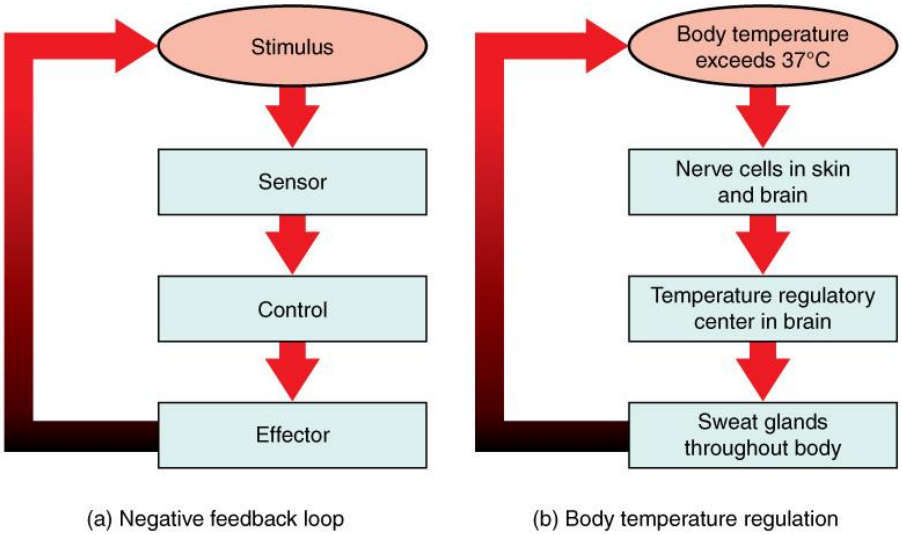


Figure 1. Negative Feedback Loop

In a negative feedback loop, a stimulus—a deviation from a set point—is resisted through a physiological process that returns the body to homeostasis. (a) A negative feedback loop has four basic parts. (b) Body temperature is regulated by negative feedback.

In order to set the system in motion, a stimulus change an internal environment beyond its normal range (that is, beyond homeostasis). This stimulus is detected by a specific receptor. For example, in the control of blood glucose, specific endocrine cells in the pancreas detect excess glucose (the stimulus) in the bloodstream. These pancreatic beta cells respond to the increased level of blood glucose by releasing the hormone insulin into the bloodstream. The insulin signals skeletal muscle fibers, fat cells (adipocytes), and liver cells to take up the excess glucose, removing it from the bloodstream. As glucose concentration in the bloodstream drops, the decrease in concentration—the actual negative feedback—is detected by pancreatic alpha cells, and insulin release stops. This prevents blood sugar levels from continuing to drop below the normal range.

Humans have a similar temperature regulation feedback system that works by promoting either heat loss or heat gain (Figure 1b). When the brain's temperature regulation center receives data from the sensors indicating that the body's temperature exceeds its normal range, it stimulates a cluster of brain cells referred to as the "heat-loss center." This stimulation has three major effects:

- Blood vessels in the skin begin to dilate allowing more blood from the body core to flow to the surface of the skin allowing the heat to radiate into the environment.
- As blood flow to the skin increases, sweat glands are activated to increase their output. As the sweat evaporates from the skin surface into the surrounding air, it takes heat with it.
- The depth of respiration increases, and a person may breathe through an open mouth instead of through the nasal passageways. This further increases heat loss from the lungs.

In contrast, activation of the brain's heat-gain center by exposure to cold reduces blood flow to the skin, and blood returning from the limbs is diverted into a network of deep veins. This arrangement traps heat closer to the body core and restricts heat loss.

If heat loss is severe, the brain triggers an increase in random signals to skeletal muscles, causing them to contract and producing shivering. The muscle contractions of shivering release heat while using up ATP. The brain triggers the thyroid gland in the endocrine system to release thyroid hormone, which increases metabolic activity and heat production in cells throughout the body. The brain also signals the adrenal glands to release epinephrine (adrenaline), a hormone that causes the breakdown of glycogen into glucose, which can be used as an energy source. The breakdown of glycogen into glucose also results in increased metabolism and heat production.

Water concentration in the body is critical for proper functioning. A person's body retains very tight control on water levels without conscious control by the person.

Positive feedback intensifies a change in the body's physiological condition rather than reversing it. A deviation from the normal range results in more change, and the system moves farther away from the normal range. Positive feedback in the body is normal only when there is a definite end point. Childbirth and the body's response to blood loss are two examples of positive feedback loops that are normal but are activated only when needed.

Childbirth at full term is an example of a situation in which the maintenance of the existing body state is not desired. Enormous changes in the mother's body are required to expel the baby at the end of pregnancy. And the events of childbirth, once begun, must progress rapidly to a conclusion or the life of the mother and the baby are at risk. The extreme muscular work of labor and delivery are the result of a positive feedback system (Figure 1.11).

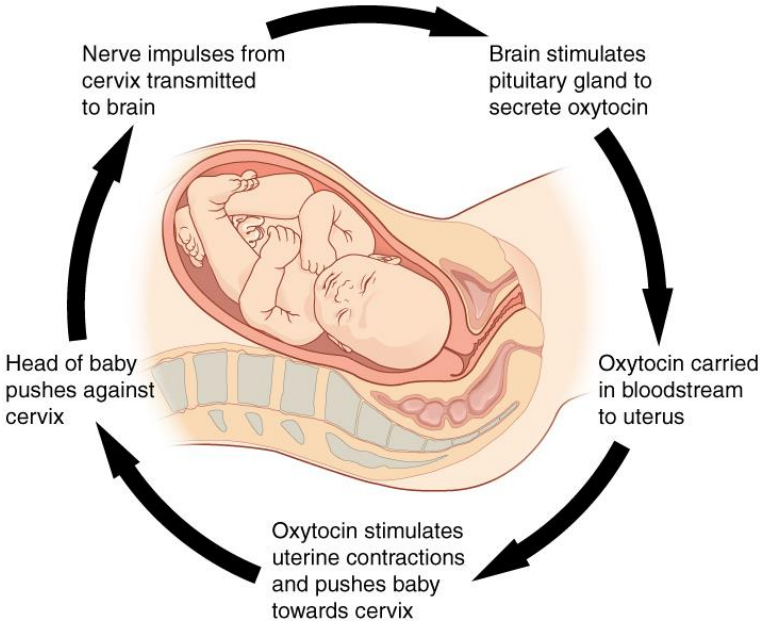


Figure 2. Positive Feedback Loop

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.

The first contractions of labor (the stimulus) push the baby toward the cervix (the lowest part of the uterus). The cervix contains stretch-sensitive nerve cells that monitor the degree of stretching (the sensors).

These nerve cells send messages to the brain, which in turn causes the pituitary gland at the base of the brain to release the hormone oxytocin into the bloodstream. Oxytocin causes stronger contractions of the smooth muscles in of the uterus (the effectors), pushing the baby further down the birth canal. This causes even greater stretching of the cervix. The cycle of stretching, oxytocin release, and increasingly more forceful contractions stops only when the baby is born. At this point, the stretching of the cervix halts, stopping the release of oxytocin.

A second example of positive feedback centers on reversing extreme damage to the body. Following a penetrating wound, the most immediate threat is excessive blood loss. Less blood circulating means reduced blood pressure and reduced perfusion (penetration of blood) to the brain and other vital organs. If perfusion is severely reduced, vital organs will shut down and the person will die. The body responds to this potential catastrophe by releasing substances in the injured blood vessel wall that begin the process of blood clotting. As each step of clotting occurs, it stimulates the release of more clotting substances. This accelerates the processes of clotting and sealing off the damaged area. Clotting is contained in a local area based on the tightly controlled availability of clotting proteins. This is an adaptive, life-saving cascade of events.

Integrating Systems

Each organ system performs specific functions for the body, and each organ system is typically studied independently. However, the organ systems also work together to help the body maintain homeostasis.

For example, the cardiovascular, urinary, and lymphatic systems all help the body control water balance. The cardiovascular and lymphatic systems transport fluids throughout the body and help sense both solute and water levels and regulate pressure. If the water level gets too high, the urinary system produces more dilute urine (urine with a higher water content) to help eliminate the excess water. If the water level gets too low, more concentrated urine is produced so that water is conserved. The digestive system also plays a role with variable water absorption. Water can be lost through the integumentary and respiratory systems, but that loss is not directly involved in maintaining body fluids and is usually associated with other homeostatic mechanisms.

Similarly, the cardiovascular, integumentary, respiratory, and muscular systems work together to help the body maintain a stable internal temperature. If body temperature rises, blood vessels in the skin dilate, allowing more blood to flow near the skin's surface. This allows heat to dissipate through the skin and into the surrounding air. The skin may also produce sweat if the body gets too hot; when the sweat evaporates, it helps to cool the body. Rapid breathing can also help the body eliminate excess heat. Together, these responses to increased body temperature explain why you sweat, pant, and become red in the face when you exercise hard. (Heavy breathing during exercise is also one way the body gets more oxygen to your muscles, and gets rid of the extra carbon dioxide produced by the muscles.)

Conversely, if your body is too cold, blood vessels in the skin contract, and blood flow to the extremities (arms and legs) slows. Muscles contract and relax rapidly, which generates heat to keep you warm. The hair on your skin rises, trapping more air, which is a good insulator, near your skin. These responses to decreased body temperature explain why you shiver, get "goose bumps," and have cold, pale extremities when you are cold.

BASIC ANATOMICAL TERMINOLOGY

Before we get into the following learning units, which will provide more detailed discussion of topics on different human body systems, it is necessary to learn some useful terms for describing body structure. Knowing these terms will make it much easier for us to understand the content of the following learning units. Three groups of terms are introduced here:

- Directional Terms
- Planes of the Body
- Body Cavities

Directional Terms

Directional terms describe the positions of structures relative to other structures or locations in the body.

Superior or cranial - toward the head end of the body; upper (example, the hand is part of the superior extremity).

Inferior or caudal - away from the head; lower (example, the foot is part of the inferior extremity).

Anterior or ventral - front (example, the kneecap is located on the anterior side of the leg).

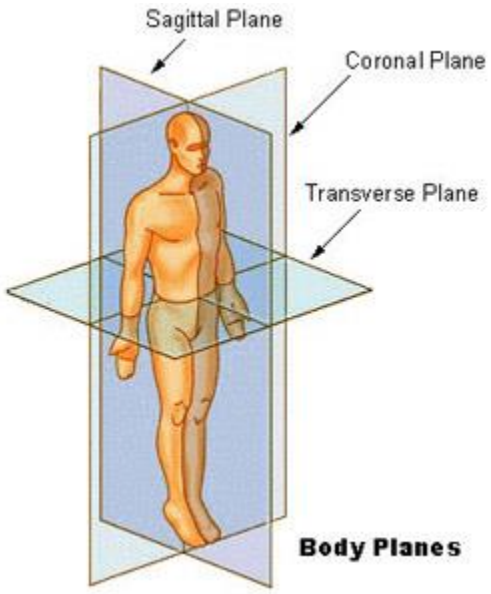
Posterior or dorsal - back (example, the shoulder blades are located on the posterior side of the body).

Medial - toward the midline of the body (example, the middle toe is located at the medial side of the foot).

Lateral - away from the midline of the body (example, the little toe is located at the lateral side of the foot).

Proximal - toward or nearest the trunk or the point of origin of a part (example, the proximal end of the femur joins with the pelvic bone).

Distal - away from or farthest from the trunk or the point or origin of a part (example, the hand is located at the distal end of the forearm).



Planes of the Body

Coronal Plane (Frontal Plane) - A vertical plane running from side to side; divides the body or any of its parts into anterior and posterior portions.

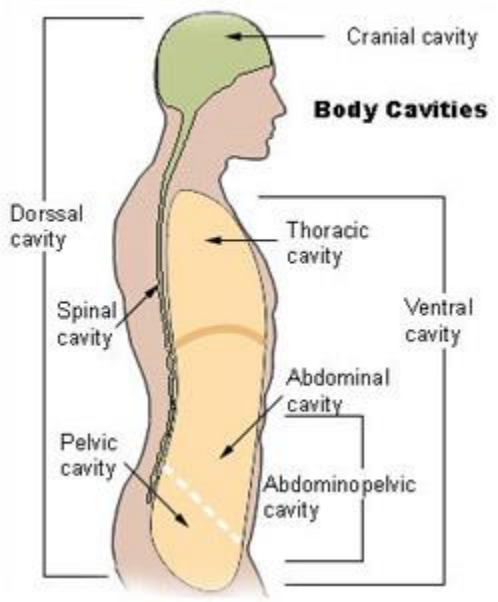
Sagittal Plane (Lateral Plane) - A vertical plane running from front to back; divides the body or any of its parts into right and left sides.

Axial Plane (Transverse Plane) - A horizontal plane; divides the body or any of its parts into upper and lower parts.

Median plane - Sagittal plane through the midline of the body; divides the body or any of its parts into right and left halves.

Body Cavities

The cavities, or spaces, of the body contain the internal organs, or viscera. The two main cavities are called the ventral and dorsal cavities. The ventral is the larger cavity and is subdivided into two parts (thoracic and abdominopelvic cavities) by the diaphragm, a dome-shaped respiratory muscle.



Thoracic cavity

The upper ventral, thoracic, or chest cavity contains the heart, lungs, trachea, esophagus, large blood vessels, and nerves. The thoracic cavity is bound laterally by the ribs (covered by costal pleura) and the diaphragm caudally (covered by diaphragmatic pleura).

Abdominal and pelvic cavity

The lower part of the ventral (abdominopelvic) cavity can be further divided into two portions: abdominal portion and pelvic portion. The abdominal cavity contains most of the gastrointestinal tract as well as the kidneys and adrenal glands. The abdominal cavity is bound cranially by the diaphragm, laterally by the body wall, and caudally by the pelvic cavity. The pelvic cavity contains most of the urogenital system as well as the rectum. The pelvic cavity is bounded cranially by the abdominal cavity, dorsally by the sacrum, and laterally by the pelvis.

Dorsal cavity

The smaller of the two main cavities is called the dorsal cavity. As its name implies, it contains organs lying more posterior in the body. The dorsal cavity, again, can be divided into two portions. The upper portion, or the cranial cavity, houses the brain, and the lower portion, or vertebral canal houses the spinal cord.

Structure and Functions of Cell

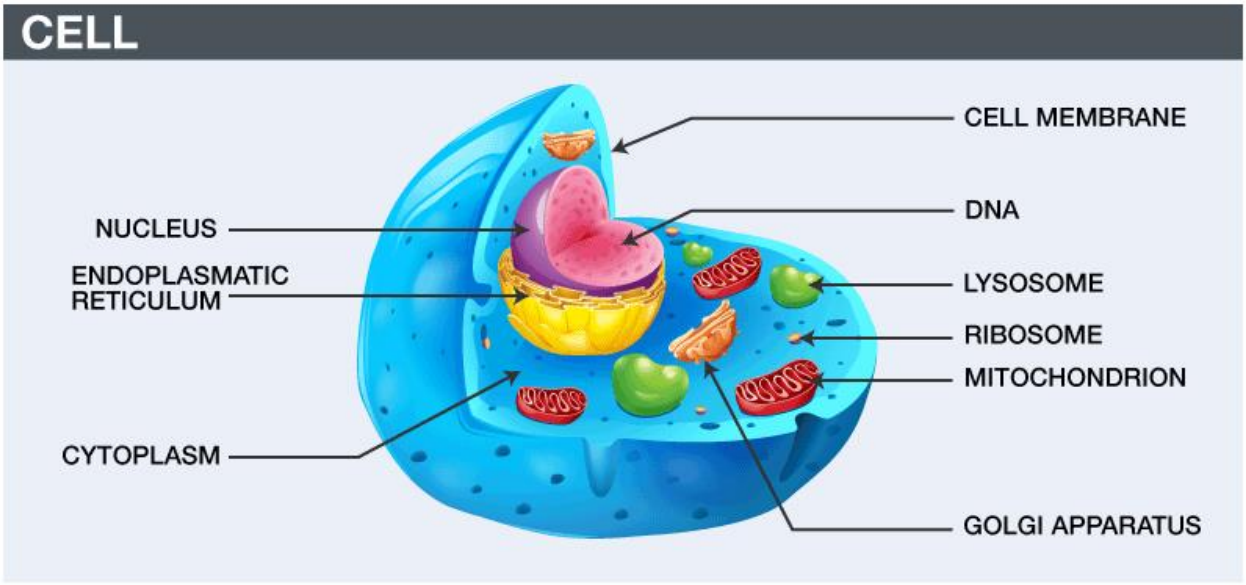


Figure 1: Structure of Human Cell

Cells are the structural, functional, and biological units of all living beings. A cell can replicate itself independently. Hence, they are known as the building blocks of life**.**

Each cell contains a fluid called the cytoplasm, which is enclosed by a membrane. Also present in the cytoplasm are several biomolecules like proteins, nucleic acids and lipids. Moreover, cellular structures called cell organelles are suspended in the cytoplasm.

What is a Cell?

A cell is the structural and fundamental unit of life. The study of cells from its basic structure to the functions of every cell organelle is called Cell Biology. Robert Hooke was the first Biologist who discovered cells.

All organisms are made up of cells. They may be made up of a single cell (unicellular), or many cells (multicellular). Mycoplasmas are the smallest known cells. Cells are the building blocks of all living beings. They provide structure to the body and convert the nutrients taken from the food into energy.

Cells are complex, and their components perform various functions in an organism. They are of different shapes and sizes, pretty much like bricks of the buildings. Our body is made up of cells of different shapes and sizes.

Cells are the lowest level of organisation in every life form. From organism to organism, the count of cells may vary. Humans have the number of cells compared to that of bacteria.

Cells comprise several cell organelles that perform specialised functions to carry out life processes. Every organelle has a specific structure. The hereditary material of the organisms is also present in the cells.

Discovery of Cells

Discovery of cells is one of the remarkable advancements in the field of science. It helped us know that all the organisms are made up of cells, and these cells help in carrying out various life processes. The structure and functions of cells helped us to understand life in a better way.

Who discovered cells?

Robert Hooke discovered the cell in 1665. Robert Hooke observed a piece of bottle cork under a compound microscope and noticed minuscule structures that reminded him of small rooms. Consequently, he named these "rooms" as cells. However, his compound microscope had limited magnification, and hence, he could not see any details in the structure. Because of this limitation, Hooke concluded that these were non-living entities.

Later Anton Van Leeuwenhoek observed cells under another compound microscope with higher magnification. This time, he had noted that the cells exhibited some form of movement (motility). As a result, Leeuwenhoek concluded that these microscopic entities were "alive." Eventually, after a host of other observations, these entities were named as animalcules.

In 1883, Robert Brown, a Scottish botanist, provided the very first insights into the cell structure. He was able to describe the nucleus present in the cells of orchids.

Characteristics of Cells

Following are the various essential characteristics of cells:

- Cells provide structure and support to the body of an organism.
- The cell interior is organised into different individual organelles surrounded by a separate membrane.
- The nucleus (major organelle) holds genetic information necessary for reproduction and cell growth.

- Every cell has one nucleus and membrane-bound organelles in the cytoplasm.
- Mitochondria, a double membrane-bound organelle is mainly responsible for the energy transactions vital for the survival of the cell.
- Lysosomes digest unwanted materials in the cell.
- Endoplasmic reticulum plays a significant role in the internal organisation of the cell by synthesising selective molecules and processing, directing and sorting them to their appropriate locations.

Types of Cells

Cells are similar to factories with different labourers and departments that work towards a common objective. Various types of cells perform different functions. Based on cellular structure, there are two types of cells:

- Prokaryotes
- Eukaryotes

Prokaryotic Cells

1. Prokaryotic cells have no nucleus. Instead, some prokaryotes such as bacteria have a region within the cell where the genetic material is freely suspended. This region is called the nucleoid.
2. They all are single-celled microorganisms. Examples include archaea, bacteria, and cyanobacteria.
3. The cell size ranges from 0.1 to 0.5 µm in diameter.
4. The hereditary material can either be DNA or RNA.
5. Prokaryotes reproduce by binary fission, a form of sexual reproduction.

Eukaryotic Cells

1. Eukaryotic cells are characterised by a true nucleus.
2. The size of the cells ranges between 10–100 µm in diameter.
3. This broad category involves plants, fungi, protozoans, and animals.
4. The plasma membrane is responsible for monitoring the transport of nutrients and electrolytes in and out of the cells. It is also responsible for cell to cell communication.
5. They reproduce sexually as well as asexually.
6. There are some contrasting features between plant and animal cells. For eg., the plant cell contains chloroplast, central vacuoles, and other plastids, whereas the animal cells do not.

Cell Structure

The cell structure comprises individual components with specific functions essential to carry out life's processes. These components include- cell wall, cell membrane, cytoplasm, nucleus, and cell organelles. Read on to explore more insights on cell structure and function.

Cell Membrane

- The cell membrane supports and protects the cell. It controls the movement of substances in and out of the cells. It separates the cell from the external environment. The cell membrane is present in all the cells.
- The cell membrane is the outer covering of a cell within which all other organelles, such as the cytoplasm and nucleus, are enclosed. It is also referred to as the plasma membrane.

- By structure, it is a porous membrane (with pores) which permit the movement of selective substances in and out of the cell. Besides this, the cell membrane also protects the cellular component from damage and leakage.
- It forms the wall-like structure between two cells as well as between the cell and its surroundings.
- Plants are immobile, so their cell structures are well-adapted to protect from them from external factors. The cell wall helps to reinforce this function.

Cell Wall

- The cell wall is the most prominent part of the plant's cell structure. It is made up of cellulose, hemicellulose and pectin.
- The cell wall is present exclusively in plant cells. It protects the plasma membrane and other cellular components. The cell wall is also the outermost layer of plant cells.
- It is a rigid and stiff structure surrounding the cell membrane.
- It provides shape and support to the cells and protects them from mechanical shocks and injuries.

Cytoplasm

- The cytoplasm is a thick, clear, jelly-like substance present inside the cell membrane.
- Most of the chemical reactions within a cell take place in this cytoplasm.
- The cell organelles such as endoplasmic reticulum, vacuoles, mitochondria, ribosomes, are suspended in this cytoplasm.

Nucleus

- The nucleus contains the hereditary material of the cell, the DNA.
- It sends signals to the cells to grow, mature, divide and die.
- The nucleus is surrounded by the nuclear envelope that separates the DNA from the rest of the cell.
- The nucleus protects the DNA and is an integral component of a plant's cell structure.

Cell Organelles

Cells are composed of various cell organelles that perform certain specific functions to carry out life's processes. The different cell organelles, along with its principal functions, are as follows:

Cell Organelle and its Functions
Nucleolus
The nucleolus is the site of ribosome synthesis. Also, it is involved in controlling cellular activities and cellular reproduction
Nuclear membrane
The nuclear membrane protects the nucleus by forming a boundary between the nucleus and other cell organelles.

Chromosomes
Chromosomes play a crucial role in determining the sex of an individual. Each human cells contain 23 pairs of chromosomes
Endoplasmic reticulum
The endoplasmic reticulum is involved in the transportation of substances throughout the cell. It plays a primary role in the metabolism of carbohydrates, synthesis of lipids, steroids, and proteins.
Golgi Bodies
Golgi bodies are called the cell's post office as it is involved in the transportation of materials within the cell
Ribosome
Ribosomes are the protein synthesisers of the cell
Mitochondria
The mitochondrion is called "the powerhouse of the cell." It is called so because it produces ATP – the cell's energy currency
Lysosomes

Lysosomes protect the cell by engulfing the foreign bodies entering the cell and helps in cell renewal. Therefore, it is known as the cell's suicide bags
Chloroplast
Chloroplasts are the primary organelles for photosynthesis. It contains the pigment chlorophyll
Vacuoles
Vacuoles stores food, water, and other waste materials in the cell

Cell Theory

Cell Theory was proposed by the German scientists, Theodor Schwann, Matthias Schleiden, and Rudolf Virchow. The cell theory states that:

- All living species on Earth are composed of cells.
- A cell is the basic unit of life.
- All cells arise from pre-existing cells.

A **modern version of the cell theory** was eventually formulated, and it contains the following postulates:

- Energy flows within the cells.
- Genetic information is passed on from one cell to the other.
- The chemical composition of all the cells is the same.

Functions of Cell

A cell performs these major functions essential for the growth and development of an organism. Important functions of cell are as follows:

Provides Support and Structure

All the organisms are made up of cells. They form the structural basis of all the organisms. The cell wall and the cell membrane are the main components that function to provide support and structure to the organism. For eg., the skin is made up of a large number of cells. Xylem present in the vascular plants is made of cells that provide structural support to the plants.

Facilitate Growth Mitosis

In the process of mitosis, the parent cell divides into the daughter cells. Thus, the cells multiply and facilitate the growth in an organism.

Allows Transport of Substances

Various nutrients are imported by the cells to carry out various chemical processes going on inside the cells. The waste produced by the chemical processes is eliminated from the cells by active and passive transport. Small molecules such as oxygen, carbon dioxide, and ethanol diffuse across the cell membrane along the concentration gradient. This is known as passive transport. The larger molecules diffuse across the cell membrane through active transport where the cells require a lot of energy to transport the substances.

Energy Production

Cells require energy to carry out various chemical processes. This energy is produced by the cells through a process called photosynthesis in plants and respiration in animals.

Aids in Reproduction

A cell aids in reproduction through the processes called mitosis and meiosis. Mitosis is termed as the asexual reproduction where the parent cell divides to form daughter cells. Meiosis causes the daughter cells to be genetically different from the parent cells. Thus, we can understand why cells are known as the structural and functional unit of life. This is because they are responsible for providing structure to the organisms and performs several functions necessary for carrying out life's processes.

TRANSPORT ACROSS CELL MEMBRANE, CELL DIVISION AND CELL JUNCTIONS

Diffusion

Diffusion is a process of passive transport in which molecules move from an area of higher concentration to one of lower concentration.

Diffusion is a passive process of transport. A single substance tends to move from an area of high concentration to an area of low concentration until the concentration is equal across a space. You are familiar with diffusion of substances through the air. For example, think about someone opening a bottle of ammonia in a room filled with people. The ammonia gas is at its highest concentration in the bottle; its lowest concentration is at the edges of the room. The ammonia vapor will diffuse, or spread away, from the bottle; gradually, more and more people will smell the ammonia as it spreads. Materials move within the cell‘s cytosol by diffusion, and certain materials move through the plasma membrane by diffusion. Diffusion expends no energy. On the contrary, concentration gradients are a form of potential energy, dissipated as the gradient is eliminated.

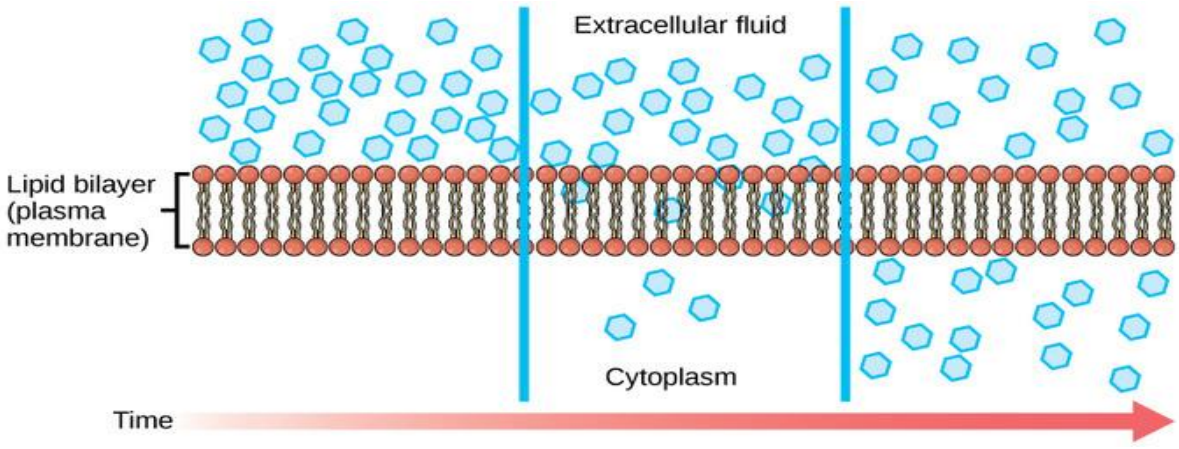


Figure 1: Diffusion: Diffusion through a permeable membrane moves a substance from an area of high concentration (extracellular fluid, in this case) down its concentration gradient (into the cytoplasm).

Each separate substance in a medium, such as the extracellular fluid, has its own concentration gradient independent of the concentration gradients of other materials. In addition, each substance will diffuse according to that gradient. Within a system, there will be different rates of diffusion of the different substances in the medium.

Factors That Affect Diffusion

Molecules move constantly in a random manner at a rate that depends on their mass, their environment, and the amount of thermal energy they possess, which in turn is a function of temperature. This movement accounts for the diffusion of molecules through whatever medium in which they are localized. A substance will tend to move into any space available to it until it is evenly distributed throughout it. After a substance has diffused completely through a space removing its concentration gradient, molecules will still move around in the space, but there will be no net movement of the number of molecules from one area to another. This lack of a concentration gradient in which there is no net movement of a substance is known as dynamic equilibrium. While diffusion will go forward in the presence of a concentration gradient of a substance, several factors affect the rate of diffusion:

- Extent of the concentration gradient: The greater the difference in concentration, the more rapid the diffusion. The closer the distribution of the material gets to equilibrium, the slower the rate of diffusion becomes.
- Mass of the molecules diffusing: Heavier molecules move more slowly; therefore, they diffuse more slowly. The reverse is true for lighter molecules.

- Temperature: Higher temperatures increase the energy and therefore the movement of the molecules, increasing the rate of diffusion. Lower temperatures decrease the energy of the molecules, thus decreasing the rate of diffusion.
- Solvent density: As the density of a solvent increases, the rate of diffusion decreases. The molecules slow down because they have a more difficult time getting through the denser medium. If the medium is less dense, diffusion increases. Because cells primarily use diffusion to move materials within the cytoplasm, any increase in the cytoplasm's density will inhibit the movement of the materials. An example of this is a person experiencing dehydration. As the body's cells lose water, the rate of diffusion decreases in the cytoplasm, and the cells' functions deteriorate. Neurons tend to be very sensitive to this effect. Dehydration frequently leads to unconsciousness and possibly coma because of the decrease in diffusion rate within the cells.
- Solubility: As discussed earlier, nonpolar or lipid-soluble materials pass through plasma membranes more easily than polar materials, allowing a faster rate of diffusion.
- Surface area and thickness of the plasma membrane: Increased surface area increases the rate of diffusion, whereas a thicker membrane reduces it.
- Distance travelled: The greater the distance that a substance must travel, the slower the rate of diffusion. This places an upper limitation on cell size. A large, spherical cell will die because nutrients or waste cannot reach or leave the center of the cell. Therefore, cells must either be small in size, as in the case of many prokaryotes, or be flattened, as with many single-celled eukaryotes.

A variation of diffusion is the process of filtration. In filtration, material moves according to its concentration gradient through a membrane; sometimes the rate of diffusion is

enhanced by pressure, causing the substances to filter more rapidly. This occurs in the kidney where blood pressure forces large amounts of water and accompanying dissolved substances, or solutes, out of the blood and into the renal tubules. The rate of diffusion in this instance is almost totally dependent on pressure. One of the effects of high blood pressure is the appearance of protein in the urine, which is "squeezed through" by the abnormally high pressure.

Osmosis

Osmosis is the movement of water across a membrane from an area of low solute concentration to an area of high solute concentration.

Osmosis and Semipermeable Membranes

Osmosis is the movement of water through a semipermeable membrane according to the concentration gradient of water across the membrane, which is inversely proportional to the concentration of solutes. Semipermeable membranes, also termed selectively permeable membranes or partially permeable membranes, allow certain molecules or ions to pass through by diffusion.

While diffusion transports materials across membranes and within cells, osmosis transports only water across a membrane. The semipermeable membrane limits the diffusion of solutes in the water. Not surprisingly, the aquaporin proteins that facilitate water movement play a large role in osmosis, most prominently in red blood cells and the membranes of kidney tubules.

Mechanism of Osmosis

Osmosis is a special case of diffusion. Water, like other substances, moves from an area of high concentration to one of low concentration. An obvious question is what makes water

move at all? Imagine a beaker with a semipermeable membrane separating the two sides or halves. On both sides of the membrane the water level is the same, but there are different concentrations of a dissolved substance, or solute, that cannot cross the membrane (otherwise the concentrations on each side would be balanced by the solute crossing the membrane). If the volume of the solution on both sides of the membrane is the same but the concentrations of solute are different, then there are different amounts of water, the solvent, on either side of the membrane. If there is more solute in one area, then there is less water; if there is less solute in one area, then there must be more water.

To illustrate this, imagine two full glasses of water. One has a single teaspoon of sugar in it, whereas the second one contains one-quarter cup of sugar. If the total volume of the solutions in both cups is the same, which cup contains more water? Because the large amount of sugar in the second cup takes up much more space than the teaspoon of sugar in the first cup, the first cup has more water in it.

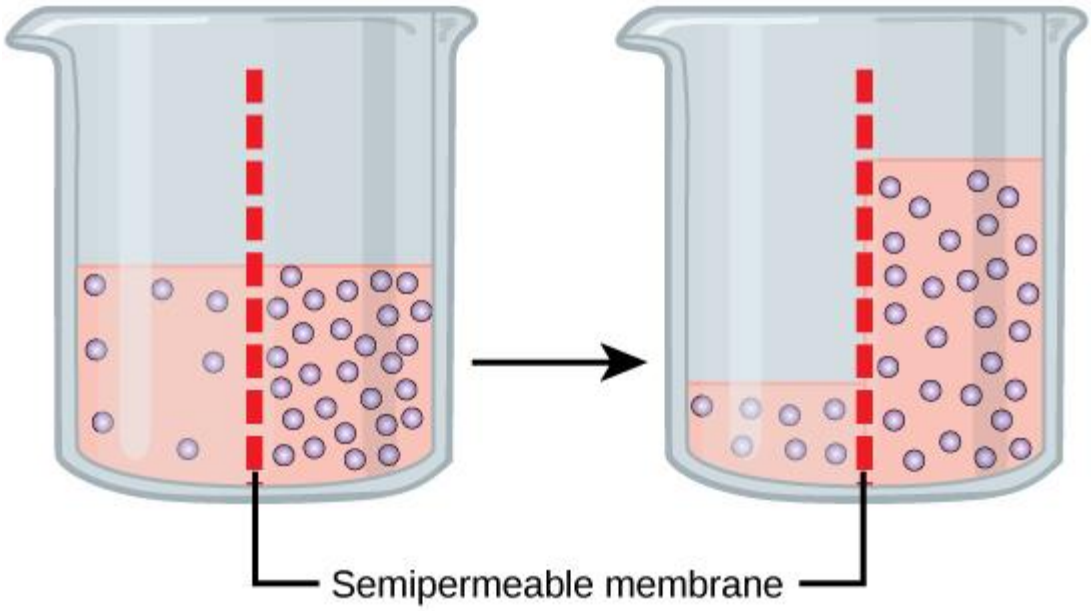


Figure 2: Osmosis: In osmosis, water always moves from an area of higher water concentration to one of lower concentration. In the diagram shown, the solute cannot pass through the selectively permeable membrane, but the water can.

Returning to the beaker example, recall that it has a mixture of solutes on either side of the membrane. A principle of diffusion is that the molecules move around and will spread evenly throughout the medium if they can. However, only the material capable of passing through the membrane will diffuse through it. In this example, the solute cannot diffuse through the membrane, but the water can. Water has a concentration gradient in this system. Thus, water will diffuse down its concentration gradient, crossing the membrane to the side where it is less concentrated. This diffusion of water through the membrane—osmosis—will continue until the concentration gradient of water goes to zero or until the hydrostatic pressure of the water balances the osmotic pressure. In the beaker example, this means that the level of fluid in the side with a higher solute concentration will go up.

Tonicity

Tonicity, which is directly related to the osmolarity of a solution, affects osmosis by determining the direction of water flow.

Tonicity describes how an extracellular solution can change the volume of a cell by affecting osmosis. A solution's tonicity often directly correlates with the osmolarity of the solution. Osmolarity describes the total solute concentration of the solution. A solution with low osmolarity has a greater number of water molecules relative to the number of solute particles; a solution with high osmolarity has fewer water molecules with respect to solute particles. In a situation in which solutions of two different osmolarities are separated by a membrane permeable to water, though not to the solute, water will move from the side of the membrane with lower osmolarity (and more water) to the side with higher osmolarity (and less water). This effect makes sense if you remember that the solute cannot move

across the membrane, and thus the only component in the system that can move—the water—moves along its own concentration gradient. An important distinction that concerns living systems is that osmolarity measures the number of particles (which may be molecules) in a solution. Therefore, a solution that is cloudy with cells may have a lower osmolarity than a solution that is clear if the second solution contains more dissolved molecules than there are cells.

Hypotonic Solutions

Three terms—hypotonic, isotonic, and hypertonic—are used to relate the osmolarity of a cell to the osmolarity of the extracellular fluid that contains the cells. In a hypotonic situation, the extracellular fluid has lower osmolarity than the fluid inside the cell, and water enters the cell. (In living systems, the point of reference is always the cytoplasm, so the prefix hypo- means that the extracellular fluid has a lower concentration of solutes, or a lower osmolarity, than the cell cytoplasm.) It also means that the extracellular fluid has a higher concentration of water in the solution than does the cell. In this situation, water will follow its concentration gradient and enter the cell, causing the cell to expand.

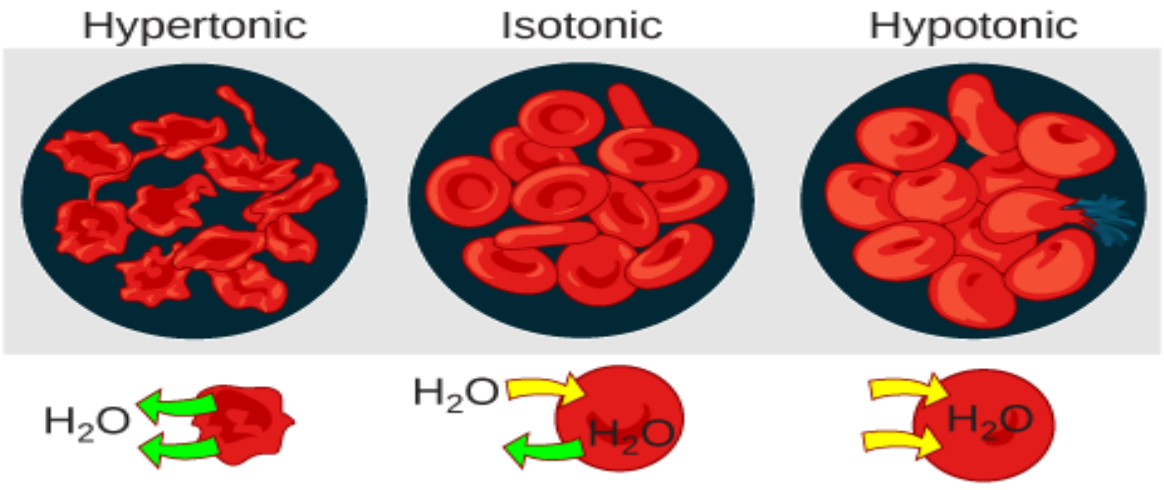


Figure 3: Changes in Cell Shape Due to Dissolved Solutes: Osmotic pressure changes the shape of red blood cells in hypertonic, isotonic, and hypotonic solutions.

Hypertonic Solutions

As for a hypertonic solution, the prefix hyper- refers to the extracellular fluid having a higher osmolarity than the cell's cytoplasm; therefore, the fluid contains less water than the cell does. Because the cell has a relatively higher concentration of water, water will leave the cell, and the cell will shrink.

Isotonic Solutions

In an isotonic solution, the extracellular fluid has the same osmolarity as the cell. If the osmolarity of the cell matches that of the extracellular fluid, there will be no net movement of water into or out of the cell, although water will still move in and out.

Blood cells and plant cells in hypertonic, isotonic, and hypotonic solutions take on characteristic appearances. Cells in an isotonic solution retain their shape. Cells in a hypotonic solution swell as water enters the cell, and may burst if the concentration gradient is large enough between the inside and outside of the cell. Cells in a hypertonic solution shrink as water exits the cell, becoming shriveled.

Facilitated transport

Facilitated diffusion is a process by which molecules are transported across the plasma membrane with the help of membrane proteins.

Facilitated transport is a type of passive transport. Unlike simple diffusion where materials pass through a membrane without the help of proteins, in facilitated transport, also called facilitated diffusion, materials diffuse across the plasma membrane with the help of

membrane proteins. A concentration gradient exists that would allow these materials to diffuse into the cell without expending cellular energy. However, these materials are ions or polar molecules that are repelled by the hydrophobic parts of the cell membrane. Facilitated transport proteins shield these materials from the repulsive force of the membrane, allowing them to diffuse into the cell.

The material being transported is first attached to protein or glycoprotein receptors on the exterior surface of the plasma membrane. This allows the material that is needed by the cell to be removed from the extracellular fluid. The substances are then passed to specific integral proteins that facilitate their passage. Some of these integral proteins are collections of beta-pleated sheets that form a channel through the phospholipid bilayer. Others are carrier proteins which bind with the substance and aid its diffusion through the membrane.

Channels

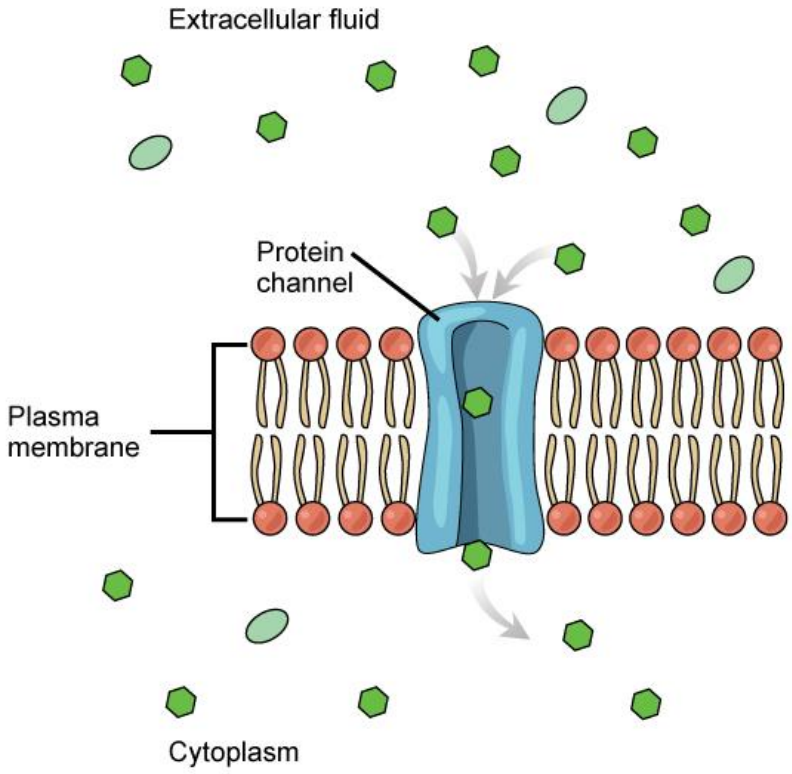


Figure 4: Channel Proteins in Facilitated Transport: Facilitated transport moves substances down their concentration gradients. They may cross the plasma membrane with the aid of channel proteins.

The integral proteins involved in facilitated transport are collectively referred to as transport proteins; they function as either channels for the material or carriers. In both cases, they are transmembrane proteins. Channels are specific for the substance that is being transported. Channel proteins have hydrophilic domains exposed to the intracellular and extracellular fluids; they additionally have a hydrophilic channel through their core that provides a hydrated opening through the membrane layers. Passage through the channel allows polar compounds to avoid the nonpolar central layer of the plasma membrane that would otherwise slow or prevent their entry into the cell. Aquaporins are channel proteins that allow water to pass through the membrane at a very high rate.

Channel proteins are either open at all times or they are "gated," which controls the opening of the channel. The attachment of a particular ion to the channel protein may control the opening or other mechanisms or substances may be involved. In some tissues, sodium and chloride ions pass freely through open channels, whereas in other tissues, a gate must be opened to allow passage. An example of this occurs in the kidney, where both forms of channels are found in different parts of the renal tubules. Cells involved in the transmission of electrical impulses, such as nerve and muscle cells, have gated channels for sodium, potassium, and calcium in their membranes. Opening and closing of these channels changes the relative concentrations on opposing sides of the membrane of these ions, resulting in the facilitation of electrical transmission along membranes (in the case of nerve cells) or in muscle contraction (in the case of muscle cells).

Carrier Proteins

Another type of protein embedded in the plasma membrane is a carrier protein. This protein binds a substance and, in doing so, triggers a change of its own shape, moving the bound molecule from the outside of the cell to its interior; depending on the gradient, the material may move in the opposite direction. Carrier proteins are typically specific for a single substance. This adds to the overall selectivity of the plasma membrane. The exact mechanism for the change of shape is poorly understood. Proteins can change shape when their hydrogen bonds are affected, but this may not fully explain this mechanism. Each carrier protein is specific to one substance, and there are a finite number of these proteins in any membrane. This can cause problems in transporting enough of the material for the cell to function properly.

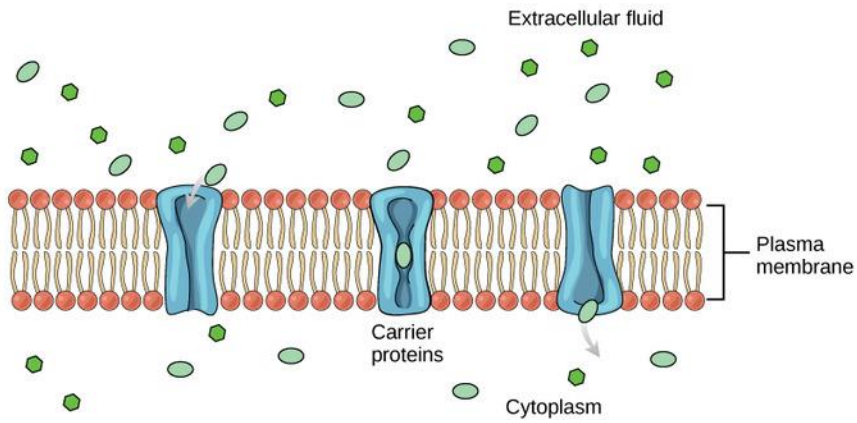


Figure 5: Carrier Proteins: Some substances are able to move down their concentration gradient across the plasma membrane with the aid of carrier proteins. Carrier proteins change shape as they move molecules across the membrane.

An example of this process occurs in the kidney. Glucose, water, salts, ions, and amino acids needed by the body are filtered in one part of the kidney. This filtrate, which includes glucose, is then reabsorbed in another part of the kidney. Because there are only a finite number of carrier proteins for glucose, if more glucose is present than the proteins can

handle, the excess is not transported; it is excreted from the body in the urine. In a diabetic individual, this is described as "spilling glucose into the urine." A different group of carrier proteins called glucose transport proteins, or GLUTs, are involved in transporting glucose and other hexose sugars through plasma membranes within the body.

Channel and carrier proteins transport material at different rates. Channel proteins transport much more quickly than do carrier proteins. Channel proteins facilitate diffusion at a rate of tens of millions of molecules per second, whereas carrier proteins work at a rate of a thousand to a million molecules per second.

The Role of Passive Transport

Passive transport, such as diffusion and osmosis, moves materials of small molecular weight across membranes.

Introduction: Passive Transport

Plasma membranes must allow or prevent certain substances from entering or leaving a cell. In other words, plasma membranes are selectively permeable; they allow some substances to pass through, but not others. If they were to lose this selectivity, the cell would no longer be able to sustain itself, and it would be destroyed. Some cells require larger amounts of specific substances than other cells; they must have a way of obtaining these materials from extracellular fluids. This may happen passively, as certain materials move back and forth, or the cell may have special mechanisms that facilitate transport. Some materials are so important to a cell that it spends some of its energy (hydrolyzing adenosine triphosphate (ATP)) to obtain these materials. Red blood cells use some of their energy to do this. All cells spend the majority of their energy to maintain an imbalance of sodium and potassium ions between the interior and exterior of the cell.

The most direct forms of membrane transport are passive. Passive transport is a naturally-occurring phenomenon and does not require the cell to exert any of its energy to accomplish the movement. In passive transport, substances move from an area of higher concentration to an area of lower concentration. A physical space in which there is a range of concentrations of a single substance is said to have a concentration gradient.

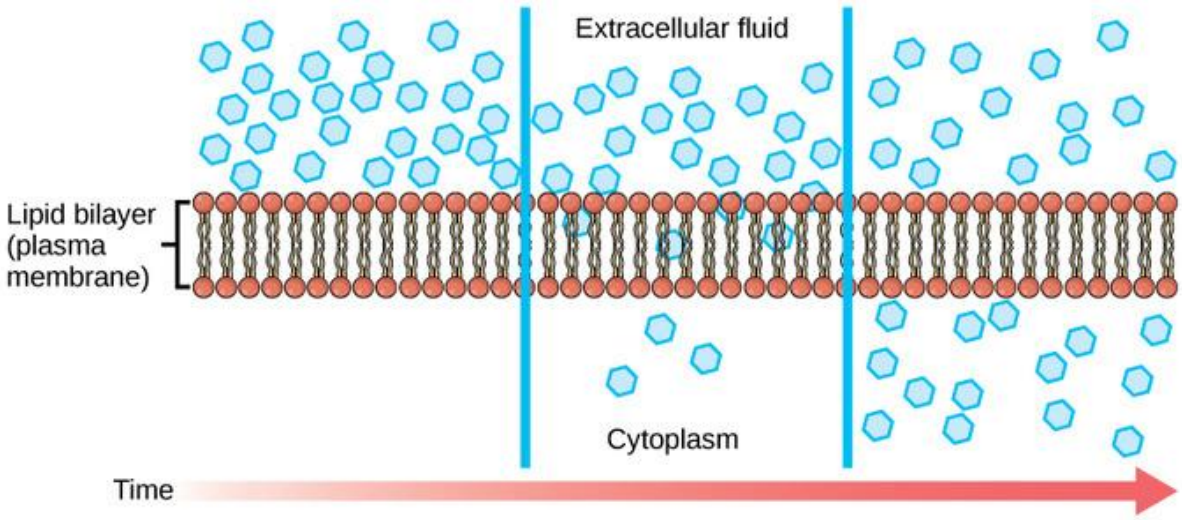


Figure 6: Passive Transport: Diffusion is a type of passive transport. Diffusion through a permeable membrane moves a substance from an area of high concentration (extracellular fluid, in this case) down its concentration gradient (into the cytoplasm).

The passive forms of transport, diffusion and osmosis, move materials of small molecular weight across membranes. Substances diffuse from areas of high concentration to areas of lower concentration; this process continues until the substance is evenly distributed in a system. In solutions containing more than one substance, each type of molecule diffuses according to its own concentration gradient, independent of the diffusion of other substances. Many factors can affect the rate of diffusion, including, but not limited to, concentration gradient, size of the particles that are diffusing, and temperature of the system.

In living systems, diffusion of substances in and out of cells is mediated by the plasma membrane. Some materials diffuse readily through the membrane, but others are hindered; their passage is made possible by specialized proteins, such as channels and transporters. The chemistry of living things occurs in aqueous solutions; balancing the concentrations of those solutions is an ongoing problem. In living systems, diffusion of some substances would be slow or difficult without membrane proteins that facilitate transport.

Primary Active Transport

The sodium-potassium pump maintains the electrochemical gradient of living cells by moving sodium in and potassium out of the cell.

The primary active transport that functions with the active transport of sodium and potassium allows secondary active transport to occur. The secondary transport method is still considered active because it depends on the use of energy as does primary transport.

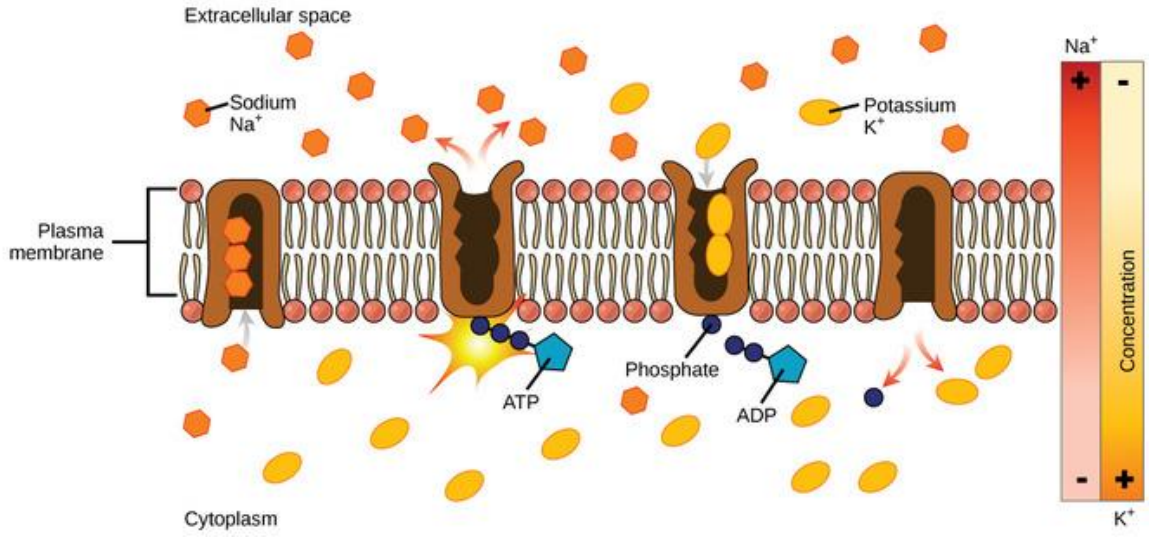


Figure 7: Active Transport of Sodium and Potassium: Primary active transport moves ions across a membrane, creating an electrochemical gradient (electrogenic transport).

One of the most important pumps in animals cells is the sodium-potassium pump (Na^+K^+ ATPase), which maintains the electrochemical gradient (and the correct concentrations of Na^+ and K^+) in living cells. The sodium-potassium pump moves two K^+ into the cell while moving three Na^+ out of the cell. The Na+-K+ ATPase exists in two forms, depending on its orientation to the interior or exterior of the cell and its affinity for either sodium or potassium ions. The process consists of the following six steps:

- With the enzyme oriented towards the interior of the cell, the carrier has a high affinity for sodium ions. Three sodium ions bind to the protein.
- ATP is hydrolyzed by the protein carrier, and a low-energy phosphate group attaches to it.
- As a result, the carrier changes shape and re-orients itself towards the exterior of the membrane. The protein's affinity for sodium decreases, and the three sodium ions leave the carrier.
- The shape change increases the carrier's affinity for potassium ions, and two such ions attach to the protein. Subsequently, the low-energy phosphate group detaches from the carrier.
- With the phosphate group removed and potassium ions attached, the carrier protein repositions itself towards the interior of the cell.
- The carrier protein, in its new configuration, has a decreased affinity for potassium, and the two ions are released into the cytoplasm. The protein now has a higher affinity for sodium ions, and the process starts again.

Several things have happened as a result of this process. At this point, there are more sodium ions outside of the cell than inside and more potassium ions inside than out. For every three ions of sodium that move out, two ions of potassium move in. This results in the interior being slightly more negative relative to the exterior. This difference in charge

is important in creating the conditions necessary for the secondary process. The sodium-potassium pump is, therefore, an electrogenic pump (a pump that creates a charge imbalance), creating an electrical imbalance across the membrane and contributing to the membrane potential.

Electrochemical Gradient

To move substances against the membrane's electrochemical gradient, the cell utilizes active transport, which requires energy from ATP.

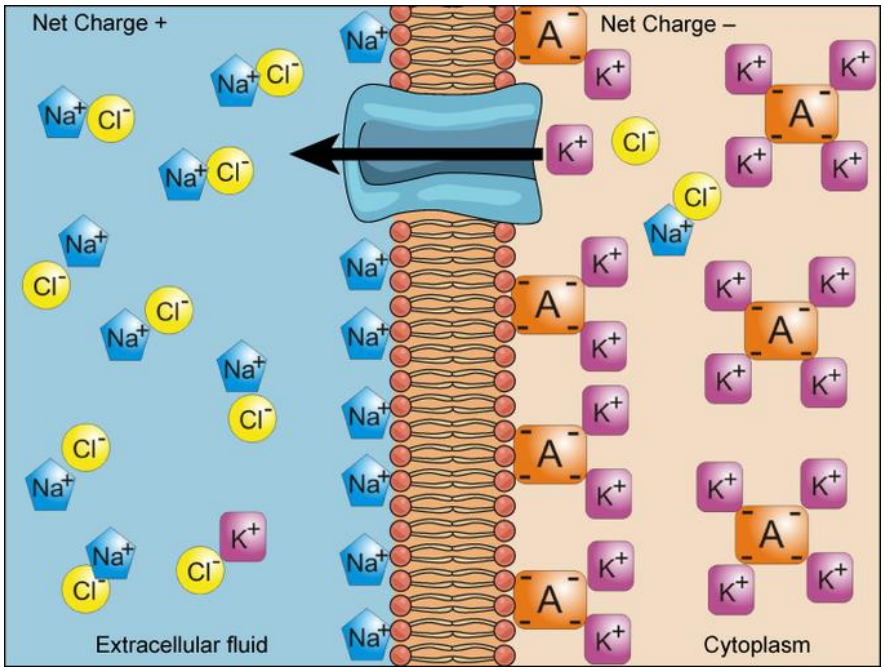


Figure 8: Electrochemical Gradient: Electrochemical gradients arise from the combined effects of concentration gradients and electrical gradients.

Simple concentration gradients are differential concentrations of a substance across a space or a membrane, but in living systems, gradients are more complex. Because ions move into and out of cells and because cells contain proteins that do not move across the membrane

and are mostly negatively charged, there is also an electrical gradient, a difference of charge, across the plasma membrane. The interior of living cells is electrically negative with respect to the extracellular fluid in which they are bathed. At the same time, cells have higher concentrations of potassium (K^+) and lower concentrations of sodium (Na^+) than does the extracellular fluid. In a living cell, the concentration gradient of Na^+ tends to drive it into the cell, and the electrical gradient of Na^+ (a positive ion) also tends to drive it inward to the negatively-charged interior. The situation is more complex, however, for other elements such as potassium. The electrical gradient of K^+, a positive ion, also tends to drive it into the cell, but the concentration gradient of K^+ tends to drive K^+ out of the cell. The combined gradient of concentration and electrical charge that affects an ion is called its electrochemical gradient.

Moving Against a Gradient

To move substances against a concentration or electrochemical gradient, the cell must use energy. This energy is harvested from adenosine triphosphate (ATP) generated through the cell's metabolism. Active transport mechanisms, collectively called pumps, work against electrochemical gradients. Small substances constantly pass through plasma membranes. Active transport maintains concentrations of ions and other substances needed by living cells in the face of these passive movements. Much of a cell's supply of metabolic energy may be spent maintaining these processes. For example, most of a red blood cell's metabolic energy is used to maintain the imbalance between exterior and interior sodium and potassium levels required by the cell. Because active transport mechanisms depend on a cell's metabolism for energy, they are sensitive to many metabolic poisons that interfere with the supply of ATP.

Two mechanisms exist for the transport of small-molecular weight material and small molecules. Primary active transport moves ions across a membrane and creates a difference in charge across that membrane, which is directly dependent on ATP. Secondary active

transport describes the movement of material that is due to the electrochemical gradient established by primary active transport that does not directly require ATP.

Carrier Proteins for Active Transport

An important membrane adaption for active transport is the presence of specific carrier proteins or pumps to facilitate movement. There are three types of these proteins or transporters: uniporters, symporters, and antiporters. A uniporter carries one specific ion or molecule. A symporter carries two different ions or molecules, both in the same direction. An antiporter also carries two different ions or molecules, but in different directions. All of these transporters can also transport small, uncharged organic molecules like glucose. These three types of carrier proteins are also found in facilitated diffusion, but they do not require ATP to work in that process. Some examples of pumps for active transport are Na^+-K^+ ATPase, which carries sodium and potassium ions, and H^+-K^+ ATPase, which carries hydrogen and potassium ions. Both of these are antiporter carrier proteins. Two other carrier protein pumps are Ca^{2+} ATPase and H^+ ATPase, which carry only calcium and only hydrogen ions, respectively.

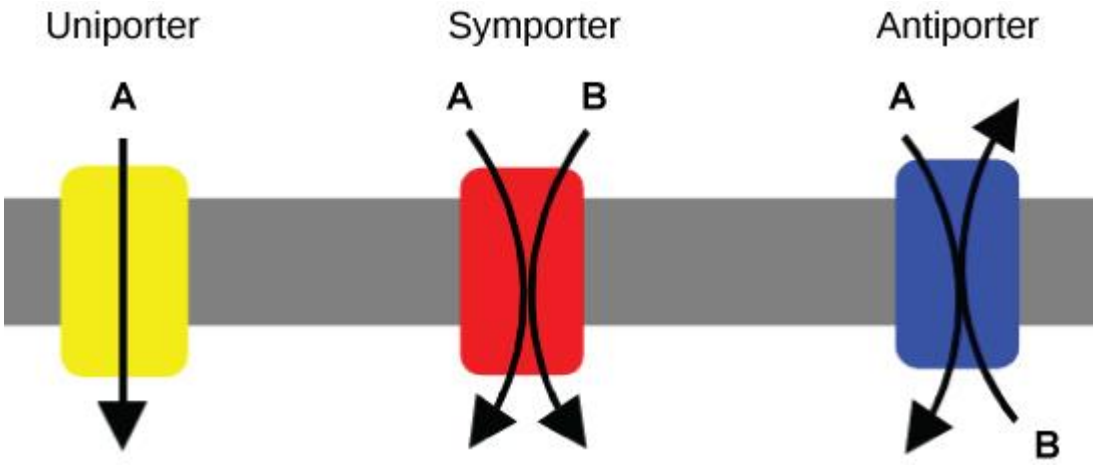


Figure 9: Uniporters, Symporters, and Antiporters: A uniporter carries one molecule or ion. A symporter carries two different molecules or ions, both in the same direction. An antiporter also carries two different molecules or ions, but in different directions.

Secondary Active Transport

In secondary active transport, a molecule is moved down its electrochemical gradient as another is moved up its concentration gradient.

Unlike in primary active transport, in secondary active transport, ATP is not directly coupled to the molecule of interest. Instead, another molecule is moved up its concentration gradient, which generates an electrochemical gradient. The molecule of interest is then transported down the electrochemical gradient. While this process still consumes ATP to generate that gradient, the energy is not directly used to move the molecule across the membrane, hence it is known as secondary active transport. Both antiporters and symporters are used in secondary active transport. Co-transporters can be classified as symporters and antiporters depending on whether the substances move in the same or opposite directions across the cell membrane.

Secondary active transport brings sodium ions, and possibly other compounds, into the cell. As sodium ion concentrations build outside the plasma membrane because of the action of the primary active transport process, an electrochemical gradient is created. If a channel protein exists and is open, the sodium ions will be pulled through the membrane. This movement is used to transport other substances that can attach themselves to the transport protein through the membrane. Many amino acids, as well as glucose, enter a cell this way. This secondary process is also used to store high-energy hydrogen ions in the mitochondria of plant and animal cells for the production of ATP. The potential energy that accumulates in the stored hydrogen ions is translated into kinetic energy as the ions

surge through the channel protein ATP synthase, and that energy is used to convert ADP into ATP.

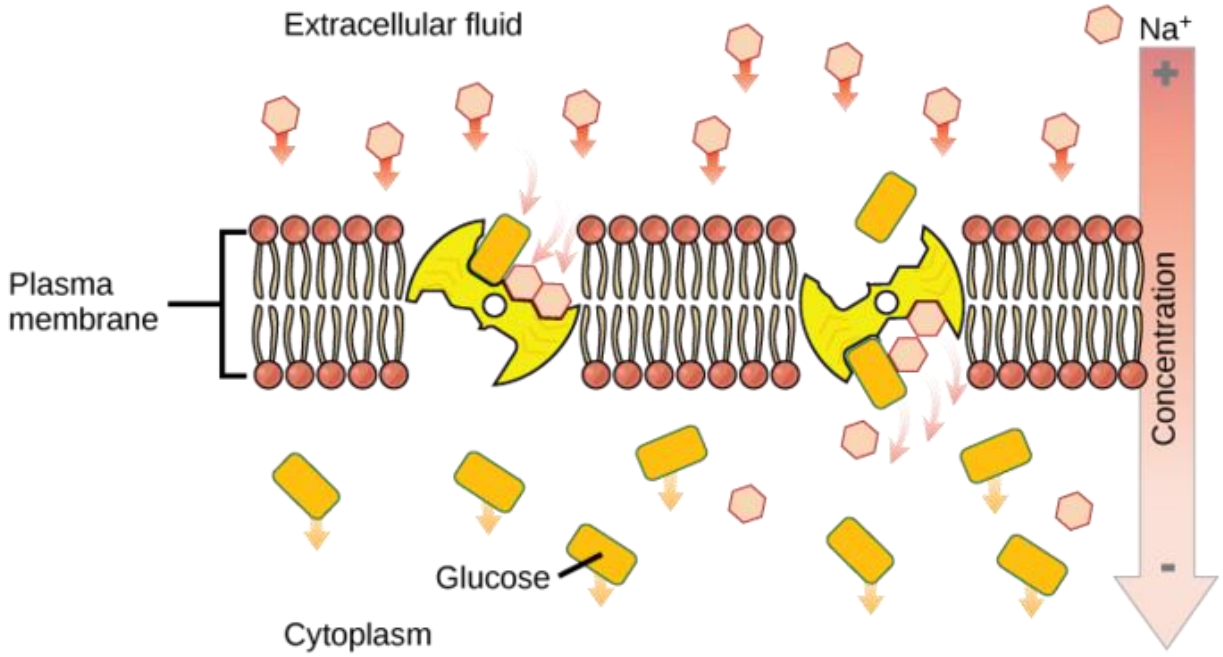


Figure 10: Secondary Active Transport: An electrochemical gradient, created by primary active transport, can move other substances against their concentration gradients, a process called co-transport or secondary active transport.

Endocytosis

Endocytosis takes up particles into the cell by invaginating the cell membrane, resulting in the release of the material inside of the cell.

Endocytosis is a type of active transport that moves particles, such as large molecules, parts of cells, and even whole cells, into a cell. There are different variations of endocytosis, but all share a common characteristic: the plasma membrane of the cell invaginates, forming a pocket around the target particle. The pocket pinches off, resulting in the particle being contained in a newly-created intracellular vesicle formed from the plasma membrane.

Phagocytosis

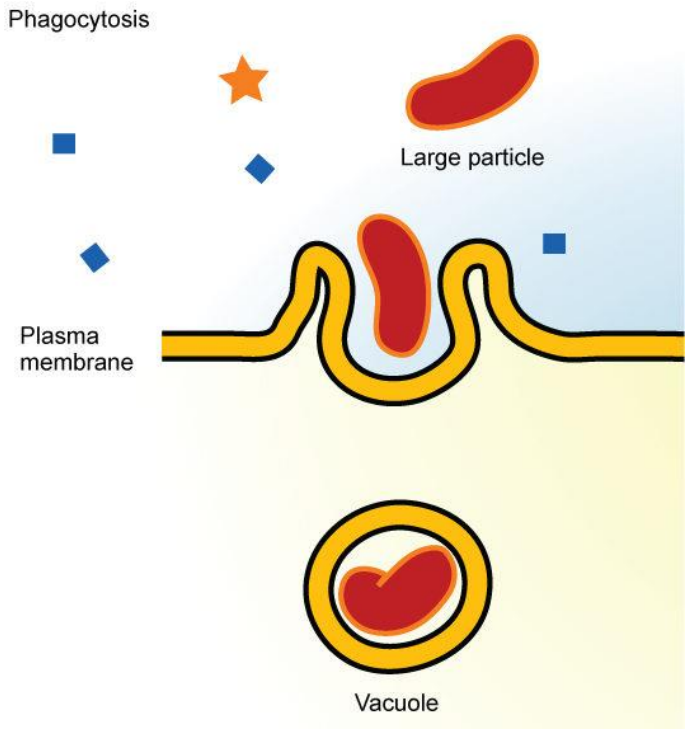


Figure 11: Phagocytosis: In phagocytosis, the cell membrane surrounds the particle and engulfs it.

Phagocytosis (the condition of "cell eating") is the process by which large particles, such as cells or relatively large particles, are taken in by a cell. For example, when microorganisms invade the human body, a type of white blood cell called a neutrophil will remove the invaders through this process, surrounding and engulfing the microorganism, which is then destroyed by the neutrophil.

In preparation for phagocytosis, a portion of the inward-facing surface of the plasma membrane becomes coated with a protein called clathrin, which stabilizes this section of the membrane. The coated portion of the membrane then extends from the body of the cell and surrounds the particle, eventually enclosing it. Once the vesicle containing the particle

is enclosed within the cell, the clathrin disengages from the membrane and the vesicle merges with a lysosome for the breakdown of the material in the newly-formed compartment (endosome). When accessible nutrients from the degradation of the vesicular contents have been extracted, the newly-formed endosome merges with the plasma membrane and releases its contents into the extracellular fluid. The endosomal membrane again becomes part of the plasma membrane.

Pinocytosis

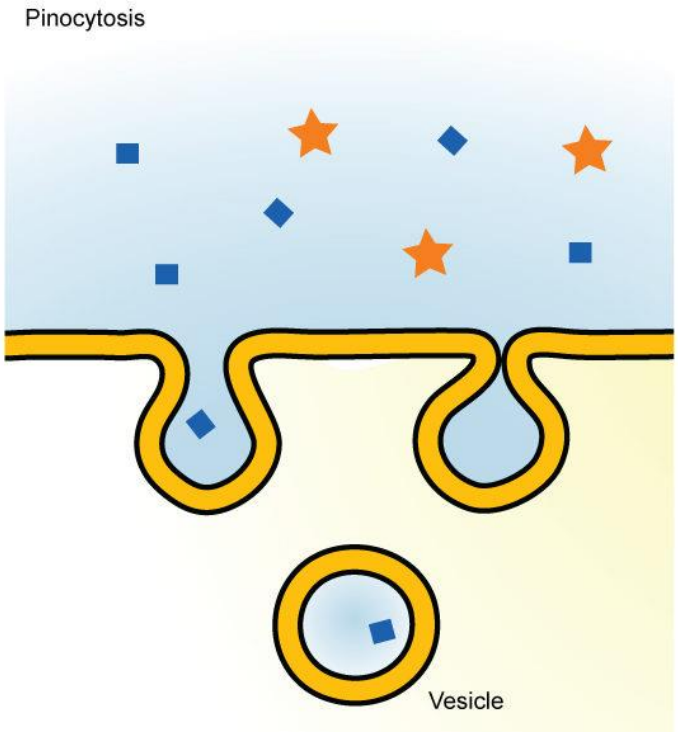


Figure 12: Pinocytosis: In pinocytosis, the cell membrane invaginates, surrounds a small volume of fluid, and pinches off.

A variation of endocytosis is called pinocytosis. This literally means “cell drinking” and was named at a time when the assumption was that the cell was purposefully taking in extracellular fluid. In reality, this is a process that takes in molecules, including water,

which the cell needs from the extracellular fluid. Pinocytosis results in a much smaller vesicle than does phagocytosis, and the vesicle does not need to merge with a lysosome.

Potocytosis, a variant of pinocytosis, is a process that uses a coating protein, called caveolin, on the cytoplasmic side of the plasma membrane, which performs a similar function to clathrin. The cavities in the plasma membrane that form the vacuoles have membrane receptors and lipid rafts in addition to caveolin. The vacuoles or vesicles formed in caveolae (singular caveola) are smaller than those in pinocytosis. Potocytosis is used to bring small molecules into the cell and to transport these molecules through the cell for their release on the other side of the cell, a process called transcytosis.

Receptor-mediated Endocytosis

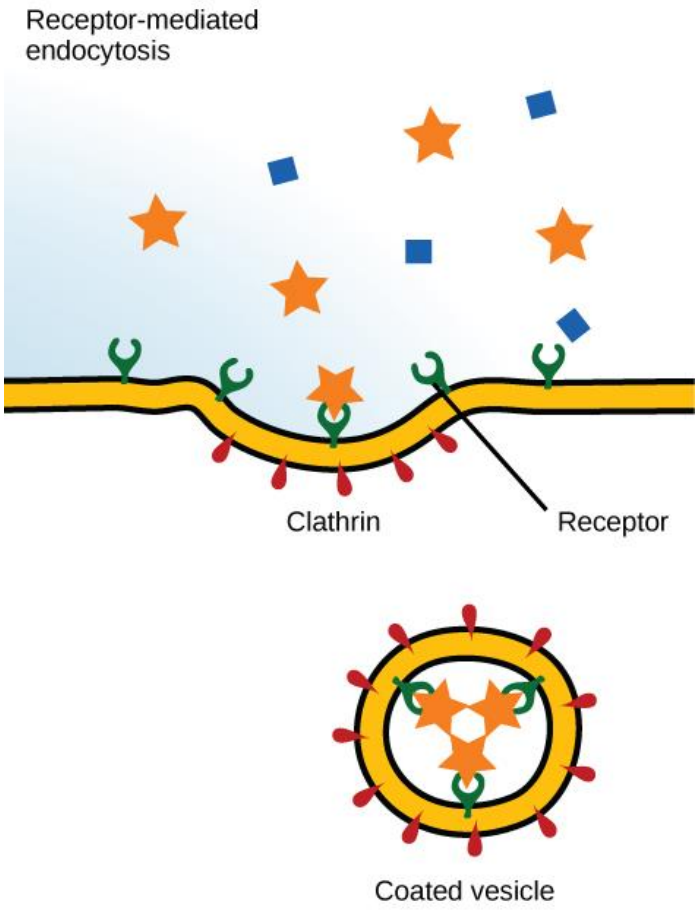


Figure 13: Receptor-Mediated Endocytosis: In receptor-mediated endocytosis, uptake of substances by the cell is targeted to a single type of substance that binds to the receptor on the external surface of the cell membrane.

A targeted variation of endocytosis, known as receptor-mediated endocytosis, employs receptor proteins in the plasma membrane that have a specific binding affinity for certain substances. In receptor-mediated endocytosis, as in phagocytosis, clathrin is attached to the cytoplasmic side of the plasma membrane. If uptake of a compound is dependent on receptor-mediated endocytosis and the process is ineffective, the material will not be removed from the tissue fluids or blood. Instead, it will stay in those fluids and increase in

concentration. Some human diseases are caused by the failure of receptor-mediated endocytosis. For example, the form of cholesterol termed low-density lipoprotein or LDL (also referred to as "bad" cholesterol) is removed from the blood by receptor-mediated endocytosis. In the human genetic disease familial hypercholesterolemia, the LDL receptors are defective or missing entirely. People with this condition have life-threatening levels of cholesterol in their blood, because their cells cannot clear LDL particles from their blood.

Although receptor-mediated endocytosis is designed to bring specific substances that are normally found in the extracellular fluid into the cell, other substances may gain entry into the cell at the same site. Flu viruses, diphtheria, and cholera toxin all have sites that cross-react with normal receptor-binding sites and gain entry into cells.

Cell division happens when a parent cell divides into two or more cells called daughter cells. Cell division usually occurs as part of a larger cell cycle. All cells reproduce by splitting into two, where each parental cell gives rise to two daughter cells.

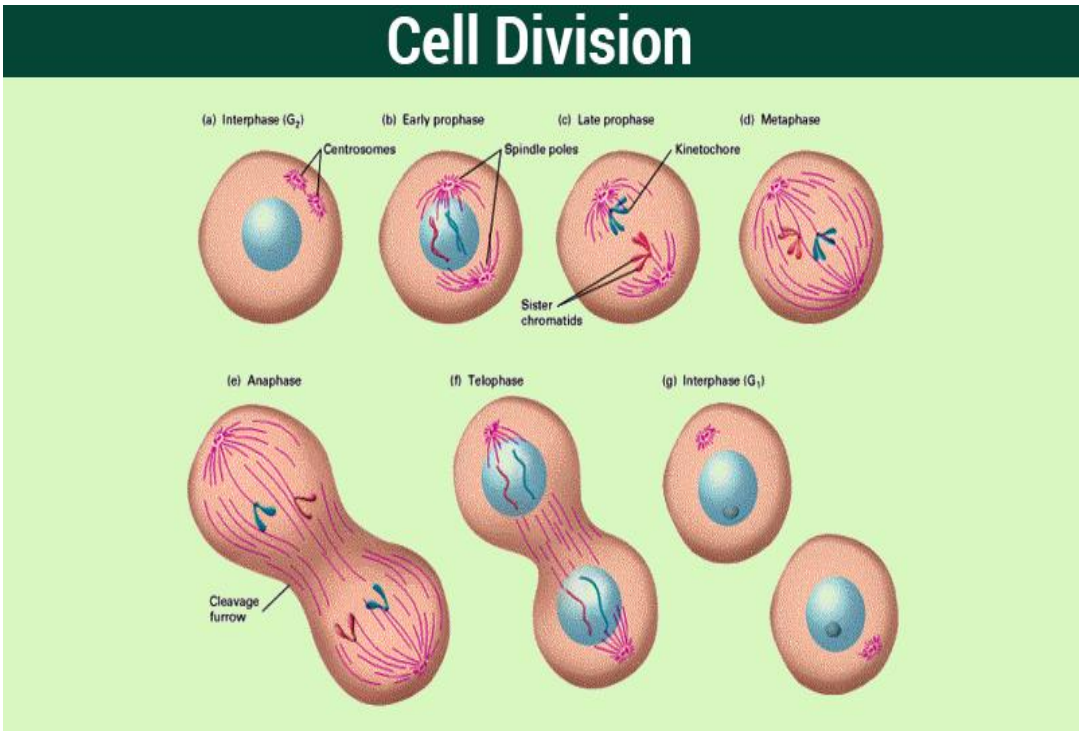


Figure 14: Cell division

These newly formed daughter cells could themselves divide and grow, giving rise to a new cell population that is formed by the division and growth of a single parental cell and its descendant.

In other words, such cycles of growth and division allow a single cell to form a structure consisting of millions of cells.

Explore the cell division notes to learn about the types and phases of cell division.

Types of Cell Division

There are two distinct types of cell division out of which the first one is vegetative division, wherein each daughter cell duplicates the parent cell called mitosis. The second one is meiosis, which divides into four haploid daughter cells.

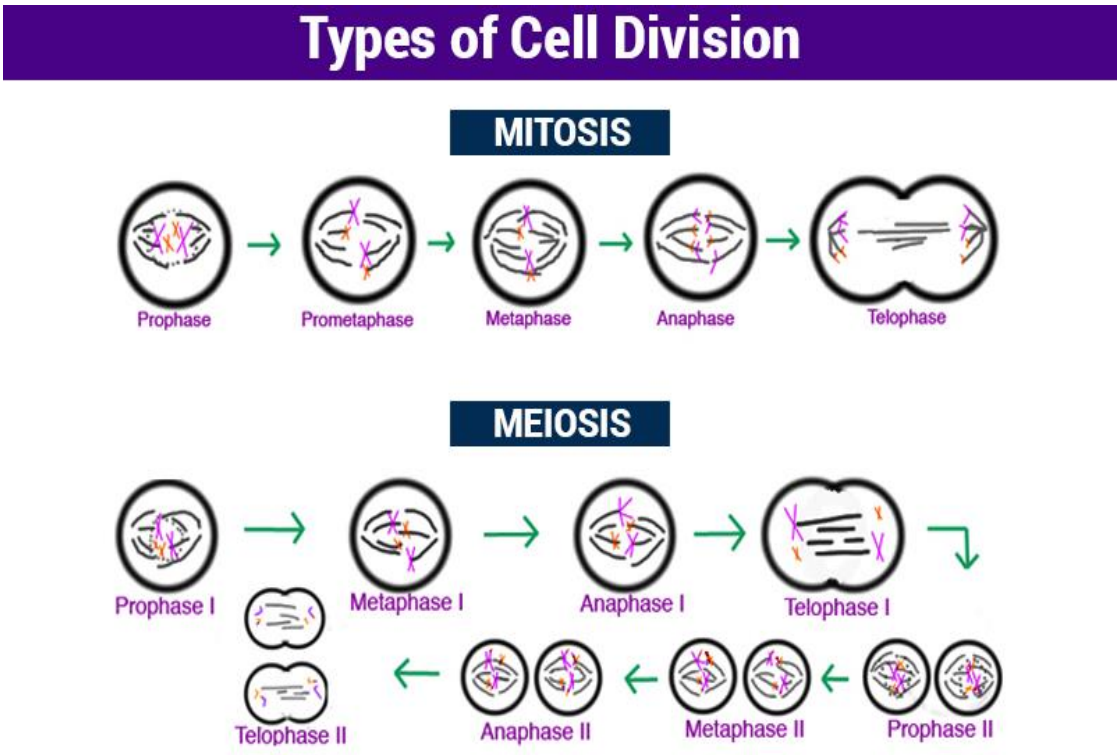


Figure 15: Types of Cell division

Mitosis: The process cells use to make exact replicas of themselves. Mitosis is observed in almost all the body's cells, including eyes, skin, hair, and muscle cells.

Meiosis: In this type of cell division, sperm or egg cells are produced instead of identical daughter cells as in mitosis.

Binary Fission: Single-celled organisms like bacteria replicate themselves for reproduction.

Phases of Cell Cycle

There are two primary phases in the cell cycle:

1. **Interphase**: This phase was thought to represent the resting stage between subsequent cell divisions, but new research has shown that it is a very active phase.

2. **M Phase (Mitosis phase)**: This is where the actual cell division occurs. There are two key steps in this phase, namely cytokinesis and karyokinesis.

The interphase further comprises three phases:

1. **G0 Phase (Resting Phase):** The cell neither divides nor prepares itself for the division.
2. **G1 Phase (Gap 1)**: The cell is metabolically active and grows continuously during this phase.
3. **S phase (Synthesis)**: The DNA replication or synthesis occurs during this stage.
4. **G2 phase (Gap 2):** Protein synthesis happens in this phase.
5. **Quiescent Stage (G0)**: The cells that do not undergo further division exits the G1 phase and enters an inactive stage. This stage is known as the quiescent stage (G0) of the cell cycle.

There are four stages in the **M Phase,** namely:

1. Prophase
2. Metaphase
3. Anaphase
4. Telophase

CELL JUNCTIONS

Introduction

If you were building a building, what kinds of connections might you want to put between the rooms? In some cases, you'd want people to be able to walk from one room to another, in which case you'd put in a door. In other cases, you'd want to hold two adjacent walls firmly together, in which case you might put in some strong bolts. And in still other cases,

you might need to ensure that the walls were sealed very tightly together – for instance, to prevent water from dripping between them.

As it turns out, cells face the same questions when they're arranged in a tissue next to other cells. Should they put in doors that connect them directly to their neighbors? Do they need to spot-weld themselves to their neighbors to make a strong layer, or perhaps even form tight seals to prevent water from passing through the tissue? Junctions serving all of these functions can be found in cells of different types, and here, we'll look at each of them in turn.

Plasmodesmata

Plant cells, surrounded as they are by cell walls, don't contact one another through wide stretches of plasma membrane the way animal cells can. However, they do have specialized junctions called plasmodesmata (singular, plasmodesma), places where a hole is punched in the cell wall to allow direct cytoplasmic exchange between two cells.

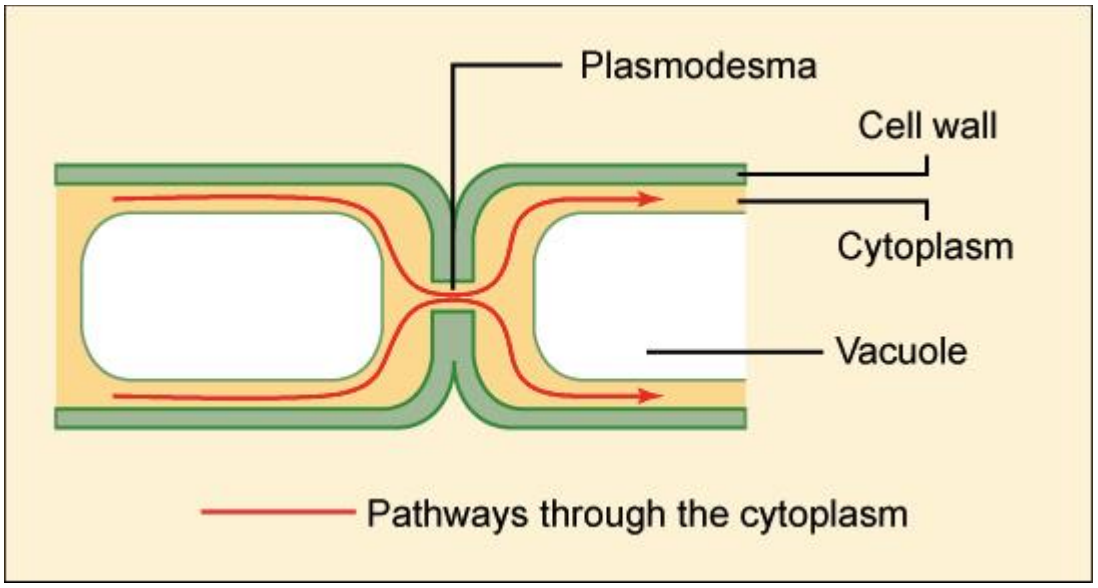


Figure 16: Image of two cells connected by a plasmodesma, showing how materials can travel from the cytoplasm of one cell to the next via the plasmodesma.

Plasmodesmata are lined with plasma membrane that is continuous with the membranes of the two cells. Each plasmodesma has a thread of cytoplasm extending through it, containing an even thinner thread of endoplasmic reticulum (not shown in the diagram above).

Molecules below a certain size (the size exclusion limit) move freely through the plasmodesmal channel by passive diffusion. The size exclusion limit varies among plants, and even among cell types within a plant. Plasmodesmata may selectively dilate (expand) to allow the passage of certain large molecules, such as proteins, although this process is poorly understood^{1,2}1,2start superscript, 1, comma, 2, end superscript.

Gap junctions

Functionally, gap junctions in animal cells are a lot like plasmodesmata in plant cells: they are channels between neighboring cells that allow for the transport of ions, water, and other substances^33cubed. Structurally, however, gap junctions and plasmodesmata are quite different.

In vertebrates, gap junctions develop when a set of six membrane proteins called connexins form an elongated, donut-like structure called a connexon. When the pores, or “doughnut holes,” of connexons in adjacent animal cells align, a channel forms between the cells. (Invertebrates also form gap junctions in a similar way, but use a different set of proteins called innexins.)^44start superscript, 4, end superscript

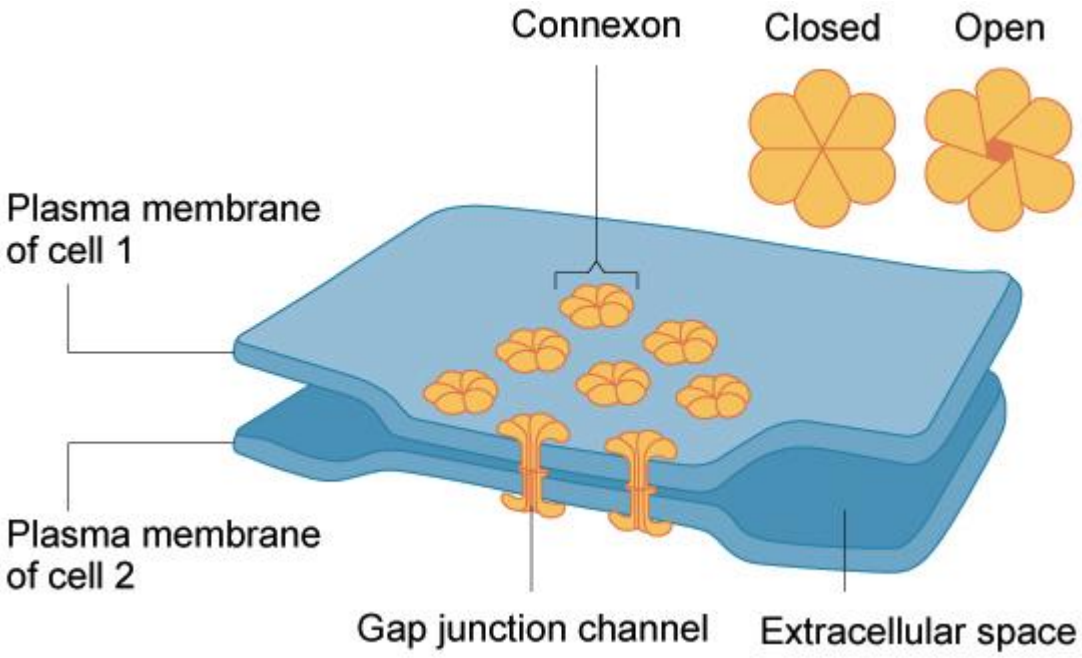


Figure 17: Image of the plasma membranes of two cells held together by gap junctions. Where two connexons from the different cells meet, they can form a channel leading from one cell into the next.

Gap junctions are particularly important in cardiac muscle: the electrical signal to contract spreads rapidly between heart muscle cells as ions pass through gap junctions, allowing the cells to contract in tandem.

Tight junctions

Not all junctions between cells produce cytoplasmic connections. Instead, tight junctions create a watertight seal between two adjacent animal cells.

At the site of a tight junction, cells are held tightly against each other by many individual groups of tight junction proteins called claudins, each of which interacts with a partner group on the opposite cell membrane. The groups are arranged into strands that form a

branching network, with larger numbers of strands making for a tighter seal^55start superscript, 5, end superscript.

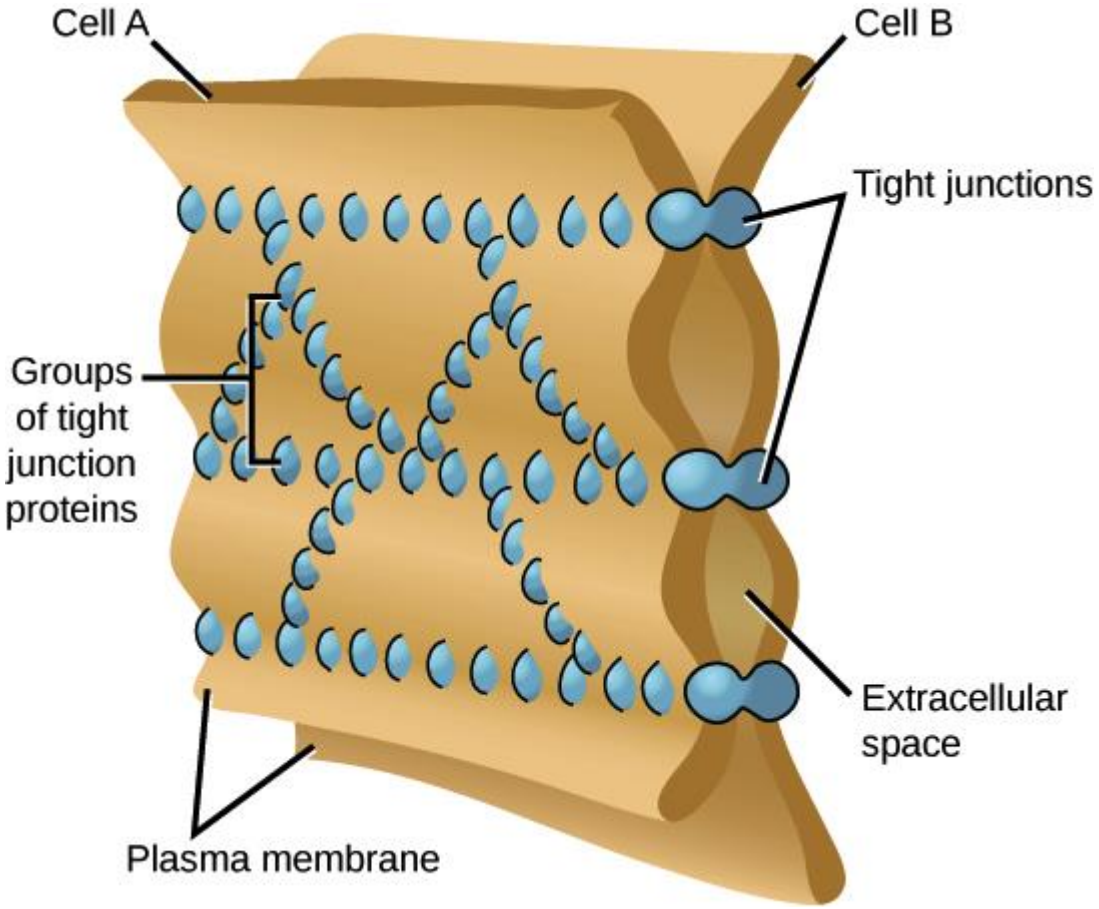


Figure 18: Image of the membranes of two cells held together by tight junctions. The tight junctions are like rivets, and they are arranged in multiple strands that form lines and triangles.

The purpose of tight junctions is to keep liquid from escaping between cells, allowing a layer of cells (for instance, those lining an organ) to act as an impermeable barrier. For example, the tight junctions between the epithelial cells lining your bladder prevent urine from leaking out into the extracellular space.

Desmosomes

Animal cells may also contain junctions called desmosomes, which act like spot welds between adjacent epithelial cells. A desmosome involves a complex of proteins. Some of these proteins extend across the membrane, while others anchor the junction within the cell.

Cadherins, specialized adhesion proteins, are found on the membranes of both cells and interact in the space between them, holding the membranes together. Inside the cell, the cadherins attach to a structure called the cytoplasmic plaque (red in the image at right), which connects to the intermediate filaments and helps anchor the junction.

Desmosomes pin adjacent cells together, ensuring that cells in organs and tissues that stretch, such as skin and cardiac muscle, remain connected in an unbroken sheet.

GENERAL PRINCIPLES OF CELL COMMUNICATION, INTRACELLULAR SIGNALING AND ITS TYPES

All organisms, whether unicellular or multicellular, need to respond to their ever-changing environment in order to survive and flourish. Such responses are governed by the ability of cells to sense physical changes and chemical cues occurring around them. The process of sensing and responding to extrinsic signals is often termed cellular communication, although scientists also use terms such as ‘signal transduction’ or ‘signalling’.

Cells respond to a wide range of extrinsic signals that include chemical messengers (e.g. hormones, growth factors, and neurotransmitters), electrical impulses, mechanical forces, pH, heat and light.

Cellular communication encompasses a vast range of extrinsic signals, intracellular signalling pathways and cellular responses. In fact, no two cell types express exactly the same repertoire of signalling components. Rather, cells have signalling systems that suit their physiological function. The main focus of this topic is cellular communication that occurs when extrinsic stimuli bind to receptors on their target cells. Although not all cellular communication relies on the activation of receptors, it is the most common mechanism by which cells sense their environment or communicate with each other. The central signalling paradigm that will be explored in this course is depicted in Figure 1.

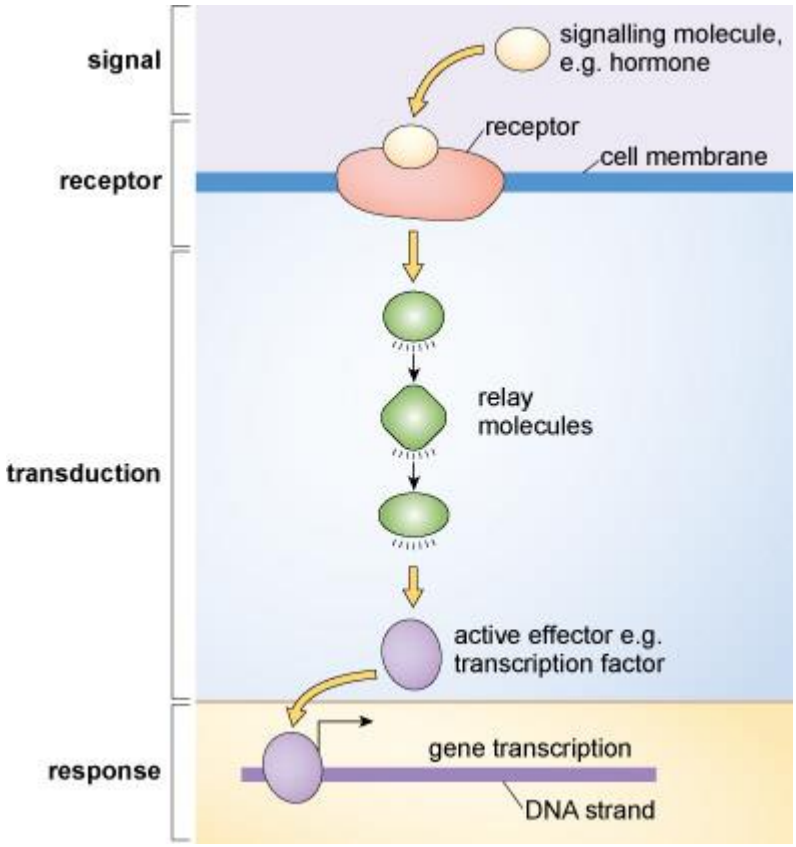


Figure 1 Hypothetical cellular communication pathway. The binding of an extrinsic signalling molecule to a specific receptor stimulates an intracellular transduction process that leads to the activation of effector molecule(s) and a cellular response. Cellular responses can be of many different kinds; in this illustration, the effector molecule is a transcription factor, which stimulates the transcription of specific genes.

By activating receptors, extrinsic signals trigger events that relay information within cells and ultimately cause cells to change their behaviour. It is important to remember that receptors are highly selective for their specific (cognate) extrinsic stimuli. In most cases, a particular kind of receptor will only be activated by one type of extrinsic stimulus.

Activated receptors often have **pleiotropic** actions. That is, they alter the activity of numerous cellular processes simultaneously. These processes could include DNA transcription, protein synthesis or changes in metabolic activity. The overall effect of switching various processes on or off determines the consequent change in cellular behaviour. The fidelity, accuracy and

appropriateness of these cellular communication processes are critically important for the cell and for the organism. It is well known that aberrant cellular communication leads to conditions such as cancer, diabetes, heart failure and neurological diseases.

Cells are simultaneously bombarded with numerous extrinsic signals and they make sense of these incoming signals through the activation of specific signalling pathways.

Just a few of the many signalling systems expressed in a typical mammalian cell are depicted in Figure 2. The key point that you should take from this illustration is that cellular communication triggers specific responses by recruiting particular signalling pathways. The activation of receptors following ligand binding is conveyed into a cell by a cascade of signalling proteins or messengers. Note that each pathway can elicit a variety of responses, although only one example is shown for each of the pathways in Figure 2

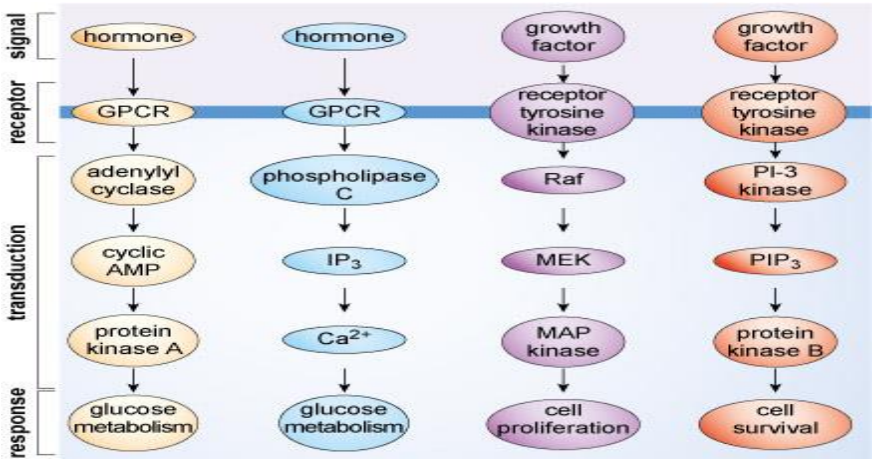


Figure 2 Some of the cell surface receptor-mediated cellular signalling pathways that operate in eukaryotic cells and some of the responses that these pathways elicit. *Key*: GPCR, G-protein coupled receptor; IP_3, inositol 1,4,5-trisphosphate; PIP_3, phosphatidylinositol 3,4,5-trisphosphate

Exactly how a cell will respond to extrinsic stimuli is sometimes hard to predict, even for scientists with considerable experience of studying cellular communication. In part, the response of a cell is determined by the input signals it receives, but there are also many intrinsic factors that determine how cells respond. For example, the age of a cell, its position within the

cell cycle and its metabolic status could impact on how it responds to particular extrinsic stimuli. Under some conditions, such as in a nutrient-rich environment, a cell could receive an extrinsic signal that activates anabolic processes and cell division. At another time, when nutrients are depleted, the same signal may trigger catabolism and cell death.

Although cellular signalling pathways are numerous and complex, there are in fact relatively few pathways in comparison to the diversity of cell types and their intricate molecular processes. For example, development in multicellular animals essentially relies on only seven distinct signalling pathways, commonly called hedgehog, wingless-related, transforming growth factor-β, receptor tyrosine kinases, Notch, JAK/STAT and nuclear hormone receptors (names that variously identify a key component, signal, receptor type or function). These seven pathways are used during development to define the size, shape and other characteristics of an animal. How can so few pathways achieve so much? The answer is that signalling pathways can act together to produce outcomes that are different from the outcome of single pathways acting alone. This combinatorial action of pathways may actually allow hundreds of different signalling–response combinations.

In general terms, the number of genes involved in signalling increases with complexity of an organism, with vertebrates (e.g. humans) having many more such genes than invertebrate species (Table 1). Whole genome duplication events, such as those that occurred in the evolution of vertebrates between 550 and 450 million years ago, were responsible for these marked differences. However, the correlation between complexity and number of genes involved in signalling is not a strict one. Thus, while a human generally has many more genes encoding components of the seven developmental signalling pathways than does the nematode worm *Caenorhabditis elegans*, the latter has many more putative nuclear hormone receptors.

INTRACELLULAR SIGNALING AND ITS TYPES

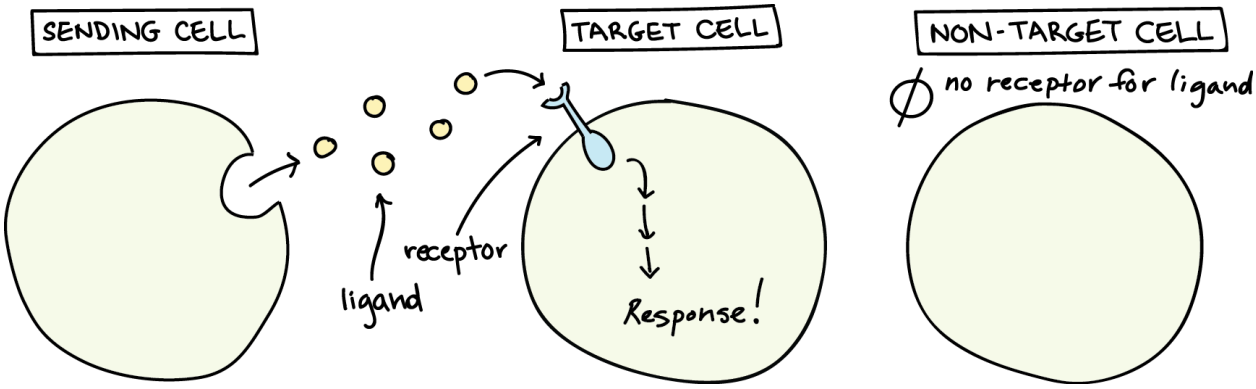
Introduction

Think your cells are just simple building blocks, unconscious and static as bricks in a wall? If so, think again! Cells can detect what's going on around them, and they can respond in real time to cues from their neighbors and environment. At this very moment, your cells are sending and receiving millions of messages in the form of chemical signaling molecules!

In this article, we'll examine the basic principles of how cells communicate with one another. We'll first look at how cell-cell signaling works, then consider different kinds of short- and long-range signaling that happen in our bodies.

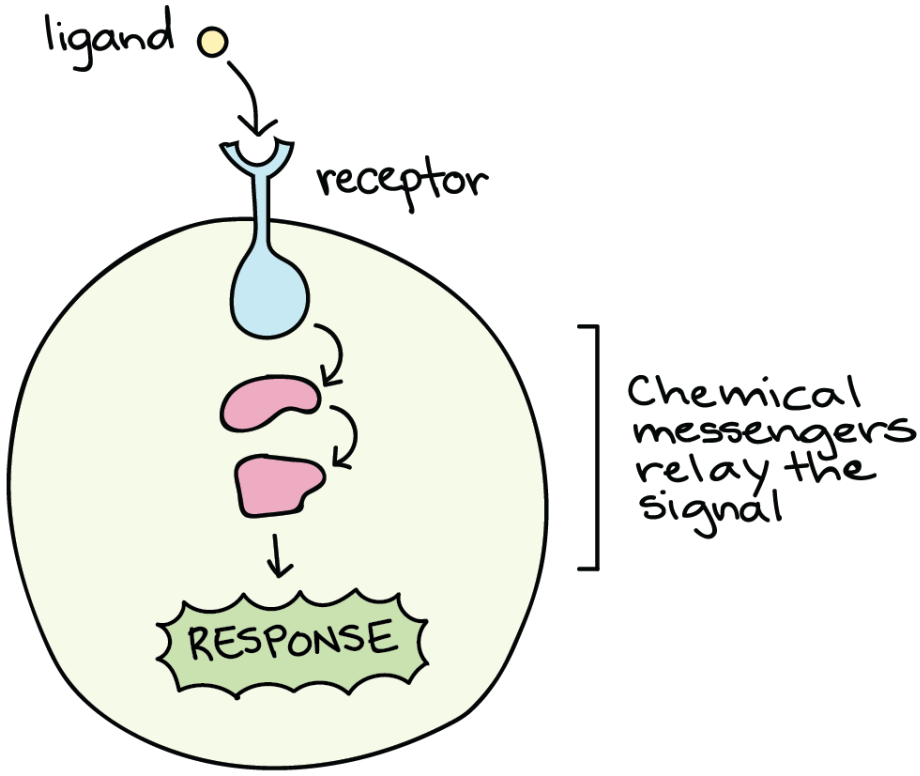
Overview of cell signaling

Cells typically communicate using chemical signals. These chemical signals, which are proteins or other molecules produced by a **sending cell**, are often secreted from the cell and released into the extracellular space. There, they can float – like messages in a bottle – over to neighboring cells.



Not all cells can "hear" a particular chemical message. In order to detect a signal (that is, to be a **target cell**), a neighbor cell must have the right **receptor** for that signal. When a signaling molecule binds to its receptor, it alters the shape or activity of the receptor, triggering a change inside of the cell. Signaling molecules are often called **ligands**, a general term for molecules that bind specifically to other molecules (such as receptors).

The message carried by a ligand is often relayed through a chain of chemical messengers inside the cell. Ultimately, it leads to a change in the cell, such as alteration in the activity of a gene or even the induction of a whole process, such as cell division. Thus, the original **intercellular** (between-cells) signal is converted into an **intracellular** (within-cell) signal that triggers a response.



Forms of signaling

Cell-cell signaling involves the transmission of a signal from a sending cell to a receiving cell. However, not all sending and receiving cells are next-door neighbors, nor do all cell pairs exchange signals in the same way.

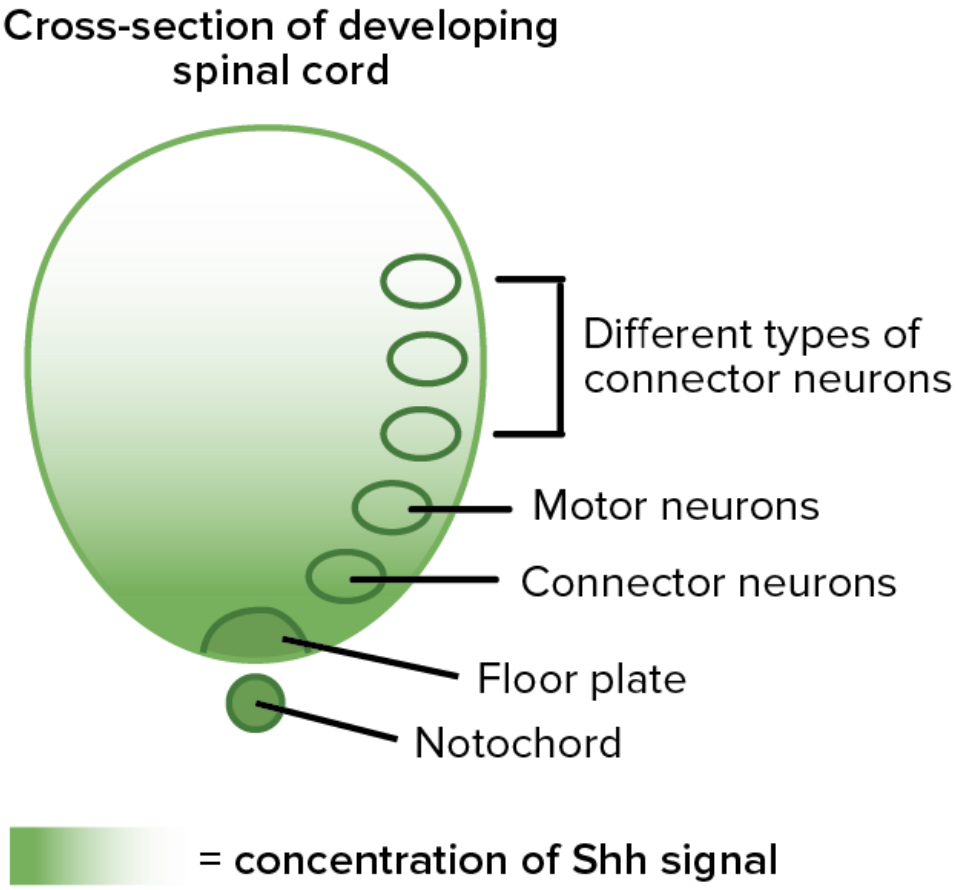
There are four basic categories of chemical signaling found in multicellular organisms: paracrine signaling, autocrine signaling, endocrine signaling, and signaling by direct contact.

The main difference between the different categories of signaling is the distance that the signal travels through the organism to reach the target cell.

Paracrine signaling

Often, cells that are near one another communicate through the release of chemical messengers (ligands that can diffuse through the space between the cells). This type of signaling, in which cells communicate over relatively short distances, is known as **paracrine signaling**.

Paracrine signaling allows cells to locally coordinate activities with their neighbors. Although they're used in many different tissues and contexts, paracrine signals are especially important during development, when they allow one group of cells to tell a neighboring group of cells what cellular identity to take on.



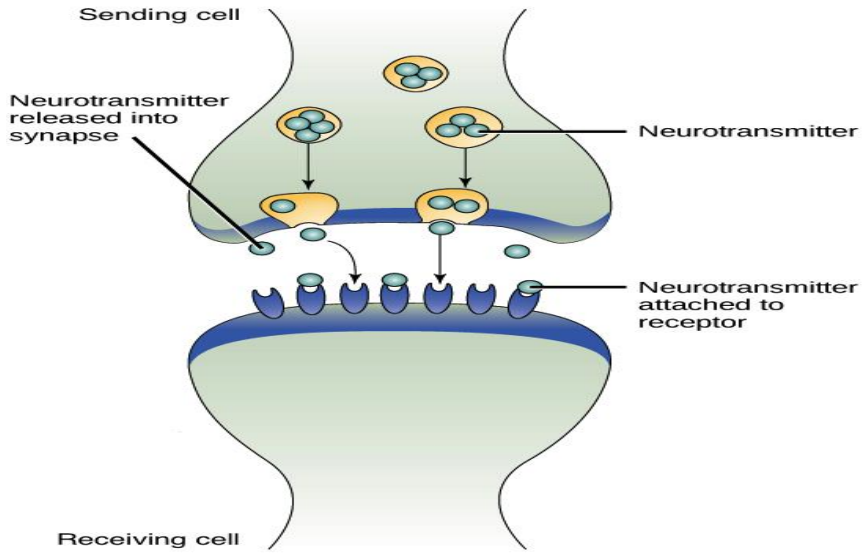
Cross-section of the developing spinal cord, showing the distribution of Shh and the specification of different types of neurons. As Shh diffuses away from the notochord and floor plate, it forms a gradient, with high levels near the source and low levels further away. The different concentrations of Shh at different points along the gradient help tell nearby cells what types of neurons they should become.

- Cells that are close to the notochord and floor plate receive a high dose of signal and become a specific type of connector neuron (interneuron).
- Cells that are a little further away get a lower dose of signal and become motor neurons (neurons that connect up to muscles).
- Cell that are even more distant from the notochord and floor plate receive progressively lower doses of signal and become other types of interneurons.

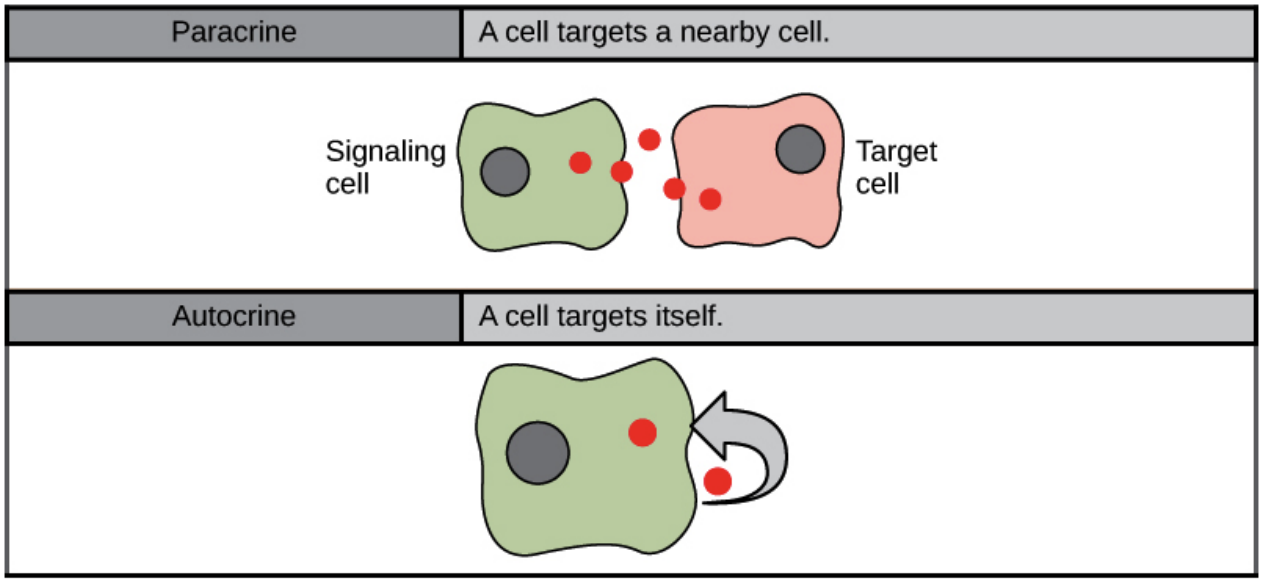
Synaptic signaling

One unique example of paracrine signaling is **synaptic signaling**, in which nerve cells transmit signals. This process is named for the **synapse**, the junction between two nerve cells where signal transmission occurs.

When the sending neuron fires, an electrical impulse moves rapidly through the cell, traveling down a long, fiber-like extension called an axon. When the impulse reaches the synapse, it triggers the release of ligands called **neurotransmitters**, which quickly cross the small gap between the nerve cells. When the neurotransmitters arrive at the receiving cell, they bind to receptors and cause a chemical change inside of the cell (often, opening ion channels and changing the electrical potential across the membrane).



The neurotransmitters that are released into the chemical synapse are quickly degraded or taken back up by the sending cell. This "resets" the system so they synapse is prepared to respond quickly to the next signal.



Paracrine signaling: a cell targets a nearby cell (one not attached by gap junctions). The image shows a signaling molecule produced by one cell diffusing a short distance to a neighboring cell.

Autocrine signaling: a cell targets itself, releasing a signal that can bind to receptors on its own surface.

Autocrine signaling

In **autocrine signaling**, a cell signals to itself, releasing a ligand that binds to receptors on its own surface (or, depending on the type of signal, to receptors inside of the cell). This may seem like an odd thing for a cell to do, but autocrine signaling plays an important role in many processes.

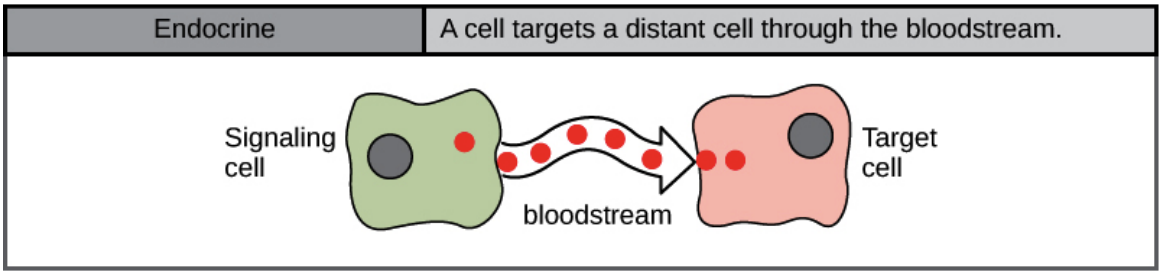
For instance, autocrine signaling is important during development, helping cells take on and reinforce their correct identities. From a medical standpoint, autocrine signaling is important in cancer and is thought to play a key role in metastasis (the spread of cancer from its original site to other parts of the body)^66start superscript, 6, end superscript. In many cases, a signal may have both autocrine and paracrine effects, binding to the sending cell as well as other similar cells in the area.

Endocrine signaling

When cells need to transmit signals over long distances, they often use the circulatory system as a distribution network for the messages they send. In long-distance **endocrine signaling**, signals are produced by specialized cells and released into the bloodstream, which carries them to target cells in distant parts of the body. Signals that are produced in one part of the body and travel through the circulation to reach far-away targets are known as **hormones**.

In humans, endocrine glands that release hormones include the thyroid, the hypothalamus, and the pituitary, as well as the gonads (testes and ovaries) and the pancreas. Each endocrine gland releases one or more types of hormones, many of which are master regulators of development and physiology.

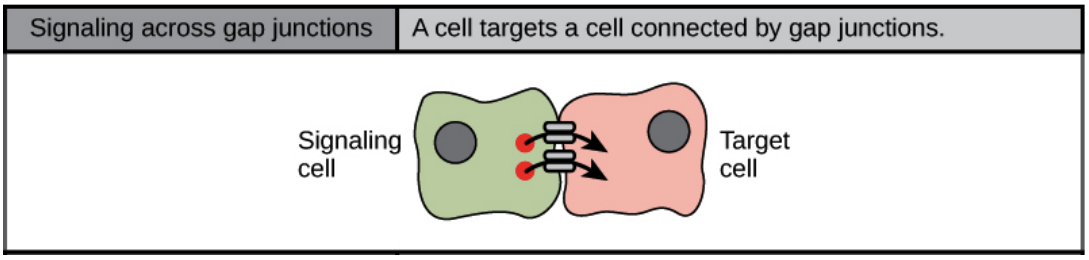
For example, the pituitary releases **growth hormone** (**GH**), which promotes growth, particularly of the skeleton and cartilage. Like most hormones, GH affects many different types of cells throughout the body. However, cartilage cells provide one example of how GH functions: it binds to receptors on the surface of these cells and encourages them to divide^77start superscript, 7, end superscript.



Endocrine signaling: a cell targets a distant cell through the bloodstream. A signaling molecule is released by one cell, then travels through the bloodstream to bind to receptors on a distant target cell elsewhere in the body.

Signaling through cell-cell contact

Gap junctions in animals and plasmodesmata in plants are tiny channels that directly connect neighboring cells. These water-filled channels allow small signaling molecules, called **intracellular mediators**, to diffuse between the two cells. The transfer of signaling molecules transmits the current state of one cell to its neighbor. This allows a group of cells to coordinate their response to a signal that only one of them may have received. In plants, there are plasmodesmata between almost all cells, making the entire plant into one giant network.



Signaling across gap junctions. A cell targets a neighboring cell connected via gap junctions. Signals travel from one cell to the other by passing through the gap junctions. In another form of direct signaling, two cells may bind to one another because they carry complementary proteins on their surfaces. When the proteins bind to one another, this interaction changes the shape of one or both proteins, transmitting a signal. This kind of signaling is especially important in the immune system, where immune cells use cell-surface markers to recognize "self" cells (the body's own cells) and cells infected by pathogens^{9}9start superscript, 9, end superscript.

CLASSIFICATION OF TISSUES AND STRUCTURE, LOCATION AND FUNCTIONS OF EPITHELIAL TISSUE

The term **tissue** is used to describe a group of cells found together in the body. The cells within a tissue share a common embryonic origin. Microscopic observation reveals that the cells in a tissue share morphological features and are arranged in an orderly pattern that achieves the tissue's functions. From the evolutionary perspective, tissues appear in more

complex organisms. For example, multicellular protists, ancient eukaryotes, do not have cells organized into tissues.

Although there are many types of cells in the human body, they are organized into four broad categories of tissues: epithelial, connective, muscle, and nervous. Each of these categories is characterized by specific functions that contribute to the overall health and maintenance of the body. A disruption of the structure is a sign of injury or disease. Such changes can be detected through **histology**, the microscopic study of tissue appearance, organization, and function.

THE FOUR TYPES OF TISSUES

Epithelial tissue, also referred to as epithelium, refers to the sheets of cells that cover exterior surfaces of the body, lines internal cavities and passageways, and forms certain glands. **Connective tissue**, as its name implies, binds the cells and organs of the body together and functions in the protection, support, and integration of all parts of the body. **Muscle tissue** is excitable, responding to stimulation and contracting to provide movement, and occurs as three major types: skeletal (voluntary) muscle, smooth muscle, and cardiac muscle in the heart. **Nervous tissue** is also excitable, allowing the propagation of electrochemical signals in the form of nerve impulses that communicate between different regions of the body.

The next level of organization is the organ, where several types of tissues come together to form a working unit. Just as knowing the structure and function of cells helps you in your study of tissues, knowledge of tissues will help you understand how organs function. The epithelial and connective tissues are discussed in detail in this chapter. Muscle and nervous tissues will be discussed only briefly in this chapter.

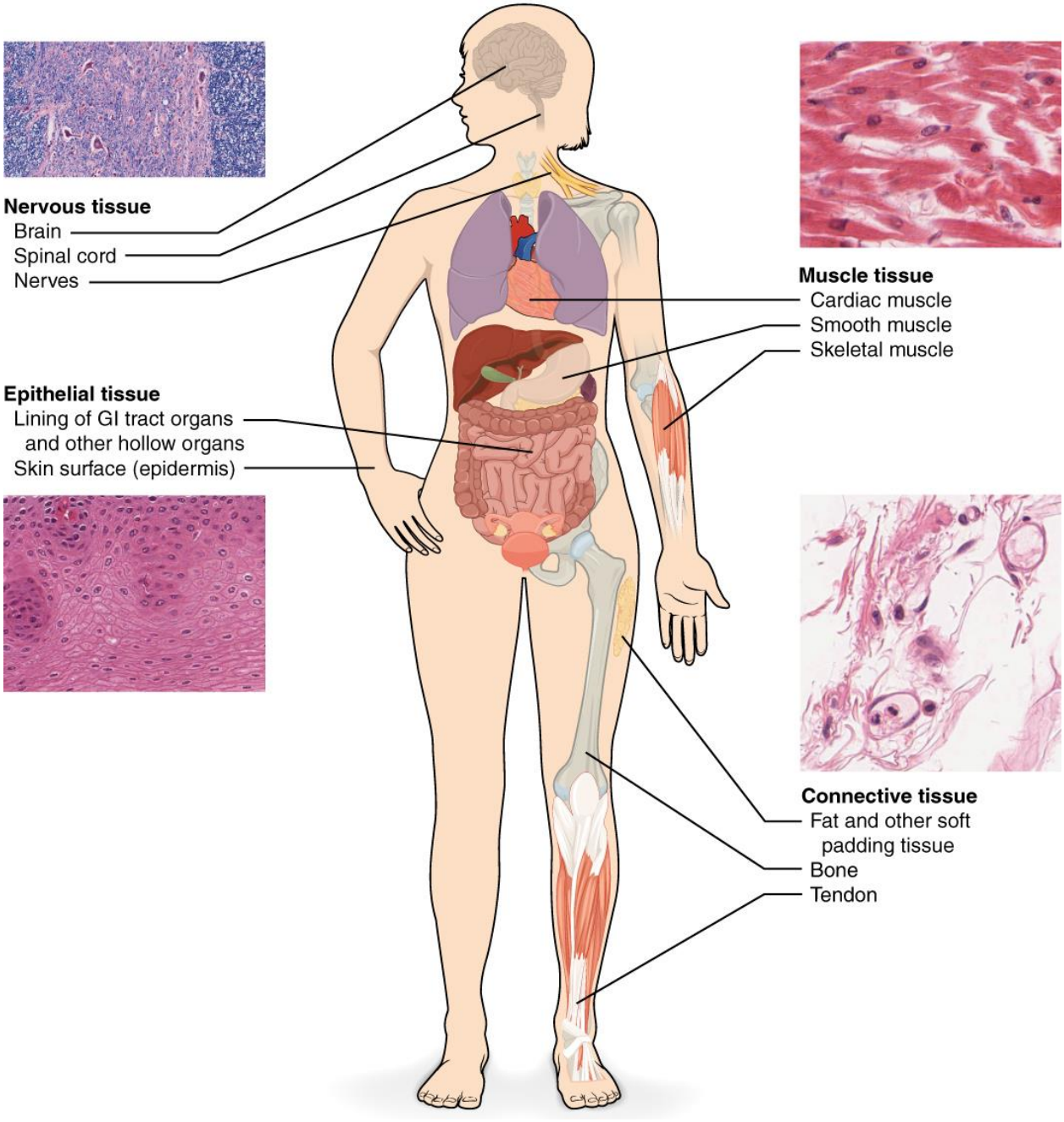


Figure 1. Four Types of Tissue: Body. The four types of tissues are exemplified in nervous tissue, stratified squamous epithelial tissue, cardiac muscle tissue, and connective tissue in small intestine

EPITHELIAL TISSUES

- Epithelium consists of closely packed, flattened cells that make up the inside or outside lining of body areas. There is little intercellular material.
- The tissue is **avascular,** meaning without blood vessels. Nutrient and waste exchange occurs through neighboring connective tissues by diffusion.
- The upper surface of epithelium is free, or exposed to the outside of the body or to an internal body cavity. The basal surface rests on connective tissue. A thin, extracellular layer called the *basement membrane* forms between the epithelial and connective tissue.

There are two kinds of epithelial tissues:

- Covering and lining epithelium covers the outside surfaces of the body and lines internal organs.
- Glandular epithelium secretes hormones or other products.

Epithelium that covers or lines

Epithelial tissues that cover or line surfaces are classified by cell shape and by the number of cell layers. The following terms are used to describe these features.

Cell shape:

- *Squamous cells* are flat. The nucleus, located near the upper surface, gives these cells the appearance of a fried egg.
- *Cuboidal cells* are cube- or hexagon-shaped with a central, round nucleus. These cells produce secretions (sweat, for example) or absorb substances such as digested food.
- *Columnar cells* are tall with an oval nucleus near the basement membrane. These thick cells serve to protect underlying tissues or may function to absorb substances. Some have microvilli, minute surface extensions, to increase surface area for absorbing

substances, while others may have cilia that help move substances over their surface (such as mucus through the respiratory tract).

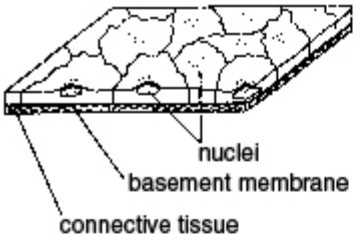
- *Transitional cells* range from flat to tall cells that can extend or compress in response to body movement.

Number of cell layers:

- *Simple epithelium* describes a single layer of cells.
- *Stratified epithelium* describes epithelium consisting of multiple layers.
- *Pseudostratified epithelium* describes a single layer of cells of different sizes, giving the appearance of being multilayered.

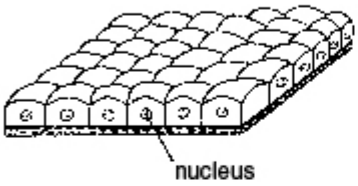
Names of epithelial tissues include a description of both their shape and their number of cell layers. The presence of cilia may also be identified in their names. For example, simple squamous describes epithelium consisting of a single layer of flat cells. Pseudostratified columnar ciliated epithelium describes a single layer of tall, ciliated cells of more than one size. Stratified epithelium is named after the shape of the outermost cell layer. Thus, stratified squamous epithelium has outermost layers of squamous cells, even though some inner layers consist of cuboidal or columnar cells. These and other epithelial tissues are illustrated in Figure 1.

Figure 1. Types of epithelial tissues.



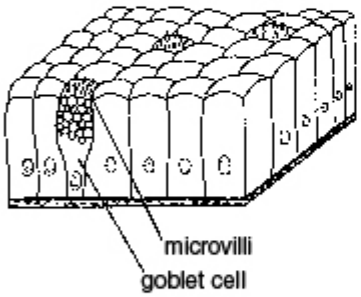
simple squamous epithelium

Cells: single (scalelike) layer
Nuclei: flattened, centrally located
Functions: diffusion, lubrication



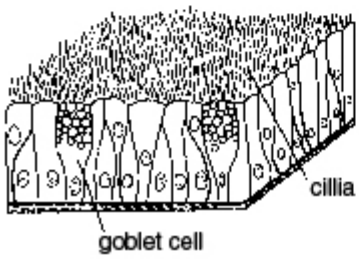
simple cuboidal epithelium

Cells: single (squarelike) layer
Nuclei: centrally located and spherical
Functions: absorption, secretion, protection



simple columnar epithelium

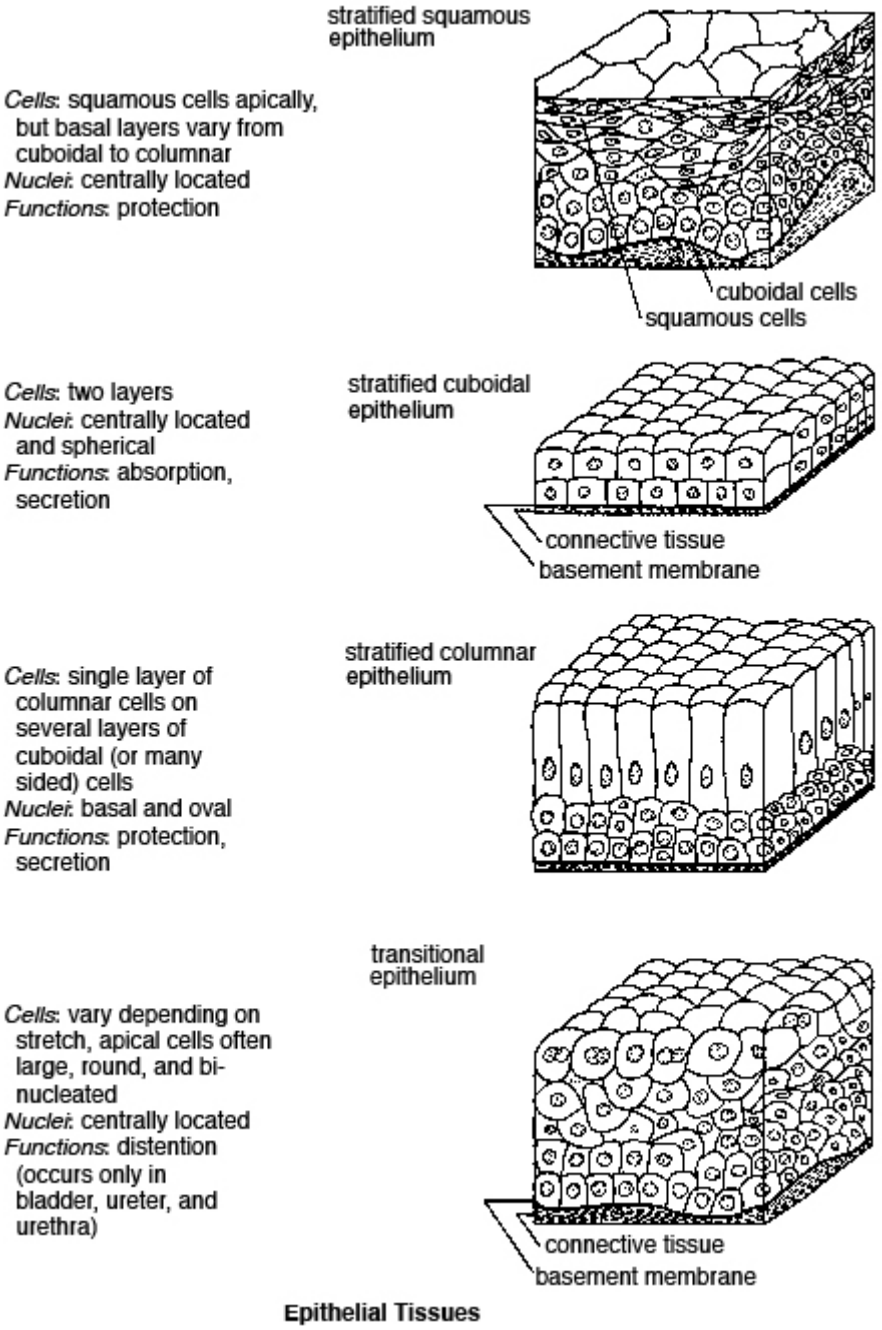
Cells: tall, single-layered
Nuclei: basally located and enlongated
Functions: absorption, secretion, protection
(May bear cilia and may contain goblet cells with microvilli)



pseudostratified epithelium

Cells: differ in height, not all cells reach the apical surface
Nuclei: at various positions
Functions: absorption, secretion, transportation

Epithelial Tissues



Glandular epithelium

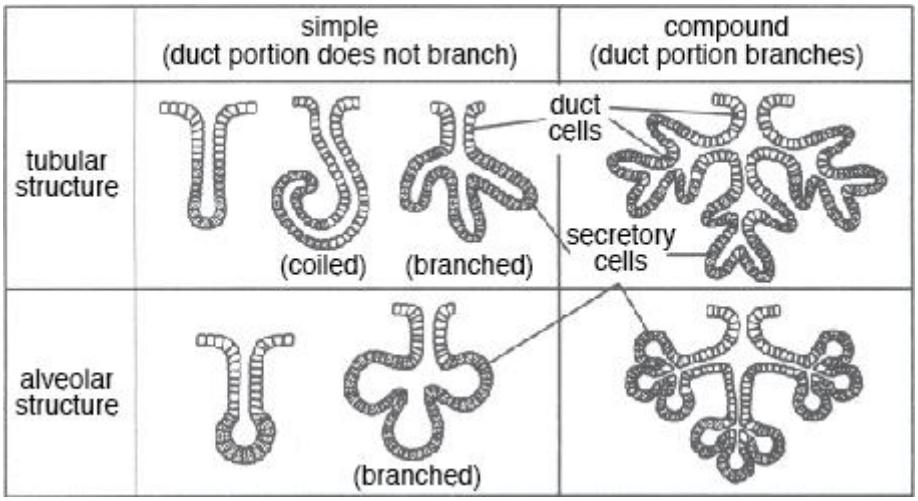
Glandular epithelium forms two kinds of glands:

- *Endocrine glands* secrete **hormones** directly into the bloodstream. For example, the thyroid gland secretes the hormone thyroxin into the bloodstream, where it is distributed throughout the body, stimulating an increase in the metabolic rate of body cells.
- *Exocrine glands* secrete their substances into tubes, or ducts, which carry the secretions to the epithelial surface. Examples of secretions include sweat, saliva, milk, stomach acid, and digestive enzymes.

Exocrine glands are classified according to their structure (see Figure 2):

- Unicellular or multicellular describes a single-celled gland or a gland made of many cells, respectively. A multicellular gland consists of a group of secretory cells and a duct through which the secretions pass as they exit the gland.
- Branched refers to the branching arrangement of secretory cells in the gland.
- Simple or compound refers to whether the duct of the gland (not the secretory portion) does or does not branch, respectively.
- Tubular describes a gland whose secretory cells form a tube, while alveolar (or acinar) describes secretory cells that form a bulblike sac.

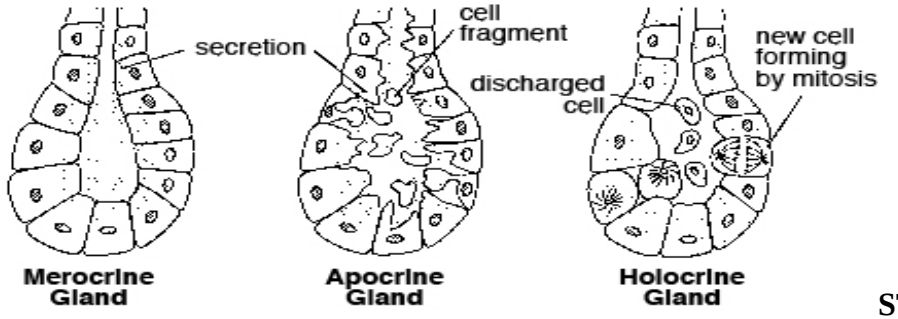
Figure 2. Exocrine glands can be classified as simple or compound with either a tubular or alveolar structure.



Exocrine glands are also classified according to their function (see Figure 3):

- In merocrine glands, secretions pass through the cell membranes of the secretory cells (exocytosis). For example, goblet cells of the trachea release mucus via exocytosis.
- In apocrine glands, a portion of the cell containing secretions is released as it separates from the rest of the cell. For example, the apical portion of lactiferous glands release milk in this manner.
- In holocrine glands, entire secretory cells disintegrate and are released along with their contents. For example, sebaceous glands release sebum to lubricate the skin in this manner.

Figure 3. Exocrine glands can be classified according to their function.



STRUCTURE, LOCATION AND FUNCTIONS OF CONNECTIVE TISSUE

As may be obvious from its name, one of the major functions of connective tissue is to connect tissues and organs. Unlike epithelial tissue, which is composed of cells closely packed with little or no extracellular space in between, connective tissue cells are dispersed in a **matrix**. The matrix usually includes a large amount of extracellular material produced by the connective tissue cells that are embedded within it. The matrix plays a major role in the functioning of this tissue. The major component of the matrix is a **ground substance** often crisscrossed by protein fibers. This ground substance is usually a fluid, but it can also be mineralized and solid, as in bones. Connective tissues come in a vast variety of forms, yet they typically have in common three characteristic components: cells, large amounts of amorphous ground substance, and protein fibers. The amount and structure of each component correlates with the function of the tissue, from the rigid ground substance in bones supporting the body to the inclusion of specialized cells; for example, a phagocytic cell that engulfs pathogens and also rids tissue of cellular debris.

FUNCTIONS OF CONNECTIVE TISSUES

Connective tissues perform many functions in the body, but most importantly, they support and connect other tissues; from the connective tissue sheath that surrounds muscle cells, to the tendons that attach muscles to bones, and to the skeleton that supports the positions of the body. Protection is another major function of connective tissue, in the form of fibrous capsules and bones that protect delicate organs and, of course, the skeletal system. Specialized cells in connective tissue defend the body from microorganisms that enter the body. Transport of fluid,

nutrients, waste, and chemical messengers is ensured by specialized fluid connective tissues, such as blood and lymph. Adipose cells store surplus energy in the form of fat and contribute to the thermal insulation of the body

CLASSIFICATION OF CONNECTIVE TISSUES

The three broad categories of connective tissue are classified according to the characteristics of their ground substance and the types of fibers found within the matrix (Table 1). **Connective tissue proper** includes **loose connective tissue** and **dense connective tissue**. Both tissues have a variety of cell types and protein fibers suspended in a viscous ground substance. Dense connective tissue is reinforced by bundles of fibers that provide tensile strength, elasticity, and protection. In loose connective tissue, the fibers are loosely organized, leaving large spaces in between. **Supportive connective tissue**—bone and cartilage—provide structure and strength to the body and protect soft tissues. A few distinct cell types and densely packed fibers in a matrix characterize these tissues. In bone, the matrix is rigid and described as calcified because of the deposited calcium salts. In **fluid connective tissue**, in other words, lymph and blood, various specialized cells circulate in a watery fluid containing salts, nutrients, and dissolved proteins.

Connective Tissue Examples (Table 1)

Connective tissue proper	Supportive connective tissue	Fluid connective tissue
Loose connective tissue	Cartilage	
• Areolar • Adipose • Reticular	• Hyaline • Fibrocartilage • Elastic	Blood
Dense connective tissue	Bones	Lymph

Connective Tissue Examples (Table 1)

Connective tissue proper	Supportive connective tissue	Fluid connective tissue
• Regular elastic	• Compact bone	
• Irregular elastic	• Cancellous bone	

CONNECTIVE TISSUE PROPER

Fibroblasts are present in all connective tissue proper (Figure 1). Fibrocytes, adipocytes, and mesenchymal cells are fixed cells, which means they remain within the connective tissue. Other cells move in and out of the connective tissue in response to chemical signals. Macrophages, mast cells, lymphocytes, plasma cells, and phagocytic cells are found in connective tissue proper but are actually part of the immune system protecting the body.

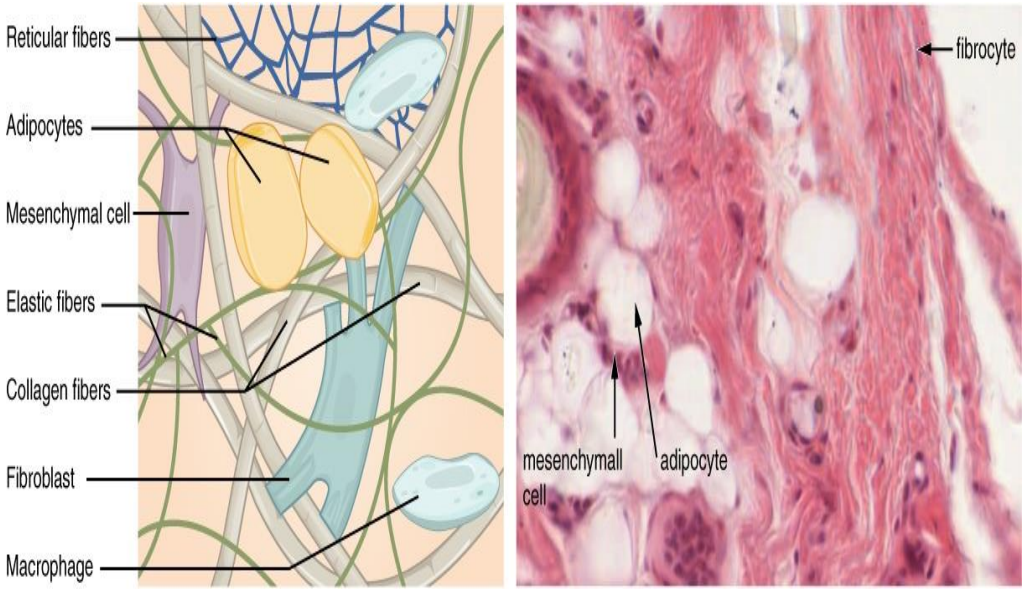


Figure 1. Connective Tissue Proper. Fibroblasts produce this fibrous tissue. Connective tissue proper includes the fixed cells fibrocytes, adipocytes, and mesenchymal cells. LM × 400. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

CELL TYPES

The most abundant cell in connective tissue proper is the **fibroblast**. Polysaccharides and proteins secreted by fibroblasts combine with extra-cellular fluids to produce a viscous ground substance that, with embedded fibrous proteins, forms the extra-cellular matrix. As you might expect, a **fibrocyte**, a less active form of fibroblast, is the second most common cell type in connective tissue proper.

Adipocytes are cells that store lipids as droplets that fill most of the cytoplasm. There are two basic types of adipocytes: white and brown. The brown adipocytes store lipids as many droplets, and have high metabolic activity. In contrast, white fat adipocytes store lipids as a single large drop and are metabolically less active. Their effectiveness at storing large amounts of fat is witnessed in obese individuals. The number and type of adipocytes depends on the tissue and location, and vary among individuals in the population.

The **mesenchymal cell is a multipotent adult stem cell. These cells can differentiate into any type of connective tissue cells needed for repair and healing of damaged tissue.**

The macrophage cell is a large cell derived from a monocyte, a type of blood cell, which enters the connective tissue matrix from the blood vessels. The macrophage cells are an essential component of the immune system, which is the body's defense against potential pathogens and degraded host cells. When stimulated, macrophages release cytokines, small proteins that act as chemical messengers. Cytokines recruit other cells of the immune system to infected sites and stimulate their activities. Roaming, or free, macrophages move rapidly by amoeboid movement, engulfing infectious agents and cellular debris. In contrast, fixed macrophages are permanent residents of their tissues.

The mast cell, found in connective tissue proper, has many cytoplasmic granules. These granules contain the chemical signals histamine and heparin. When irritated or damaged, mast cells release histamine, an inflammatory mediator, which causes vasodilation and increased blood flow at a site of injury or infection, along with itching, swelling, and redness you

recognize as an allergic response. Like blood cells, mast cells are derived from hematopoietic stem cells and are part of the immune system.

CONNECTIVE TISSUE FIBERS AND GROUND SUBSTANCE

Three main types of fibers are secreted by fibroblasts: collagen fibers, elastic fibers, and reticular fibers. **Collagen fiber** is made from fibrous protein subunits linked together to form a long and straight fiber. Collagen fibers, while flexible, have great tensile strength, resist stretching, and give ligaments and tendons their characteristic resilience and strength. These fibers hold connective tissues together, even during the movement of the body.

Elastic fiber contains the protein elastin along with lesser amounts of other proteins and glycoproteins. The main property of elastin is that after being stretched or compressed, it will return to its original shape. Elastic fibers are prominent in elastic tissues found in skin and the elastic ligaments of the vertebral column.

Reticular fiber is also formed from the same protein subunits as collagen fibers; however, these fibers remain narrow and are arrayed in a branching network. They are found throughout the body, but are most abundant in the reticular tissue of soft organs, such as liver and spleen, where they anchor and provide structural support to the **parenchyma** (the functional cells, blood vessels, and nerves of the organ).

All of these fiber types are embedded in ground substance. Secreted by fibroblasts, ground substance is made of polysaccharides, specifically hyaluronic acid, and proteins. These combine to form a proteoglycan with a protein core and polysaccharide branches. The proteoglycan attracts and traps available moisture forming the clear, viscous, colorless matrix you now know as ground substance.

LOOSE CONNECTIVE TISSUE

Loose connective tissue is found between many organs where it acts both to absorb shock and bind tissues together. It allows water, salts, and various nutrients to diffuse through to adjacent or imbedded cells and tissues.

Adipose tissue consists mostly of fat storage cells, with little extracellular matrix (Figure 2). A large number of capillaries allow rapid storage and mobilization of lipid molecules. White adipose tissue is most abundant. It can appear yellow and owes its color to carotene and related pigments from plant food. White fat contributes mostly to lipid storage and can serve as insulation from cold temperatures and mechanical injuries. White adipose tissue can be found protecting the kidneys and cushioning the back of the eye. Brown adipose tissue is more common in infants, hence the term “baby fat.” In adults, there is a reduced amount of brown fat and it is found mainly in the neck and clavicular regions of the body. The many mitochondria in the cytoplasm of brown adipose tissue help explain its efficiency at metabolizing stored fat. Brown adipose tissue is thermogenic, meaning that as it breaks down fats, it releases metabolic heat, rather than producing adenosine triphosphate (ATP), a key molecule used in metabolism.

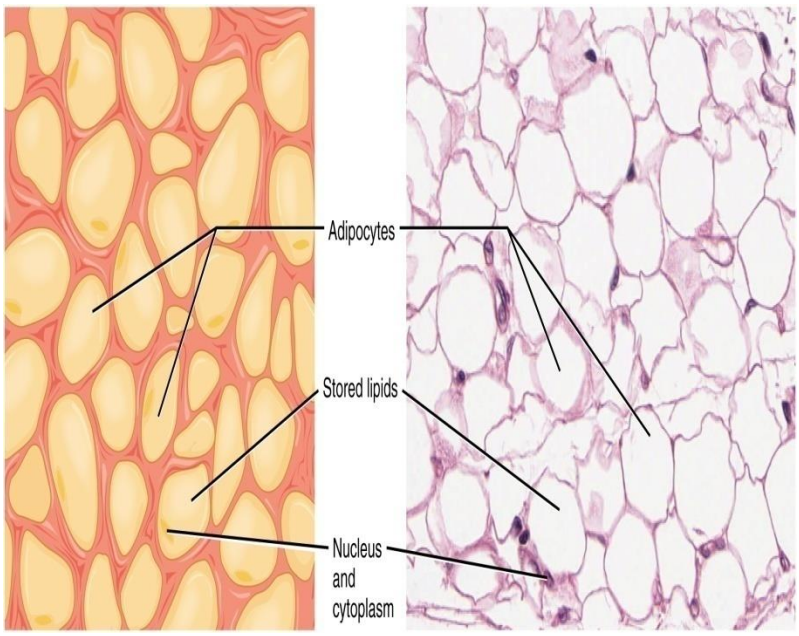


Figure 2. Adipose Tissue. This is a loose connective tissue that consists of fat cells with little extracellular matrix. It stores fat for energy and provides insulation. LM × 800. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

Areolar tissue shows little specialization. It contains all the cell types and fibers previously described and is distributed in a random, web-like fashion. It fills the spaces between muscle fibers, surrounds blood and lymph vessels, and supports organs in the abdominal cavity. Areolar tissue underlies most epithelia and represents the connective tissue component of epithelial membranes, which are described further in a later section.

Reticular tissue is a mesh-like, supportive framework for soft organs such as lymphatic tissue, the spleen, and the liver (Figure 3). Reticular cells produce the reticular fibers that form the network onto which other cells attach. It derives its name from the Latin *reticulus*, which means "little net."

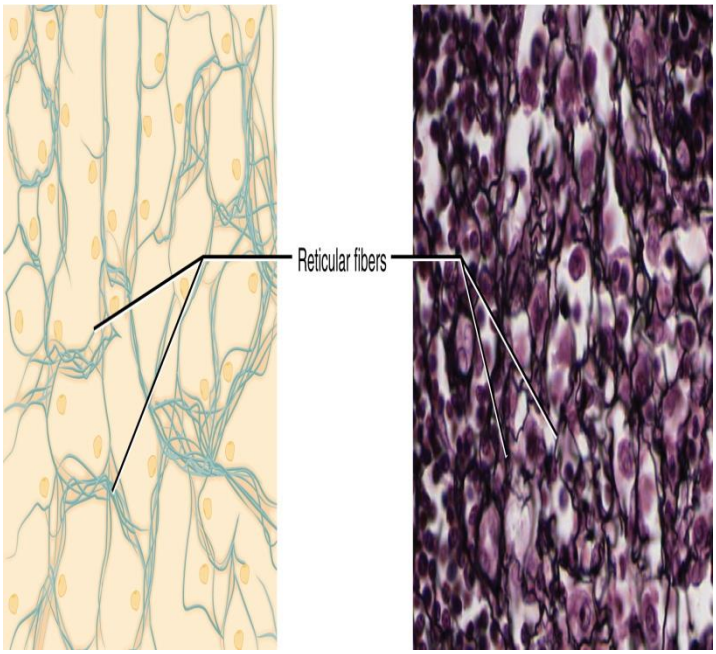


Figure 3. Reticular Tissue. This is a loose connective tissue made up of a network of reticular fibers that provides a supportive framework for soft organs. LM × 1600. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

DENSE CONNECTIVE TISSUE

Dense connective tissue contains more collagen fibers than does loose connective tissue. As a consequence, it displays greater resistance to stretching. There are two major categories of dense connective tissue: regular and irregular. Dense regular connective tissue fibers are parallel to each other, enhancing tensile strength and resistance to stretching in the direction of the fiber orientations. Ligaments and tendons are made of dense regular connective tissue, but in ligaments not all fibers are parallel. Dense regular elastic tissue contains elastin fibers in addition to collagen fibers, which allows the ligament to return to its original length after stretching. The ligaments in the vocal folds and between the vertebrae in the vertebral column are elastic.

In dense irregular connective tissue, the direction of fibers is random. This arrangement gives the tissue greater strength in all directions and less strength in one particular direction. In some tissues, fibers crisscross and form a mesh. In other tissues, stretching in several directions is achieved by alternating layers where fibers run in the same orientation in each layer, and it is the layers themselves that are stacked at an angle. The dermis of the skin is an example of dense irregular connective tissue rich in collagen fibers. Dense irregular elastic tissues give arterial walls the strength and the ability to regain original shape after stretching (Figure 4).

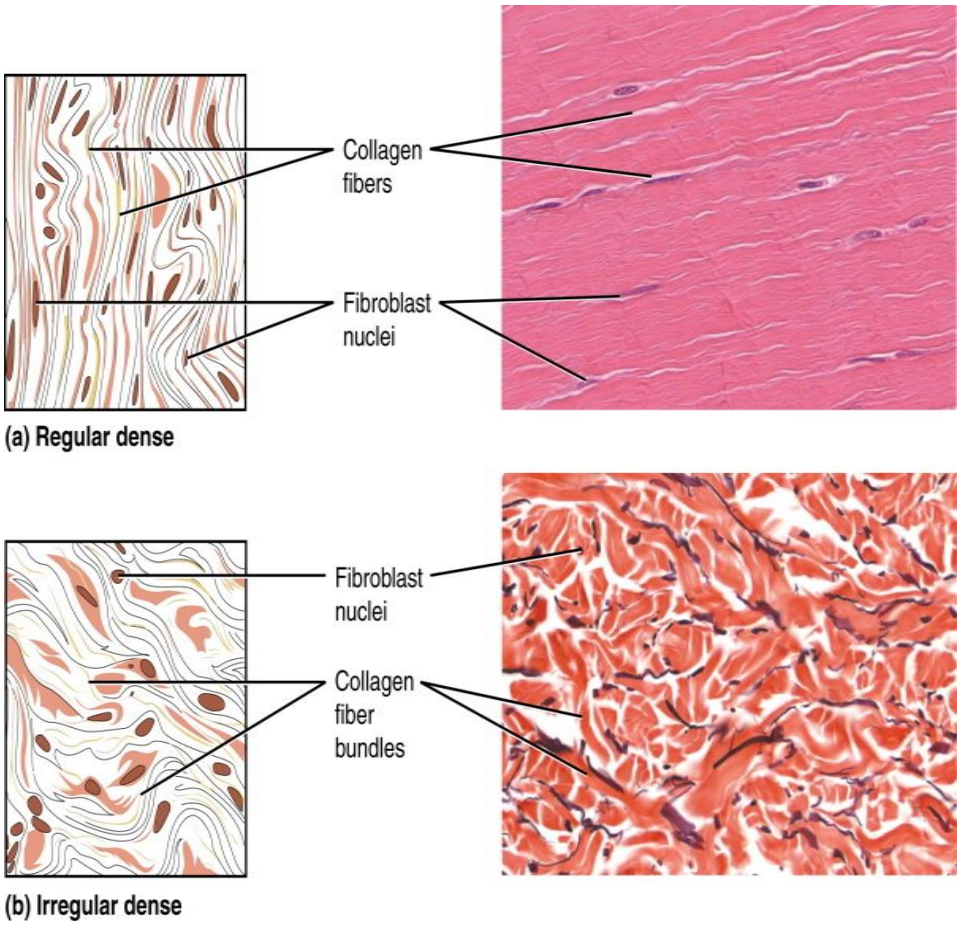


Figure 4. Dense Connective Tissue. (a) Dense regular connective tissue consists of collagenous fibers packed into parallel bundles. (b) Dense irregular connective tissue consists of collagenous fibers interwoven into a mesh-like network. From top, LM × 1000, LM × 200. (Micrographs provided by the Regents of University of Michigan Medical School © 2012)

SUPPORTIVE CONNECTIVE TISSUES

Two major forms of supportive connective tissue, cartilage and bone, allow the body to maintain its posture and protect internal organs.

CARTILAGE

The distinctive appearance of cartilage is due to polysaccharides called chondroitin sulfates, which bind with ground substance proteins to form proteoglycans. Embedded within the cartilage matrix are **chondrocytes**, or cartilage cells, and the space they occupy are called **lacunae** (singular = lacuna). A layer of dense irregular connective tissue, the perichondrium, encapsulates the cartilage. Cartilaginous tissue is avascular, thus all nutrients need to diffuse through the matrix to reach the chondrocytes. This is a factor contributing to the very slow healing of cartilaginous tissues.

The three main types of cartilage tissue are hyaline cartilage, fibrocartilage, and elastic cartilage (Figure 5). **Hyaline cartilage**, the most common type of cartilage in the body, consists of short and dispersed collagen fibers and contains large amounts of proteoglycans. Under the microscope, tissue samples appear clear. The surface of hyaline cartilage is smooth. Both strong and flexible, it is found in the rib cage and nose and covers bones where they meet to form moveable joints. It makes up a template of the embryonic skeleton before bone formation. A plate of hyaline cartilage at the ends of bone allows continued growth until adulthood. **Fibrocartilage** is tough because it has thick bundles of collagen fibers dispersed through its matrix. The knee and jaw joints and the the intervertebral discs are examples of fibrocartilage. **Elastic cartilage** contains elastic fibers as well as collagen and proteoglycans. This tissue gives rigid support as well as elasticity. Tug gently at your ear lobes, and notice that the lobes return to their initial shape. The external ear contains elastic cartilage.

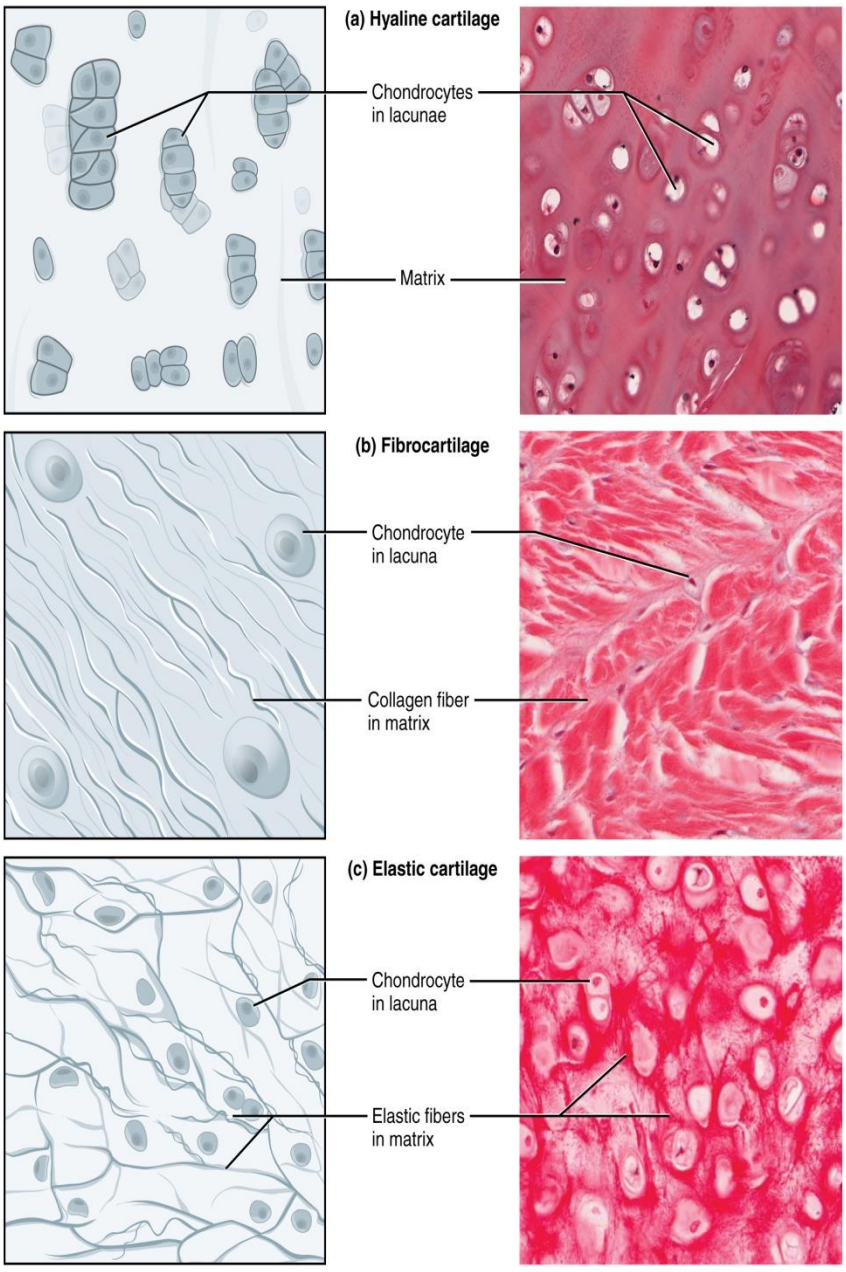


Figure 5. Types of Cartilage. Cartilage is a connective tissue consisting of collagenous fibers embedded in a firm matrix of chondroitin sulfates. (a) Hyaline cartilage provides support with some flexibility. The example is from dog tissue. (b) Fibrocartilage provides some compressibility and can absorb pressure. (c) Elastic cartilage provides firm but elastic support. From top, LM × 300, LM × 1200, LM × 1016.

BONE

Bone is the hardest connective tissue. It provides protection to internal organs and supports the body. Bone's rigid extracellular matrix contains mostly collagen fibers embedded in a mineralized ground substance containing hydroxyapatite, a form of calcium phosphate. Both components of the matrix, organic and inorganic, contribute to the unusual properties of bone. Without collagen, bones would be brittle and shatter easily. Without mineral crystals, bones would flex and provide little support. Osteocytes, bone cells like chondrocytes, are located within lacunae. The histology of transverse tissue from long bone shows a typical arrangement of osteocytes in concentric circles around a central canal. Bone is a highly vascularized tissue. Unlike cartilage, bone tissue can recover from injuries in a relatively short time.

Cancellous bone looks like a sponge under the microscope and contains empty spaces between trabeculae, or arches of bone proper. It is lighter than compact bone and found in the interior of some bones and at the end of long bones. Compact bone is solid and has greater structural strength.

FLUID CONNECTIVE TISSUE

Blood and lymph are fluid connective tissues. Cells circulate in a liquid extracellular matrix. The formed elements circulating in blood are all derived from hematopoietic stem cells located in bone marrow (Figure 6). Erythrocytes, red blood cells, transport oxygen and some carbon dioxide. Leukocytes, white blood cells, are responsible for defending against potentially harmful microorganisms or molecules. Platelets are cell fragments involved in blood clotting. Some white blood cells have the ability to cross the endothelial layer that lines blood vessels and enter adjacent tissues. Nutrients, salts, and wastes are dissolved in the liquid matrix and transported through the body.

Lymph contains a liquid matrix and white blood cells. Lymphatic capillaries are extremely permeable, allowing larger molecules and excess fluid from interstitial spaces to enter the

lymphatic vessels. Lymph drains into blood vessels, delivering molecules to the blood that could not otherwise directly enter the bloodstream. In this way, specialized lymphatic capillaries transport absorbed fats away from the intestine and deliver these molecules to the blood.

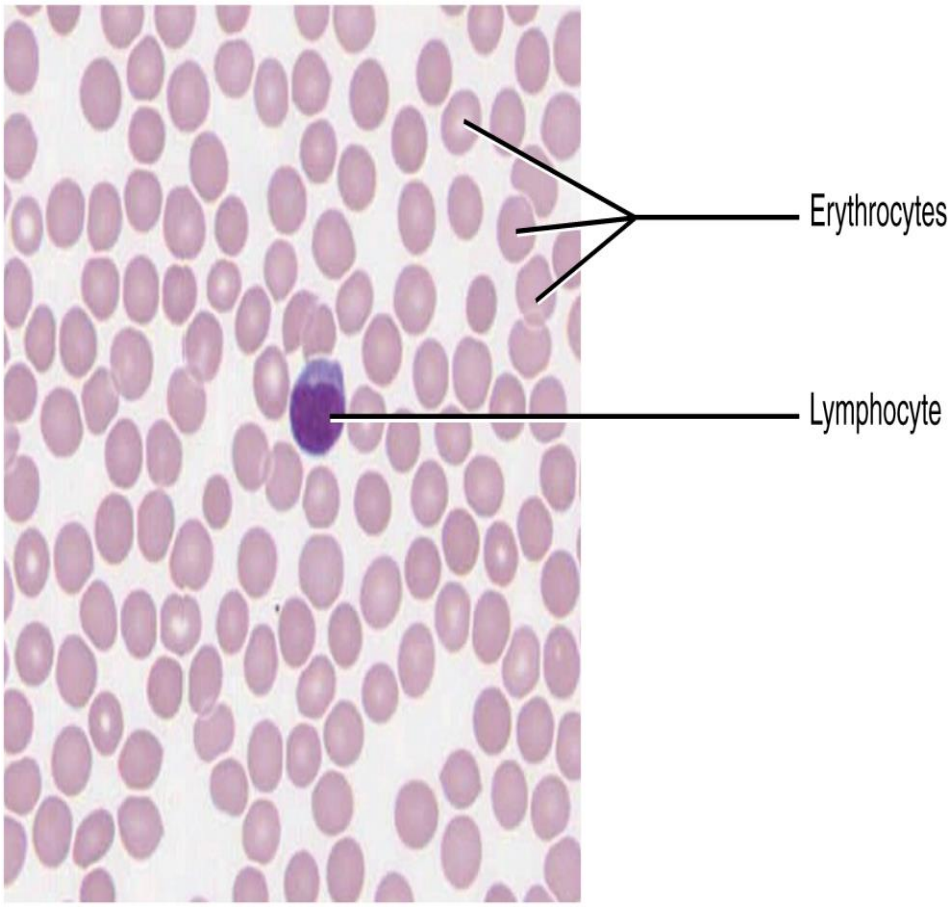


Figure 6. Blood: A Fluid Connective Tissue. Blood is a fluid connective tissue containing erythrocytes and various types of leukocytes that circulate in a liquid extracellular matrix. LM × 1600. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

Muscular tissue is a specialized tissue in animals which applies forces to different parts of the body by contraction. It is made up of thin and elongated cells called muscle fibers. It controls the movement of an organism.

The cytoplasm in the muscle fibers is called sarcoplasm. It contains a network of membrane called the sarcoplasmic reticulum. The membrane surrounding the muscle fibers is called sarcolemma.

Properties of Muscular Tissue

1. **Contractibility**– It is the ability of muscle cells to shorten forcefully.
2. **Extensibility**– A muscle has the ability to be stretched.
3. **Elasticity**– The muscles have the ability to recoil back to its original length after being stretched.
4. **Excitability**– The muscle tissue responds to a stimulus delivered from a motor neuron or hormone.

Structure of Muscular Tissue

The muscular tissues are bundled together and surrounded by a tough connective tissue similar to cartilage known as epimysium.

The bundle of nerve cells that run in long fibers called fascicles are surrounded by the epimysium.

The fascicles are surrounded by a protective layer known as perimysium. It allows the flow of nerves and blood to the individual fibers.

Another protective layer, the endomysium surrounds the fibers.

These layers and muscles help in the contraction of different parts of the muscles. The different bundles slide past one another as they contract.

The epimysium connects to the tendons attached to the periosteum connective tissue that surrounds the bones. This helps in the movement of the skeleton when the muscles contract.

The epimysium connects to other connective tissues to produce force on the organs and control everything from circulation to food processing.

Types of Muscular Tissue

The muscular tissue is of three types:

- Skeletal Muscle Tissue
- Smooth Muscle Tissue
- Cardiac Muscle Tissue

Skeletal Muscle Tissue

- These muscles are attached to the skeleton and help in its movement.
- These muscles are also known as striated muscles because of the presence of alternate patterns of light and dark bands.
- These light and dark bands are sarcomeres which are highly organized structures of actin, myosin, and proteins. These add to the contractibility and extensibility of the muscles.
- Skeletal muscles are voluntary muscles composed of muscle fibers.
- 40% of our body mass comprises of skeletal muscles.
- Each skeletal tissue contains myofibrils.
- The cells of these tissues are multinucleated.

- These are provided with blood vessels and many elongated mitochondria and glycogen granules.
- They bring about the movement of the organs of the body.

Smooth Muscle Tissue

- These are non-striated, involuntary muscles controlled by the Autonomous Nervous System.
- It stimulates the contractility of the digestive, urinary, reproductive systems, blood vessels, and airways.
- The actin and myosin filaments are very thin and arranged randomly, hence no striations.
- The cells are spindle-shaped with a single nucleus.

Cardiac Muscle Tissue

- These are found only in the heart.
- These are involuntary muscles and the heart pumps the blood through cardiac contractions.
- The cells of the cardiac muscles known as the cardiomyocytes are striated.
- They are single-celled and uninucleated.
- The ends of the cells are joined and the junctions are called intercalated discs. The cells are attached to each other by desmosomes.

Muscular Tissue Function

The muscular tissues are connected to the same nerve bundles.

The nerve impulse from the brain tells the muscles to contract.

Each muscle cell contains the proteins actin and myosin. These proteins slide past one another when the signal is received for contraction.

A single cell contracts up to 70% in length. The entire muscle shortens during contraction.

Muscular tissues help in the movement of bones, squeeze different organs, or compress chambers.

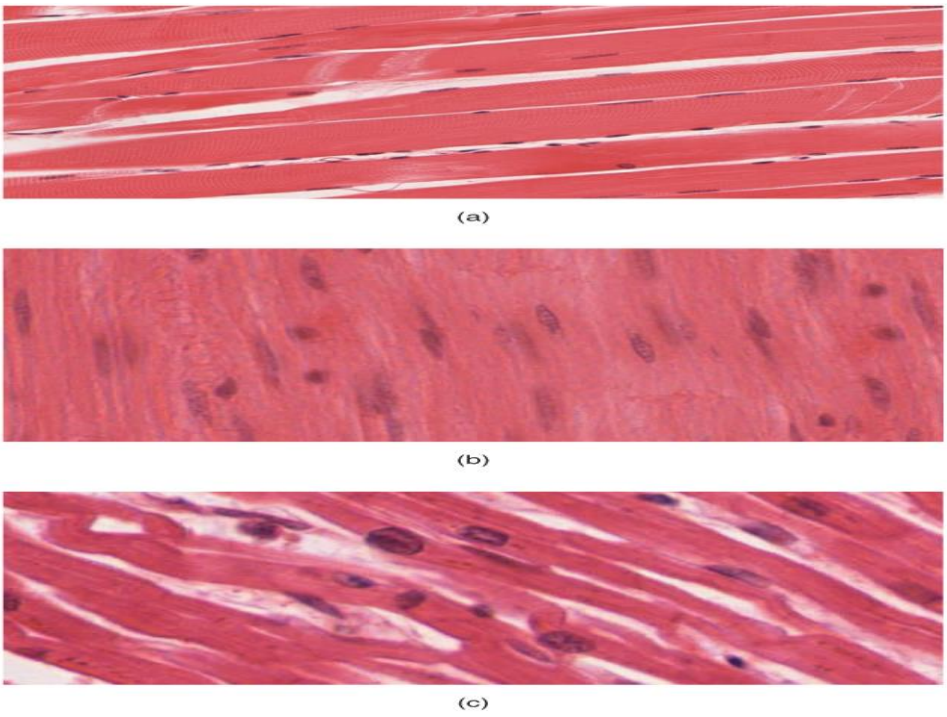


Figure 1. Muscle Tissue. (a) Skeletal muscle cells have prominent striation and nuclei on their periphery. (b) Smooth muscle cells have a single nucleus and no visible striations. (c) Cardiac muscle cells appear striated and have a single nucleus

Nervous tissue

Nervous or the nerve tissue is the main tissue of our nervous system. It monitors and regulates the functions of the body. Nervous tissue consists of two cells: nerve cells or neurons and glial cells, which helps transmit nerve impulses and also provides nutrients to neurons. Brain, Spinal

Cord, and nerves are composed of nervous tissue, they are specialized for being stimulated to transmit stimulus from one to another part of the body rapidly.

Structure of Nervous Tissue

- It is made of nerve cells or neurons, all of which consists of an axon. Axons are long stem-like projections emerging out of the cell, responsible for communicating with other cells called the Target cells, thereby passing impulses
- The main part is the cell body which contains the nucleus, cytoplasm and cell organelles. Extensions of the cell membrane are referred to as processes.
- Dendrite is a highly branched processes, responsible for receiving information from other neurons and synapses (specialized point of contact). Information of other neurons is provided by dendrites to connect with its cell body.
- Information in a neuron is unidirectional as it passes through neurons from dendrites, across the cell body down the axon.

Nervous Tissue Location

The nerve tissue or the nervous tissue is the chief tissue component of the two major parts of the nervous tissue – Central nervous system(CNS) formed by the spinal cord and the brain and the branching peripheral nerves of the peripheral nervous system (PNS) that control and regulate the functions of the body and their activities.

The nervous tissue is located in the peripheral nerves all through the body and also in the organs of the central nervous system such as the spinal cord and the brain. The nervous tissue consists of the nerve cells or the neurons. Neurons are specialized cells that react to stimuli by generating signals through the axons, which are elongated structures arising from the cell body.

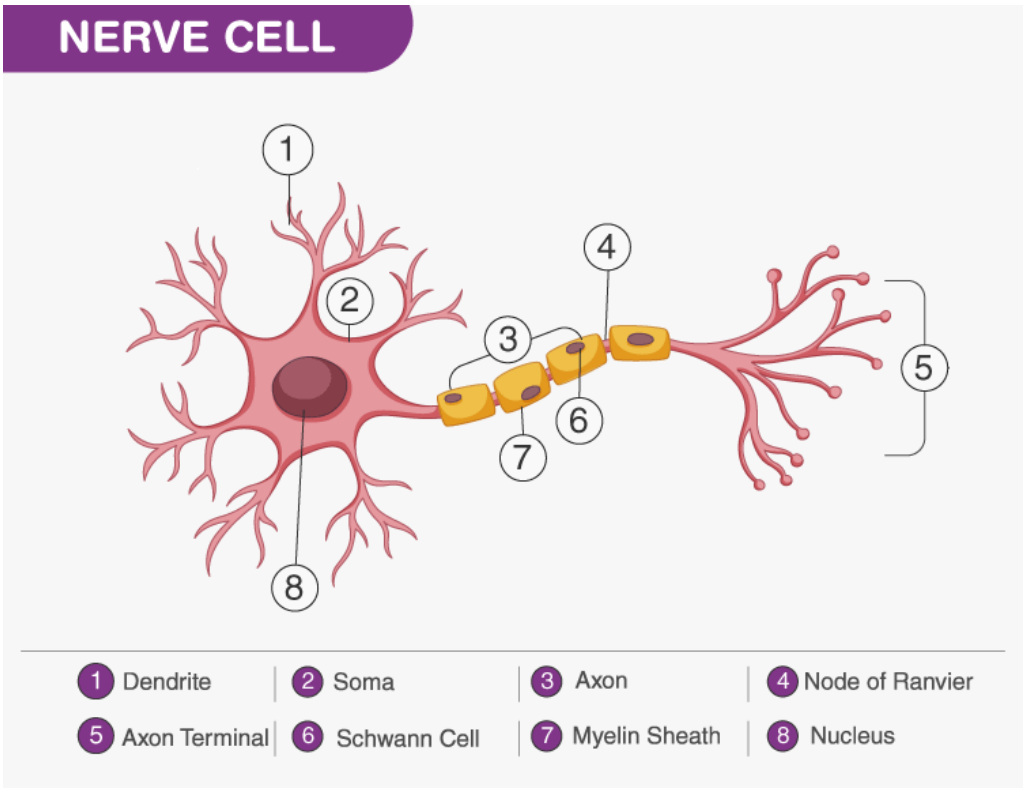


Figure 2: Nerve cell

Characteristics of Nervous Tissue

- Nervous tissue makes up for the CNS and PNS of the nervous system
- Contains two distinct cells – neurons and glial cells
- It consists of the dendrites, cell body, axon and nerve endings.
- Neurons secrete chemical neurotransmitters which are responsible for stimulating other neurons as a result of a stimuli
- Presence of specialization at axonal terminals called synapsis
- Nerve cells live long, cannot be divided and replaced(except memory cells)

Functions of Nervous Tissue

- Neurons generate and carry out nerve impulses. They produce electrical signals that are transmitted across distances, they do so by secreting chemical neurotransmitters.
- Responds to stimuli
- Carries out communication and integration
- Provides electrical insulations to nerve cells and removes debris
- Carries messages from other neurons to the cell body

Types of Nerves

The signals that are generated and initiated in the CNS(central nervous system) which typically arise from the brain and in some cases, the spinal cord, approach the outer edge to sites, for instance, the internal organs or limbs which conduct the specified organ of interest to take appropriate action. Responding to the nerve impulses, suitable actions take place such as contraction of a bicep muscle, retracting your hands from a hot cup of tea, the hair on your arms may raise due to extremely cold conditions, responding to light striking the retina, when one of the sense organs receive an input that may cause danger, etc.

The functioning of the nerves is brought about by channelling electrochemical signals or impulses that are obtained from the other nerves or brain or tissues or organs at which the nerves end. On the basis of functionality, nerves can be classified into the following:

Motor nerves

Motor neurons or motor nerves are responsible to send signals or impulses all the way from spinal cord and brain to all the muscles of the body. The impulse enables humans to carry out basic activities such as talking, walking, drinking water, blinking eyes, sitting, sleeping, etc. Damage to the motor neurons can cause muscle weakness or shrinking of the muscles. The nerve that passes from the lower back to the buttocks is known as the sciatic nerve. The sciatic nerve enables the complete leg to move which is a collection of various nerves. A few of these motor nerves function in the hamstring, feet, thighs, and feet.

Sensory nerves

The sensory nerves or sensory neurons are responsible to generate impulses or signals in the contrasting directions from another type of nerves known as the motor neurons. The sense neurons gather information such as pressure, pain, temperature, etc from the sensors that are present in the muscles, skin and other internal organs which in turn redirect it back to the brain and spinal cord. These sensory nerves have the potential of communicating information relating to motion (except for the eyes, as they themselves do it). Damage to the sensory nerves can cause numbness, pain, tingling sensation and hypersensitivity.

Autonomic nerves

The autonomic nerves system controls the actions of the muscles of the heart, such smooth muscles located in the stomach and in the interlining of glands and other organs. The autonomic nerves regulate the functions that are not under control, i.e., involuntary. There are two functional divisions in the autonomic nervous system, namely:

1. The sympathetic nervous system – Responsible for the heart rate to speed up and related flight or fight responses
2. The parasympathetic nervous system – Controls activities such as excretion, digestion, and related metabolic actions.

Cranial nerves

There are 12 pairs of cranial nerves that emerge from the lower side of the brain. Listed below are the cranial nerves mentioned from front to back:

- Olfactory
- Optic
- Oculomotor
- Trochlear
- Trigeminal

- Abducens
- Facial
- Vestibulocochlear
- Glossopharyngeal
- Vagus
- Spinal accessory
- Hypoglossal nerves

The cranial nerves are crucial in smell, vision, movement of the face and eyes, movements of the tongue and salivation.

Subject: Human Anatomy and Physiology-I **Unit No: II**

Topic: Integumentary system- Anatomy of Skin

Integumentary system- Anatomy of Skin

The skin and its accessory structures make up the **integumentary system,** which provides the body with overall protection. The skin is made of multiple layers of cells and tissues, which are held to underlying structures by connective tissue (Figure 1). The deeper layer of skin is well vascularized (has numerous blood vessels). It also has numerous sensory, and autonomic and sympathetic nerve fibers ensuring communication to and from the brain.

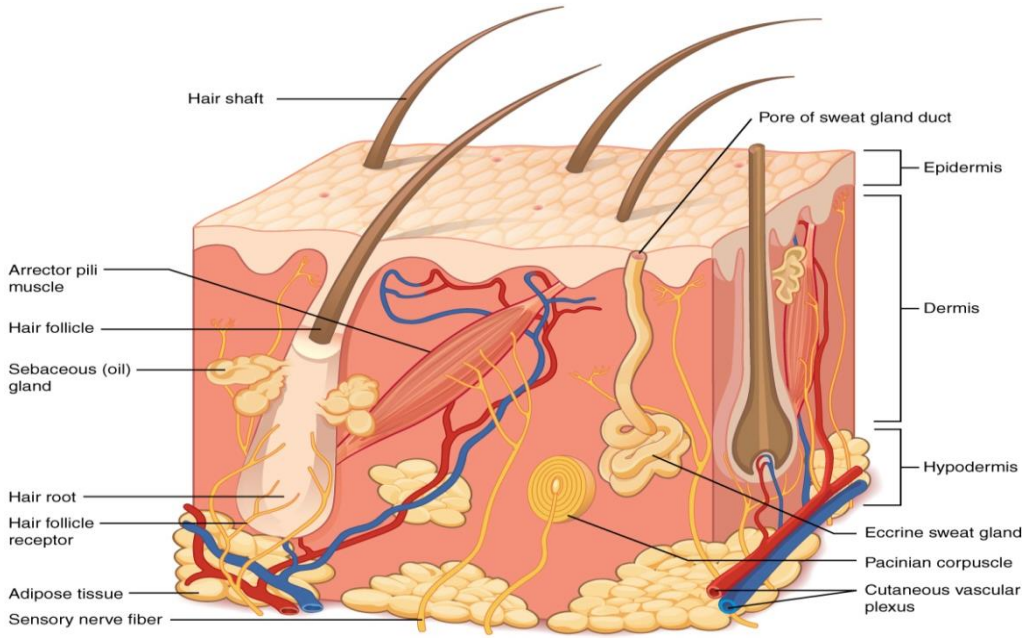


Figure 1. Layers of Skin. The skin is composed of two main layers: the epidermis, ade of closely packed epithelial cells, and the dermis, made of dense, irregular connective tissue that houses blood vessels, hair follicles, sweat glands, and other structures. Beneath the dermis lies the hypodermis, which is composed mainly of loose connective and fatty tissues.

THE EPIDERMIS

The **epidermis** is composed of keratinized, stratified squamous epithelium. It is made of four or five layers of epithelial cells, depending on its location in the body. It does not have any blood vessels within it (i.e., it is avascular). Skin that has four layers of cells is referred to as "thin skin." From deep to superficial, these layers are the stratum basale, stratum spinosum, stratum granulosum, and stratum corneum. Most of the skin can be classified as thin skin. "Thick skin" is found only on the palms of the hands and the soles of the feet. It has a fifth layer, called the stratum lucidum, located between the stratum corneum and the stratum granulosum (Figure 2).

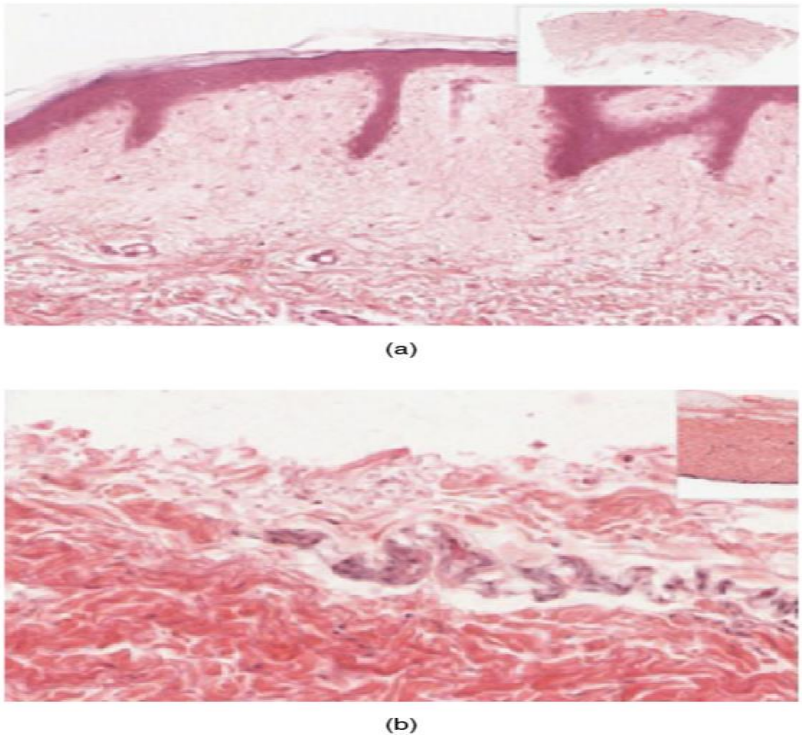


Figure 2. Thin Skin versus Thick Skin. These slides show cross-sections of the epidermis and dermis of (a) thin and (b) thick skin. Note the significant difference in the thickness of the epithelial layer of the thick skin.

The cells in all of the layers except the stratum basale are called keratinocytes.
A **keratinocyte** is a cell that manufactures and stores the protein keratin. **Keratin** is an intracellular fibrous protein that gives hair, nails, and skin their hardness and water-resistant properties. The keratinocytes in the stratum corneum are dead and regularly slough away, being replaced by cells from the deeper layers (Figure 3).

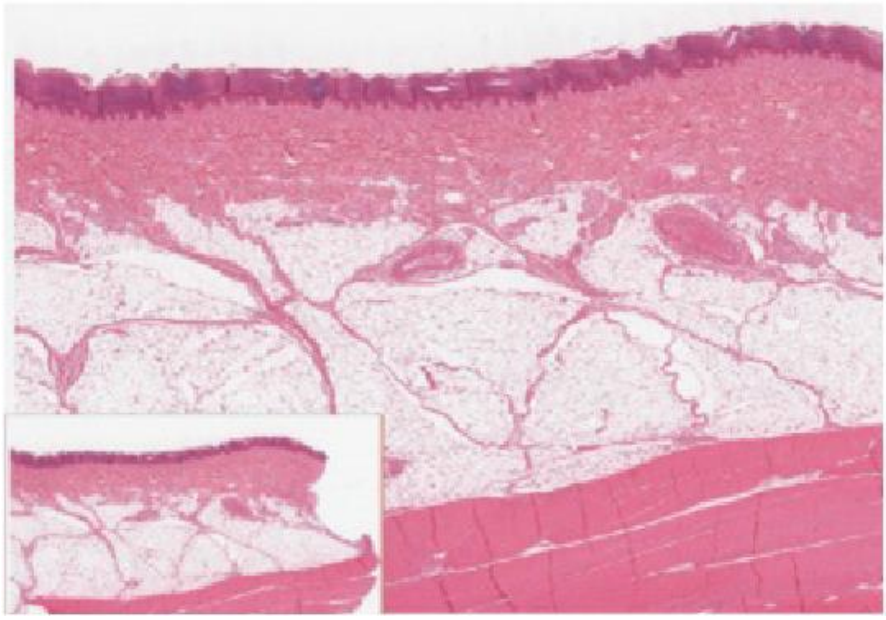


Figure 3. Epidermis. The epidermis is epithelium composed of multiple layers of cells. The basal layer consists of cuboidal cells, whereas the outer layers are squamous, keratinized cells, so the whole epithelium is often described as being keratinized stratified squamous epithelium.

STRATUM BASALE

The **stratum basale** (also called the stratum germinativum) is the deepest epidermal layer and attaches the epidermis to the basal lamina, below which lie the layers of the dermis. The cells in the stratum basale bond to the dermis via intertwining collagen fibers, referred to as the basement membrane. A finger-like projection, or fold, known as the **dermal papilla** (plural = dermal papillae) is found in the superficial portion of the dermis. Dermal papillae increase the strength of the connection between the epidermis and dermis; the greater the folding, the stronger the connections made.

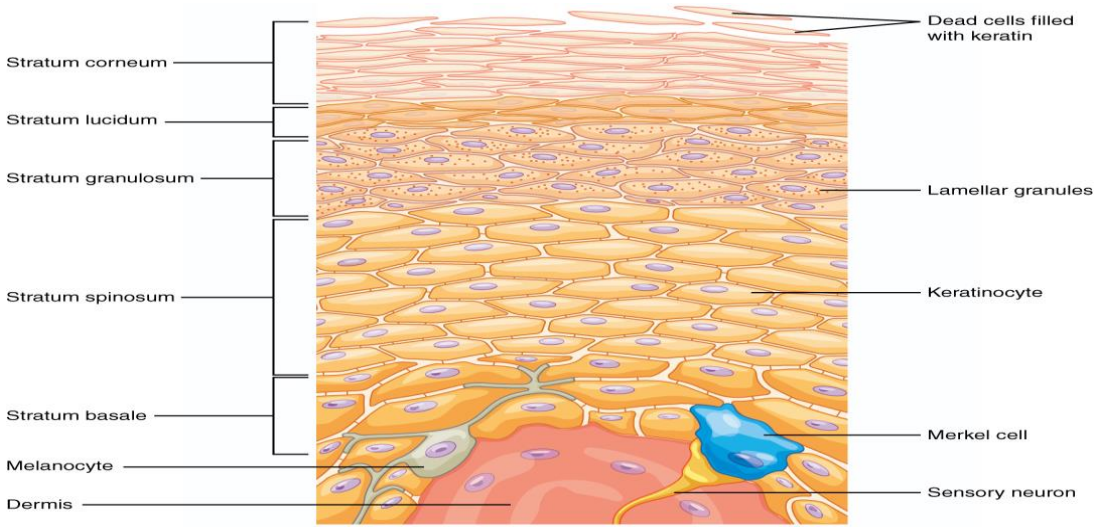


Figure 4. Layers of the Epidermis. The epidermis of thick skin has five layers: stratum basale, stratum spinosum, stratum granulosum, stratum lucidum, and stratum corneum.

The stratum basale is a single layer of cells primarily made of basal cells. A **basal cell** is a cuboidal-shaped stem cell that is a precursor of the keratinocytes of the epidermis. All of the keratinocytes are produced from this single layer of cells, which are constantly going through mitosis to produce new cells. As new cells are formed, the existing cells are pushed superficially away from the stratum basale. Two other cell types are found dispersed among the basal cells in the stratum basale. The first is a **Merkel cell**, which functions as a receptor and is responsible for stimulating sensory nerves that the brain perceives as touch. These cells are especially abundant on the surfaces of the hands and feet. The second is a **melanocyte**, a cell that produces the pigment melanin. **Melanin** gives hair and skin its color, and also helps protect the living cells of the epidermis from ultraviolet (UV) radiation damage.

In a growing fetus, fingerprints form where the cells of the stratum basale meet the papillae of the underlying dermal layer (papillary layer), resulting in the formation of the ridges on your fingers that you recognize as fingerprints. Fingerprints are unique to each individual and are used for forensic analyses because the patterns do not change with the growth and aging processes.

STRATUM SPINOSUM

As the name suggests, the **stratum spinosum** is spiny in appearance due to the protruding cell processes that join the cells via a structure called a **desmosome**. The desmosomes interlock with each other and strengthen the bond between the cells. It is interesting to note that the "spiny" nature of this layer is an artifact of the staining process. Unstained epidermis samples do not exhibit this characteristic appearance. The stratum spinosum is composed of eight to 10 layers of keratinocytes, formed as a result of cell division in the stratum basale. Interspersed among the keratinocytes of this layer is a type of dendritic cell called the **Langerhans cell**, which functions as a macrophage by engulfing bacteria, foreign particles, and damaged cells that occur in this layer.

The keratinocytes in the stratum spinosum begin the synthesis of keratin and release a water-repelling glycolipid that helps prevent water loss from the body, making the skin relatively waterproof. As new keratinocytes are produced atop the stratum basale, the keratinocytes of the stratum spinosum are pushed into the stratum granulosum.

STRATUM GRANULOSUM

The **stratum granulosum** has a grainy appearance due to further changes to the keratinocytes as they are pushed from the stratum spinosum. The cells (three to five layers deep) become flatter, their cell membranes thicken, and they generate large amounts of the proteins keratin, which is fibrous, and **keratohyalin**, which accumulates as lamellar granules within the cells. These two proteins make up the bulk of the keratinocyte mass in the stratum granulosum and give the layer its grainy appearance. The nuclei and other cell organelles disintegrate as the cells die, leaving behind the keratin, keratohyalin, and cell membranes that will form the stratum lucidum, the stratum corneum, and the accessory structures of hair and nails.

STRATUM LUCIDUM

The **stratum lucidum** is a smooth, seemingly translucent layer of the epidermis located just above the stratum granulosum and below the stratum corneum. This thin layer of cells is found only in the thick skin of the palms, soles, and digits. The keratinocytes that compose the stratum lucidum are dead and flattened (see Figure 4). These cells are densely packed with **eleiden**, a clear protein rich in lipids, derived from keratohyalin, which gives these cells their transparent (i.e., lucid) appearance and provides a barrier to water.

STRATUM CORNEUM

The **stratum corneum** is the most superficial layer of the epidermis and is the layer exposed to the outside environment (see Figure 4). The increased keratinization (also called cornification) of the cells in this layer gives it its name. There are usually 15 to 30 layers of cells in the stratum corneum. This dry, dead layer helps prevent the penetration of microbes and the dehydration of underlying tissues, and provides a mechanical protection against abrasion for the more delicate, underlying layers. Cells in this layer are shed periodically and are replaced by cells pushed up from the stratum granulosum (or stratum lucidum in the case of the palms and soles of feet). The entire layer is replaced during a period of about 4 weeks. Cosmetic procedures, such as microdermabrasion, help remove some of the dry, upper layer and aim to keep the skin looking “fresh” and healthy.

Structure and functions of Skin

DERMIS

The **dermis** might be considered the “core” of the integumentary system (derma- = “skin”), as distinct from the epidermis (epi- = “upon” or “over”) and hypodermis (hypo- = “below”). It contains blood and lymph vessels, nerves, and other structures, such as hair follicles and sweat glands. The dermis is made of two layers of connective tissue that compose an interconnected mesh of elastin and collagenous fibers, produced by fibroblasts (Figure 1).

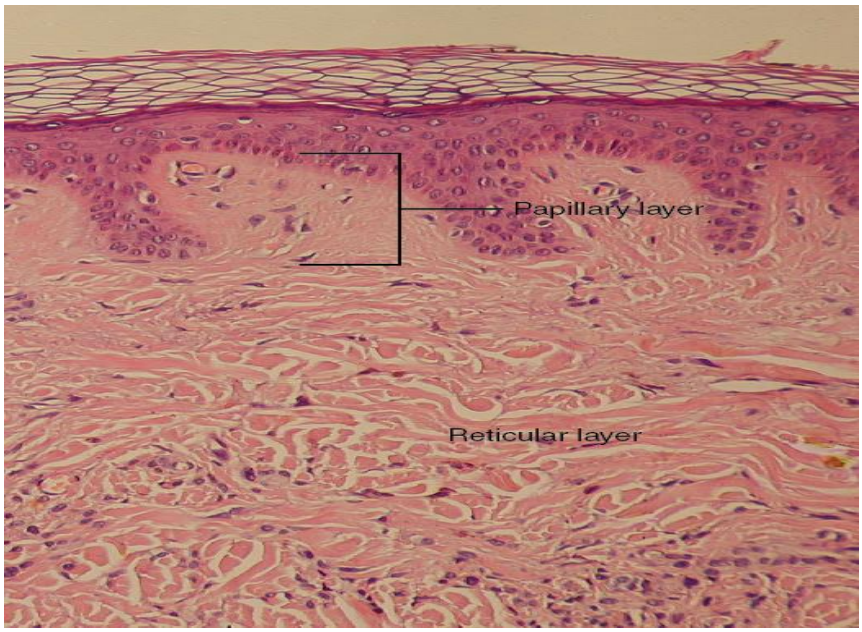


Figure 1. Layers of the Dermis. This stained slide shows the two components of the dermis—the papillary layer and the reticular layer. Both are made of connective tissue with fibers of collagen extending from one to the other, making the border between the two somewhat indistinct.

PAPILLARY LAYER

The **papillary layer** is made of loose, areolar connective tissue, which means the collagen and elastin fibers of this layer form a loose mesh. This superficial layer of the dermis projects into the stratum basale of the epidermis to form finger-like dermal papillae (see Figure 2). Within the papillary layer are fibroblasts, a small number of fat cells (adipocytes), and an abundance of small blood vessels. In addition, the papillary layer contains phagocytes, defensive cells that help fight bacteria or other infections that have breached the skin. This layer also contains lymphatic capillaries, nerve fibers, and touch receptors called the Meissner corpuscles.

RETICULAR LAYER

Underlying the papillary layer is the much thicker **reticular layer**, composed of dense, irregular connective tissue. This layer is well vascularized and has a rich sensory and sympathetic nerve supply. The reticular layer appears reticulated (net-like) due to a tight meshwork of fibers. **Elastin fibers** provide some elasticity to the skin, enabling movement. Collagen fibers provide structure and tensile strength, with strands of collagen extending into both the papillary layer and the hypodermis. In addition, collagen binds water to keep the skin hydrated. Collagen injections and Retin-A creams help restore skin turgor by either introducing collagen externally or stimulating blood flow and repair of the dermis, respectively.

HYPODERMIS

The **hypodermis** (also called the subcutaneous layer or superficial fascia) is a layer directly below the dermis and serves to connect the skin to the underlying fascia (fibrous tissue) of the bones and muscles. It is not strictly a part of the skin, although the border between the hypodermis and dermis can be difficult to distinguish. The hypodermis consists of well-vascularized, loose, areolar connective tissue and adipose tissue, which functions as a mode of fat storage and provides insulation and cushioning for the integument.

Lipid Storage

The hypodermis is home to most of the fat that concerns people when they are trying to keep their weight under control. Adipose tissue present in the hypodermis consists of fat-storing cells called adipocytes. This stored fat can serve as an energy reserve, insulate the body to prevent heat loss, and act as a cushion to protect underlying structures from trauma.

Where the fat is deposited and accumulates within the hypodermis depends on hormones (testosterone, estrogen, insulin, glucagon, leptin, and others), as well as genetic factors. Fat distribution changes as our bodies mature and age. Men tend to accumulate fat in different areas (neck, arms, lower back, and abdomen) than do women (breasts, hips, thighs, and buttocks). The body mass index (BMI) is often used as a measure of fat, although this

measure is, in fact, derived from a mathematical formula that compares body weight (mass) to height. Therefore, its accuracy as a health indicator can be called into question in individuals who are extremely physically fit.

In many animals, there is a pattern of storing excess calories as fat to be used in times when food is not readily available. In much of the developed world, insufficient exercise coupled with the ready availability and consumption of high-calorie foods have resulted in unwanted accumulations of adipose tissue in many people. Although periodic accumulation of excess fat may have provided an evolutionary advantage to our ancestors, who experienced unpredictable bouts of famine, it is now becoming chronic and considered a major health threat. Recent studies indicate that a distressing percentage of our population is overweight and/or clinically obese. Not only is this a problem for the individuals affected, but it also has a severe impact on our healthcare system. Changes in lifestyle, specifically in diet and exercise, are the best ways to control body fat accumulation, especially when it reaches levels that increase the risk of heart disease and diabetes.

PIGMENTATION

The color of skin is influenced by a number of pigments, including melanin, carotene, and hemoglobin. Recall that melanin is produced by cells called melanocytes, which are found scattered throughout the stratum basale of the epidermis. The melanin is transferred into the keratinocytes via a cellular vesicle called a **melanosome**.

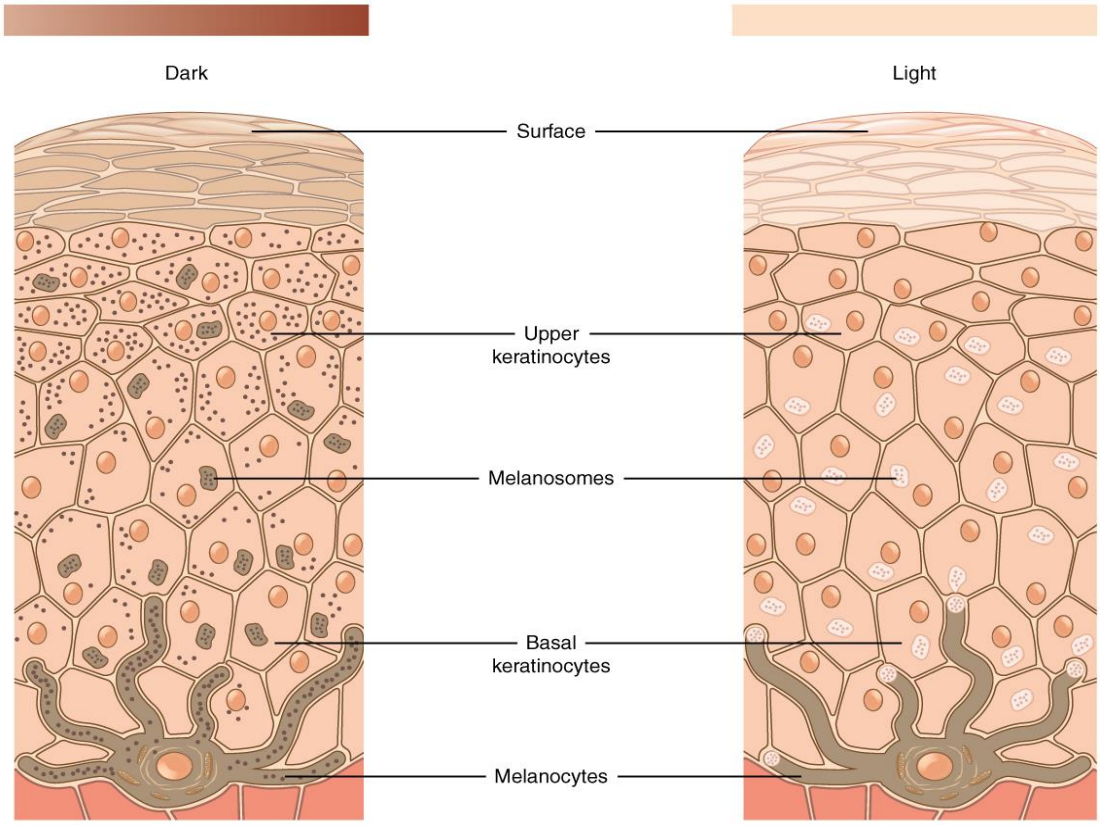


Figure 2. Skin Pigmentation. The relative coloration of the skin depends of the amount of melanin produced by melanocytes in the stratum basale and taken up by keratinocytes.

Melanin occurs in two primary forms. Eumelanin exists as black and brown, whereas pheomelanin provides a red color. Dark-skinned individuals produce more melanin than those with pale skin. Exposure to the UV rays of the sun or a tanning salon causes melanin to be manufactured and built up in keratinocytes, as sun exposure stimulates keratinocytes to secrete chemicals that stimulate melanocytes. The accumulation of melanin in keratinocytes results in the darkening of the skin, or a tan. This increased melanin accumulation protects the DNA of epidermal cells from UV ray damage and the breakdown of folic acid, a nutrient necessary for our health and well-being. In contrast, too much melanin can interfere with the production of vitamin D, an important nutrient involved in calcium absorption. Thus, the amount of melanin present in our skin is dependent on a balance between available sunlight and folic acid destruction, and protection from UV radiation and vitamin D production.

It requires about 10 days after initial sun exposure for melanin synthesis to peak, which is why pale-skinned individuals tend to suffer sunburns of the epidermis initially. Dark-skinned individuals can also get sunburns, but are more protected than are pale-skinned individuals. Melanosomes are temporary structures that are eventually destroyed by fusion with lysosomes; this fact, along with melanin-filled keratinocytes in the stratum corneum sloughing off, makes tanning impermanent.

Too much sun exposure can eventually lead to wrinkling due to the destruction of the cellular structure of the skin, and in severe cases, can cause sufficient DNA damage to result in skin cancer. When there is an irregular accumulation of melanocytes in the skin, freckles appear. Moles are larger masses of melanocytes, and although most are benign, they should be monitored for changes that might indicate the presence of cancer (Figure 3).

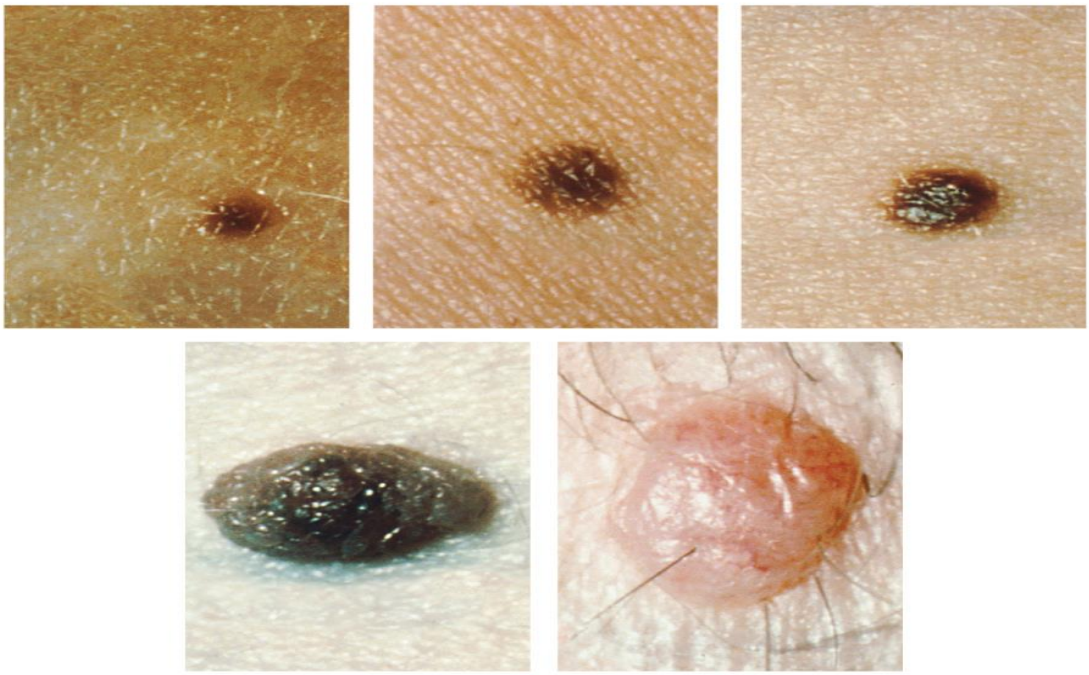


Figure 3. Moles: Moles range from benign accumulations of melanocytes to melanomas.

Divisions of Skeletal system and Types of Bones

The skeletal system includes all of the bones, cartilages, and ligaments of the body that support and give shape to the body and body structures. The **skeleton** consists of the bones of the body. For adults, there are 206 bones in the skeleton. Younger individuals have higher numbers of bones because some bones fuse together during childhood and adolescence to form an adult bone. The primary functions of the skeleton are to provide a rigid, internal structure that can support the weight of the body against the force of gravity, and to provide a structure upon which muscles can act to produce movements of the body. The lower portion of the skeleton is specialized for stability during walking or running. In contrast, the upper skeleton has greater mobility and ranges of motion, features that allow you to lift and carry objects or turn your head and trunk.

In addition to providing for support and movements of the body, the skeleton has protective and storage functions. It protects the internal organs, including the brain, spinal cord, heart, lungs, and pelvic organs. The bones of the skeleton serve as the primary storage site for important minerals such as calcium and phosphate. The bone marrow found within bones stores fat and houses the blood-cell producing tissue of the body.The skeleton is subdivided into two major divisions—the axial and appendicular.

THE AXIAL SKELETON

The skeleton is subdivided into two major divisions—the axial and appendicular. The **axial skeleton** forms the vertical, central axis of the body and includes all bones of the head, neck, chest, and back. It serves to protect the brain, spinal cord, heart, and lungs. It also serves as the attachment site for muscles that move the head, neck, and back, and for muscles that act across the shoulder and hip joints to move their corresponding limbs.

The axial skeleton of the adult consists of 80 bones, including the **skull**, the **vertebral column**, and the **thoracic cage**. The skull is formed by 22 bones. Also associated with the head

are an additional seven bones, including the **hyoid bone** and the **ear ossicles** (three small bones found in each middle ear). The vertebral column consists of 24 bones, each called a **vertebra**, plus the **sacrum** and **coccyx**. The thoracic cage includes the 12 pairs of **ribs**, and the **sternum**, the flattened bone of the anterior chest.

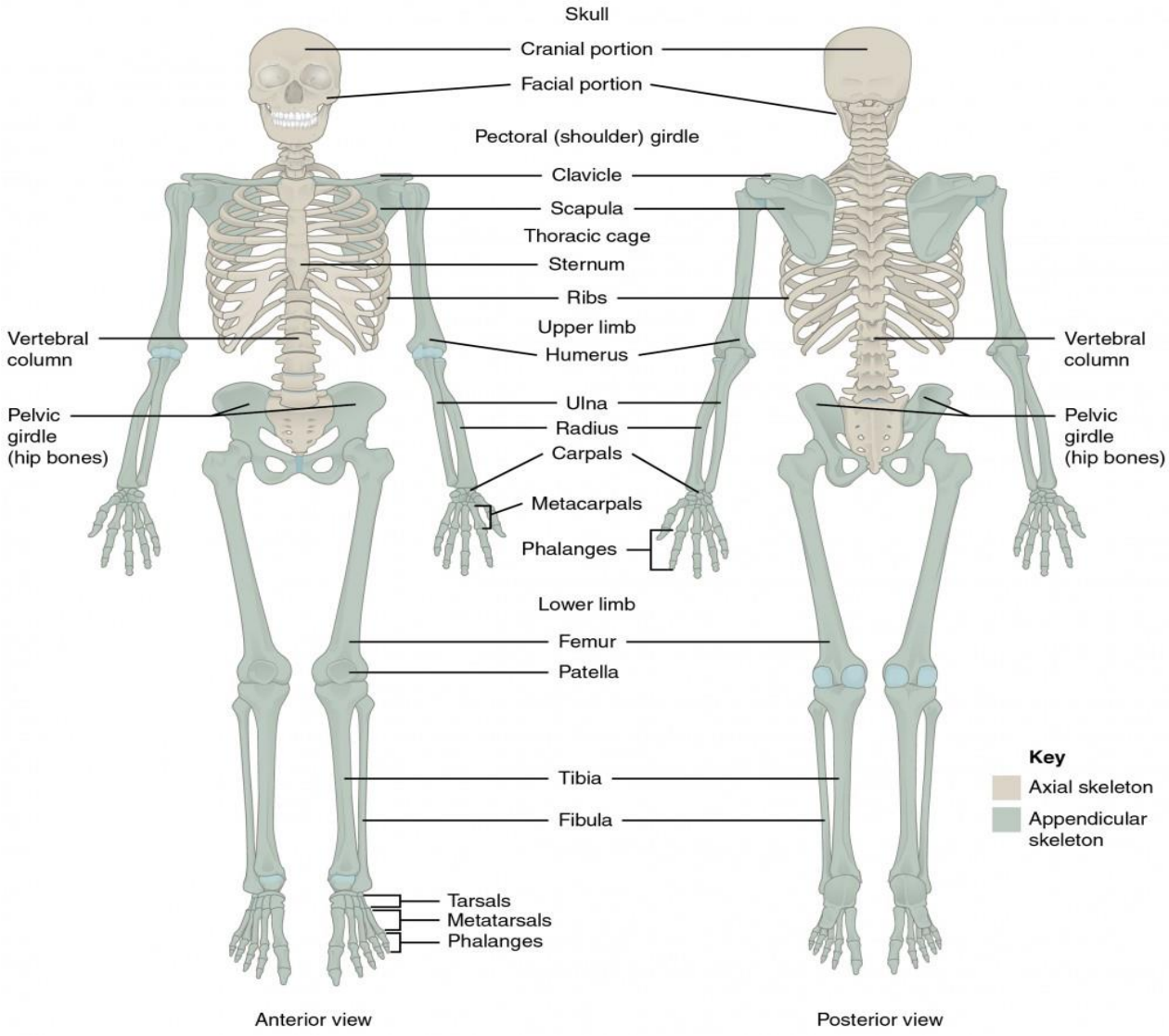


Figure 1. Axial and Appendicular Skeleton. The axial skeleton supports the head, neck, back, and chest and thus forms the vertical axis of the body. It consists of the skull, vertebral column

(including the sacrum and coccyx), and the thoracic cage, formed by the ribs and sternum. The appendicular skeleton is made up of all bones of the upper and lower limbs.

THE APPENDICULAR SKELETON

The **appendicular skeleton** includes all bones of the upper and lower limbs, plus the bones that attach each limb to the axial skeleton. There are 126 bones in the appendicular skeleton of an adult. The bones of the appendicular skeleton are covered in a separate chapter.

Types of Bones

Bone, or **osseous tissue**, is a connective tissue that constitutes the endoskeleton. It contains specialized cells and a matrix of mineral salts and collagen fibers.

The mineral salts primarily include hydroxyapatite, a mineral formed from calcium phosphate. **Calcification** is the process of deposition of mineral salts on the collagen fiber matrix that crystallizes and hardens the tissue. The process of calcification only occurs in the presence of collagen fibers.

The bones of the human skeleton are classified by their shape: long bones, short bones, flat bones, sutural bones, sesamoid bones, and irregular bones (Figure 2).

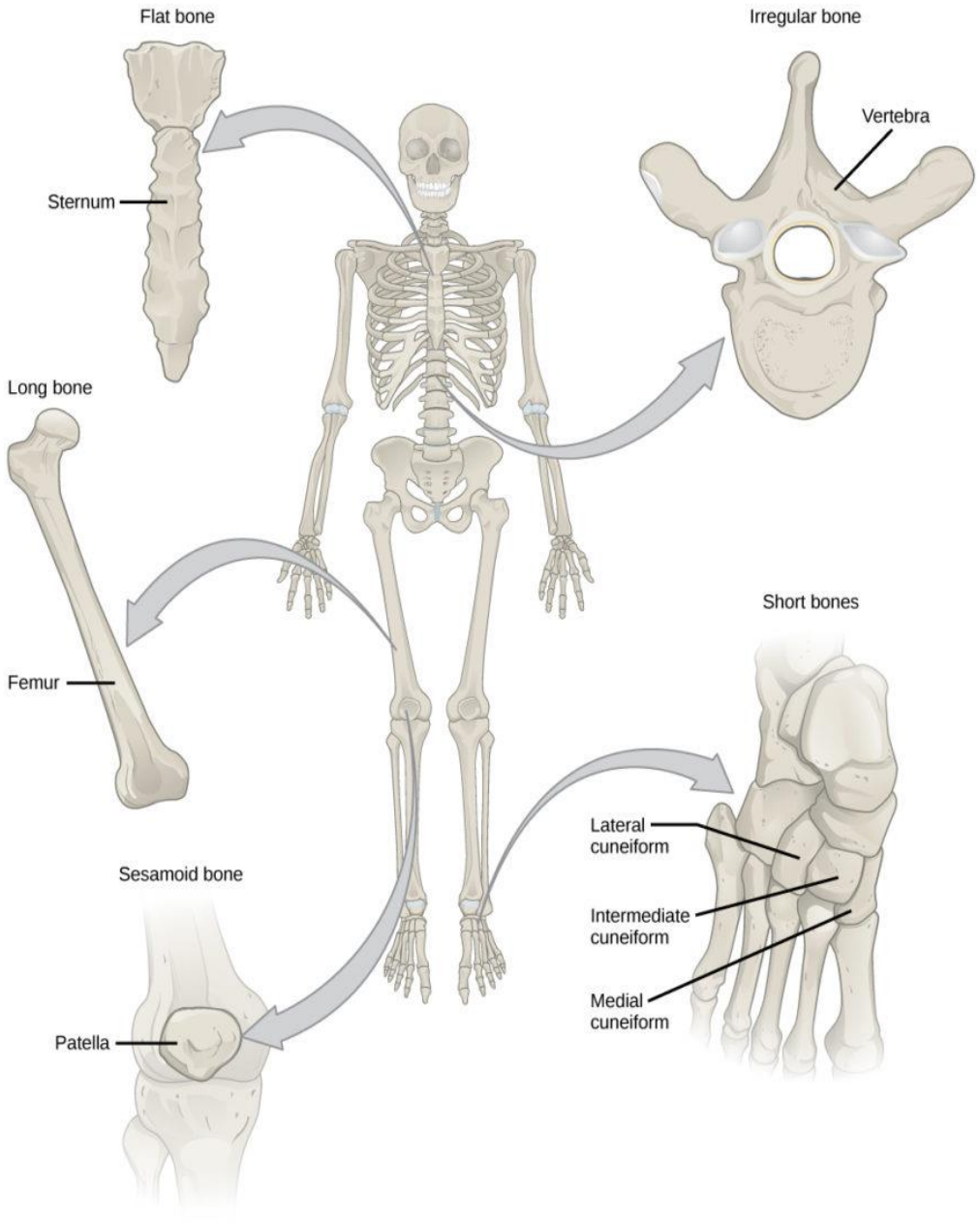


Figure 2. Shown are different types of bones: flat, irregular, long, short, and sesamoid.

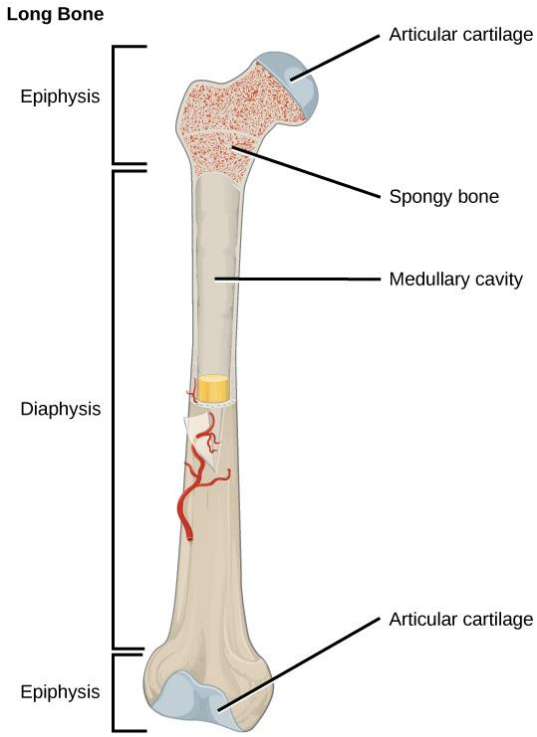


Figure 3. The long bone is covered by articular cartilage at either end and contains bone marrow (shown in yellow in this illustration) in the marrow cavity.

Long bones are longer than they are wide and have a shaft and two ends. The **diaphysis**, or central shaft, contains bone marrow in a marrow cavity. The rounded ends, the **epiphyses**, are covered with articular cartilage and are filled with red bone marrow, which produces blood cells (Figure 2). Most of the limb bones are long bones—for example, the femur, tibia, ulna, and radius. Exceptions to this include the patella and the bones of the wrist and ankle.

Short bones, or cuboidal bones, are bones that are the same width and length, giving them a cube-like shape. For example, the bones of the wrist (carpals) and ankle (tarsals) are short bones (Figure 1).

Flat bones are thin and relatively broad bones that are found where extensive protection of organs is required or where broad surfaces of muscle attachment are required. Examples of flat bones are the sternum (breast bone), ribs, scapulae (shoulder blades), and the roof of the skull (Figure 1).

Irregular bones are bones with complex shapes. These bones may have short, flat, notched, or ridged surfaces. Examples of irregular bones are the vertebrae, hip bones, and several skull bones.

Sesamoid bones are small, flat bones and are shaped similarly to a sesame seed. The patellae are sesamoid bones. Sesamoid bones develop inside tendons and may be found near joints at the knees, hands, and feet.

Sutural bones are small, flat, irregularly shaped bones. They may be found between the flat bones of the skull. They vary in number, shape, size, and position.

Human Axial Skeleton

The axial skeleton forms the central axis of the human body and consists of the skull, vertebral column, and thoracic cage. The axial skeleton forms the central axis of the human body and includes the bones of the skull, the ossicles of the middle ear, the hyoid bone of the throat, the vertebral column, and the thoracic cage (ribcage). The function of the axial skeleton is to provide support and protection for the brain, spinal cord, and organs in the ventral body cavity.

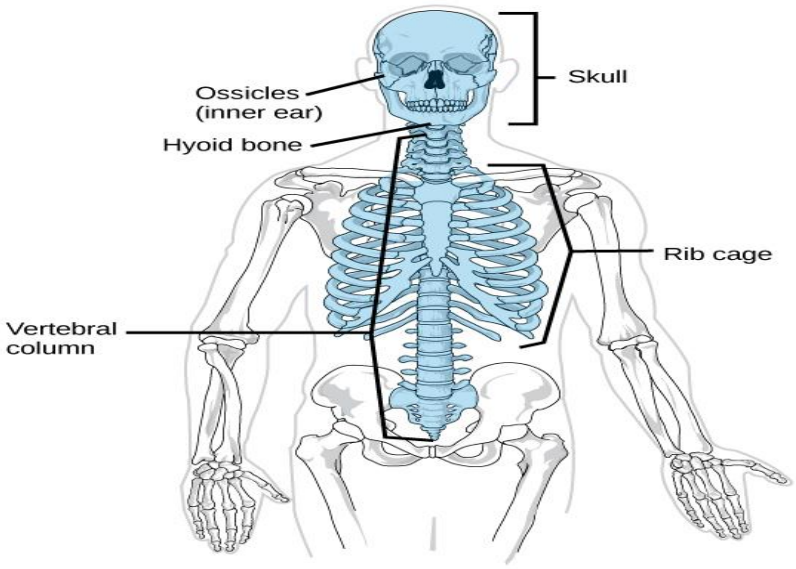


Figure 1: Axial skeleton: The axial skeleton consists of the bones of the skull, ossicles of the middle ear, hyoid bone, vertebral column, and rib cage.

The Skull

The bones of the skull support the structures of the face and protect the brain. The skull consists of 22 bones, which are divided into two categories: cranial bones and facial bones. The cranial bones are eight bones that form the cranial cavity, which encloses the brain and serves as an attachment site for the muscles of the head and neck. The eight cranial bones include the frontal bone, two parietal bones, two temporal bones, the occipital bone, the sphenoid bone, and the ethmoid bone.

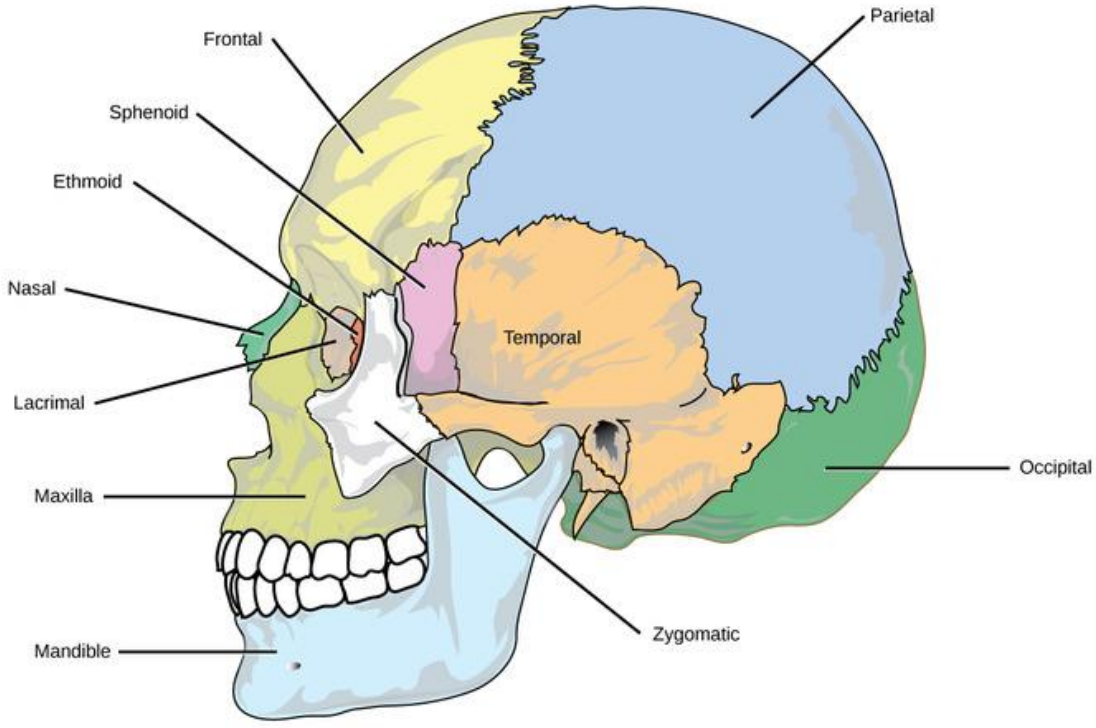


Figure 2: Skull: The bones of the skull support the structures of the face and protect the brain.

Fourteen facial bones form the face, provide cavities for the sense organs (eyes, mouth, and nose), protect the entrances to the digestive and respiratory tracts, and serve as attachment points for facial muscles. The 14 facial bones are the nasal bones, maxillary bones, zygomatic bones, palatine, vomer, lacrimal bones, inferior nasal conchae, and mandible.

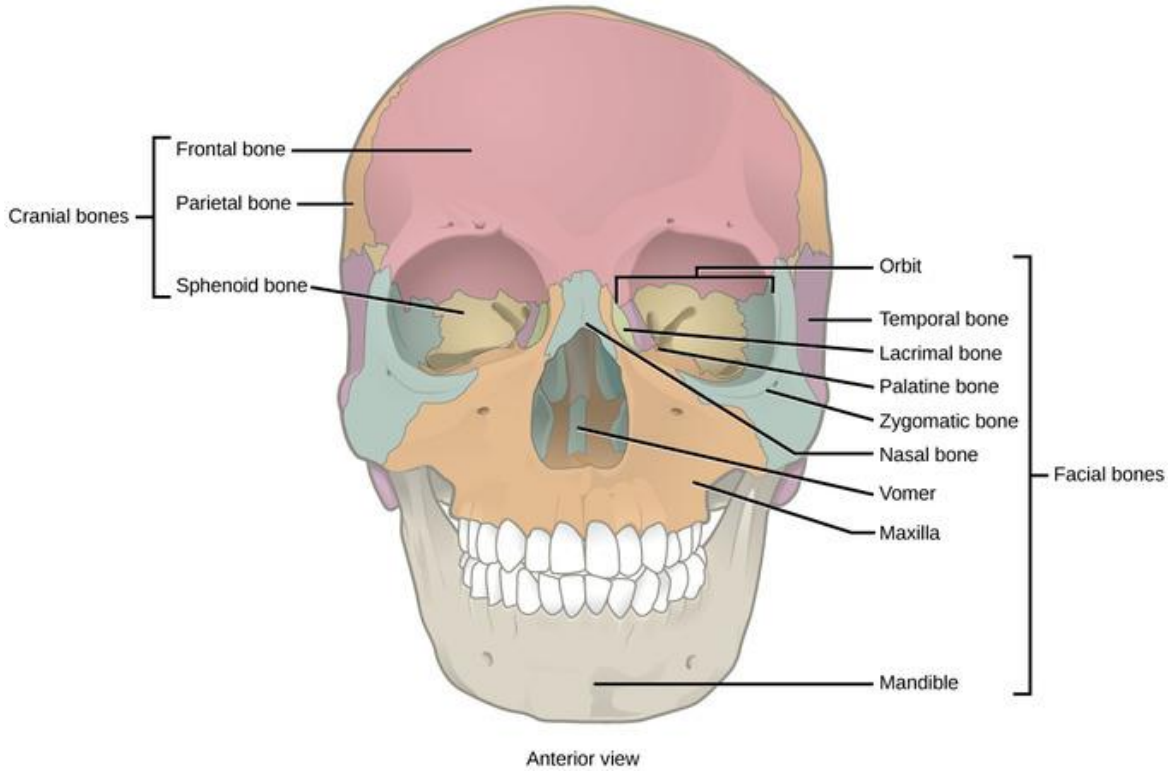


Figure 3: Cranial and facial bones: The facial bones of the skull form the face and provide cavities for the eyes, nose, and mouth. The cranial bones, including the frontal, parietal, temporal, occipital, ethmoid, and sphenoid bones.

The auditory ossicles of the middle ear transmit sounds from the air as vibrations to the fluid-filled cochlea. The auditory ossicles consist of six bones: two malleus bones, two incus bones, and two stapes, one of each on each side. These bones are unique to mammals.

The hyoid bone lies below the mandible in the front of the neck. It acts as a movable base for the tongue and is connected to muscles of the jaw, larynx, and tongue. The mandible articulates

with the base of the skull, controling the opening to the airway and gut. In animals with teeth, the mandible brings the surfaces of the teeth in contact with the maxillary teeth.

The Vertebral Column

The vertebral column, or spinal column, surrounds and protects the spinal cord, supports the head, and acts as an attachment point for the ribs and muscles of the back and neck. The adult vertebral column is comprised of 26 bones: the 24 vertebrae, the sacrum, and the coccyx bones. In the adult, the sacrum is typically composed of five vertebrae that fuse into one. We begin life with approximately 33 vertebrae, but as we grow, several vertebrae fuse together. The adult vertebrae are further divided into the 7 cervical vertebrae, 12 thoracic vertebrae, and 5 lumbar vertebrae.

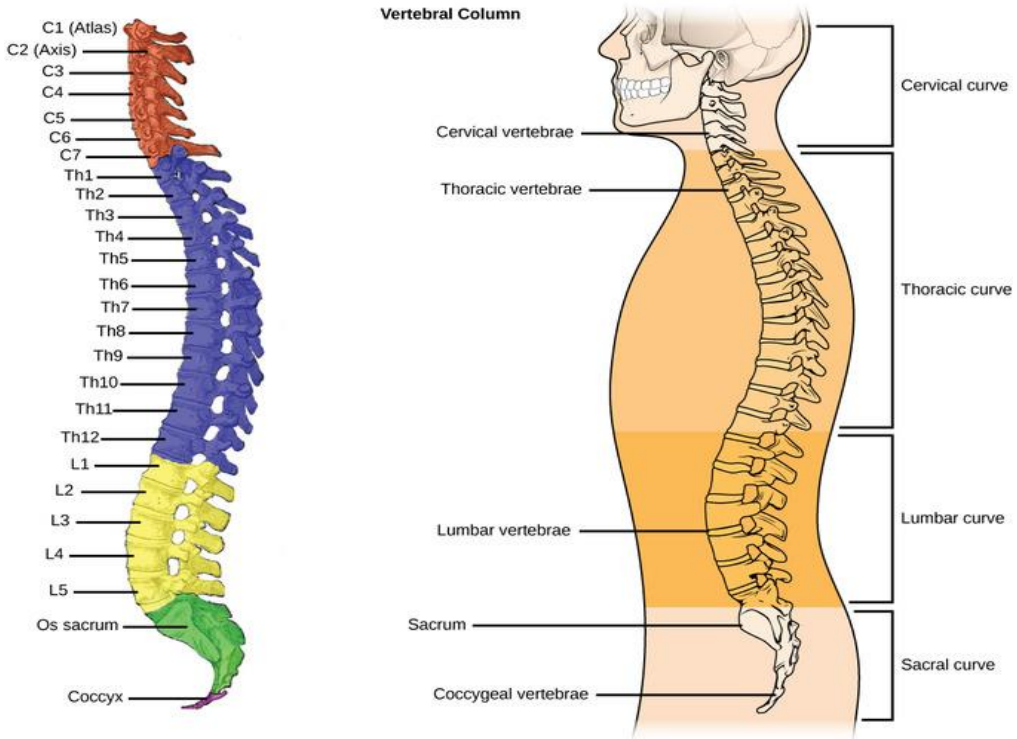


Figure 4: Vertebral column: (a) The vertebral column consists of seven cervical vertebrae (C1–7), twelve thoracic vertebrae (Th1–12), five lumbar vertebrae (L1–5), the sacrum, and the coccyx. (b) Spinal curves increase the strength and flexibility of the spine.

Each vertebral body has a large hole in the center through which the nerves of the spinal cord pass. There is also a notch on each side through which the spinal nerves, which serve the body at that level, can exit from the spinal cord. The names of the spinal curves correspond to the region of the spine in which they occur. The thoracic and sacral curves are concave, while the cervical and lumbar curves are convex. The arched curvature of the vertebral column increases its strength and flexibility, allowing it to absorb shocks like a spring.

Intervertebral discs composed of fibrous cartilage lie between adjacent vertebral bodies from the second cervical vertebra to the sacrum. Each disc is part of a joint that allows for some movement of the spine, acting as a cushion to absorb shocks from movements, such as walking and running. Intervertebral discs also act as ligaments to bind vertebrae together. The inner part of discs, the nucleus pulposus, hardens as people age, becoming less elastic. This loss of elasticity diminishes its ability to absorb shocks.

The Thoracic Cage

The thoracic cage, also known as the ribcage, is the skeleton of the chest. It consists of the ribs, sternum, thoracic vertebrae, and costal cartilages. The thoracic cage encloses and protects the organs of the thoracic cavity, including the heart and lungs. It also provides support for the shoulder girdles and upper limbs, and serves as the attachment point for the diaphragm, muscles of the back, chest, neck, and shoulders. Changes in the volume of the thorax enable breathing.

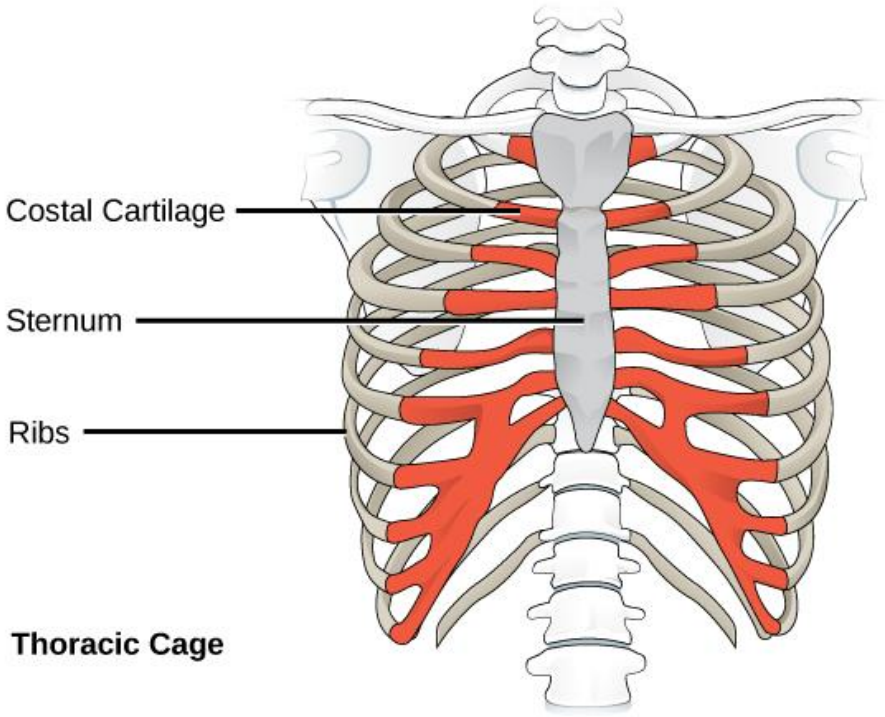


Figure 5: Thoracic cage: The thoracic cage, or rib cage, protects the heart and the lungs.

The sternum, or breastbone, is a long, flat bone located at the anterior of the chest. It is formed from three bones that fuse in the adult. The ribs are 12 pairs of long, curved bones that attach to the thoracic vertebrae and curve toward the front of the body, forming the ribcage. Costal cartilages connect the anterior ends of the ribs to the sternum, with the exception of rib pairs 11 and 12, which are free-floating ribs.

Functions of bones of axial and appendicular skeletal system

The primary functions of the skeletal system include movement, support, protection production of blood cells, storage of minerals and endocrine regulation.

Support

The primary function of the skeletal system is to provide the solid framework to support and safeguard the human body and its organs. This helps in maintaining the overall shape of the human body.

Protection

The skeletal system also helps to protect our internal organs and other delicate body organs, including the brain, heart, lungs and spinal cord by acting as a buffer. Our cranium (skull) protects our brain and eyes, the ribs protect our heart and lungs and our vertebrae (spine, backbones) protect our spinal cord.

Movement

Bones provide the basic structure for muscles to attach themselves onto so that our bodies are able to move. Tendons are tough inelastic bands that attach our muscle to that particular bone.

Storage

The bone matrix of the skeletal system is mainly involved in storing or preserving different types of essential minerals which are required to facilitate growth and repair of the body cells and tissues. The cell matrix acts as our calcium bank by storing and releasing calcium ions into the blood cell when required.

Regulation of Endocrine glands

The bone cells present within the skeletal system plays an important role in releasing the synthesized hormones from the respective endocrine glands for further requirement by the body

for different metabolisms. Apart from these functions, the skeletal system also contributes to the regulation of blood sugar.

Organization of Skeletal Muscle

Each skeletal muscle is an organ that consists of various integrated tissues. These tissues include the skeletal muscle fibers, blood vessels, nerve fibers, and connective tissue. Each skeletal muscle has three layers of connective tissue that enclose it, provide structure to the muscle, and compartmentalize the muscle fibers within the muscle (Figure 1). Each muscle is wrapped in a sheath of dense, irregular connective tissue called the **epimysium**, which allows a muscle to contract and move powerfully while maintaining its structural integrity. The epimysium also separates muscle from other tissues and organs in the area, allowing the muscle to move independently.

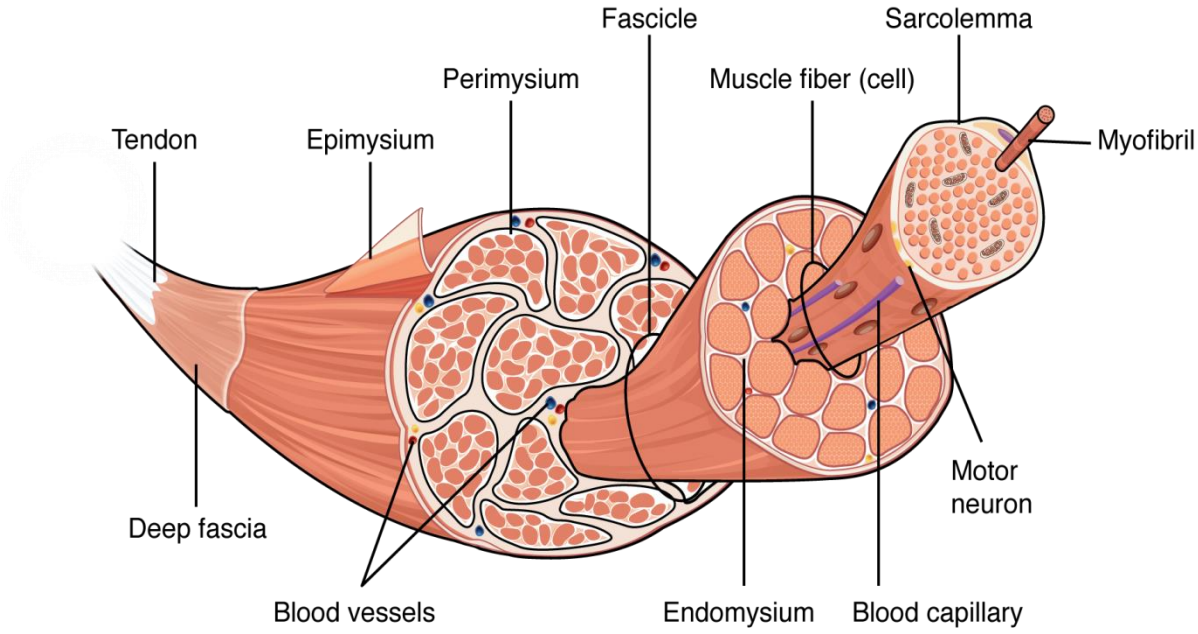


Figure 1: The Three Connective Tissue Layers: Bundles of muscle fibers, called fascicles, are covered by the perimysium. Muscle fibers are covered by the endomysium

` Inside each skeletal muscle, muscle fibers are organized into bundles, called **fascicles**, surrounded by a middle layer of connective tissue called the **perimysium**. This fascicular organization is common in muscles of the limbs; it allows the nervous system to trigger a specific movement of a muscle by activating a subset of muscle fibers within a fascicle of the muscle. Inside each fascicle, each muscle fiber is encased in a thin connective tissue layer of collagen and reticular fibers called the **endomysium**. The endomysium surrounds the extracellular matrix of the cells and plays a role in transferring force produced by the muscle fibers to the tendons.

In skeletal muscles that work with tendons to pull on bones, the collagen in the three connective tissue layers intertwines with the collagen of a tendon. At the other end of the tendon, it fuses with the periosteum coating the bone. The tension created by contraction of the muscle fibers is then transferred though the connective tissue layers, to the tendon, and then to the periosteum to pull on the bone for movement of the skeleton. In other places, the mysia may fuse with a broad, tendon-like sheet called an **aponeurosis**, or to fascia, the connective tissue between skin and bones. The broad sheet of connective tissue in the lower back that the latissimus dorsi muscles (the "lats") fuse into is an example of an aponeurosis. Every skeletal muscle is also richly supplied by blood vessels for nourishment, oxygen delivery, and waste removal. In addition, every muscle fiber in a skeletal muscle is supplied by the axon branch of a somatic motor neuron, which signals the fiber to contract. Unlike cardiac and smooth muscle, the only way to functionally contract a skeletal muscle is through signaling from the nervous system.

Skeletal Muscle Fibers

Skeletal muscle cells are long and cylindrical, they are commonly referred to as muscle fibers (or myofibers). Skeletal muscle fibers can be quite large compared to other cells, with diameters up to 100 μm and lengths up to 30 cm (11.8 in) in the Sartorius of the upper leg. Having many nuclei allows for production of the large amounts of proteins and enzymes needed for maintaining normal function of these large protein dense cells. In addition to nuclei,

skeletal muscle fibers also contain cellular organelles found in other cells, such as mitochondria and endoplasmic reticulum. Howver, some of these structures are specialized in muscle fibers. The specialized smooth endoplasmic reticulum, called the **sarcoplasmic reticulum (SR)**, stores, releases, and retrieves calcium ions (Ca^{++}).

The plasma membrane of muscle fibers is called the **sarcolemma** (from the Greek *sarco*, which means "flesh") and the cytoplasm is referred to as **sarcoplasm**. Within a muscle fiber, proteins are organized into structures called **myofibrils** that run the length of the cell and contain sarcomeres connected in series. Because myofibrils are only approximately 1.2 μm in diameter, hundreds to thousands (each with thousands of sarcomeres) can be found inside one muscle fiber. The **sarcomere** is the smallest functional unit of a skeletal muscle fiber and is a highly organized arrangement of contractile, regulatory, and structural proteins. It is the shortening of these individual sarcomeres that lead to the contraction of individual skeletal muscle fibers (and ultimately the whole muscle).

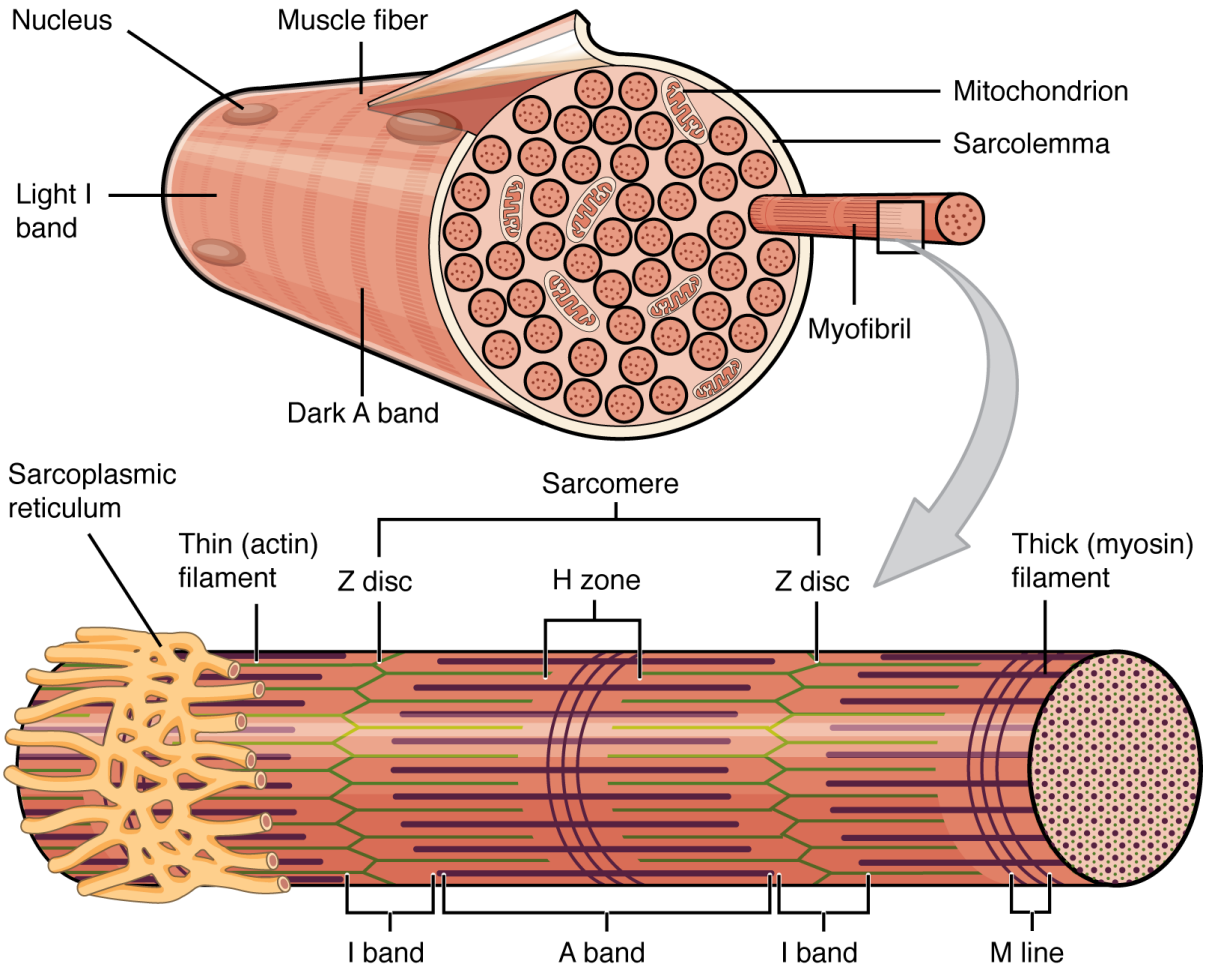


Figure 2 – Muscle Fiber: A skeletal muscle fiber is surrounded by a plasma membrane called the sarcolemma, which contains sarcoplasm, the cytoplasm of muscle cells. A muscle fiber is composed of many myofibrils, which contain sarcomeres with light and dark regions that give the cell its striated appearance.

The Sarcomere

A sarcomere is defined as the region of a myofibril contained between two cytoskeletal structures called Z-discs (also called Z-lines), and the striated appearance of skeletal muscle fibers is due to the arrangement of the thick and thin myofilaments within each sarcomere (Figure 2). The dark striated **A band** is composed of the thick filaments containing myosin,

which span the center of the sarcomere extending toward the Z-dics. The thick filaments are anchored at the middle of the sarcomere (the M-line) by a protein called myomesin. The lighter **I band** regions contain thin actin filaments anchored at the Z-discs by a protein called α-actinin. The thin filaments extend into the A band toward the M-line and overlap with regions of the thick filament. The A band is dark because of the thicker mysoin filaments as well as overlap with the actin filaments. The H zone in the middle of the A band is a little lighter in color, because the thin filaments do not extend into this region.

Because a sarcomere is defined by Z-discs, a single sarcomere contains one dark A band with half of the lighter I band on each end. During contraction the myofilaments themselves do not change length, but actually slide across each other so the distance between the Z-discs shortens. The length of the A band does not change (the thick myosin filament remains a constant length), but the H zone and I band regions shrink. These regions represent areas where the filaments do not overlap, and as filament overlap increases during contraction these regions of no overlap decrease.

Myofilament Components

The thin filaments are composed of two filamentous actin chains (F-actin) comprised of individual actin proteins. These thin filaments are anchored at the Z-disc and extend toward the center of the sarcomere. Within the filament, each globular actin monomer (G-actin) contains a mysoin binding site and is also associated with the regulatory proteins, troponin and tropomyosin. The troponin protein complex consists of three polypeptides. Troponin I (TnI) binds to actin, troponin T (TnT) binds to tropomyosin, and troponin C (TnC) binds to calcium ions. Troponin and tropomyosin run along the actin filaments and control when the actin binding sites will be exposed for binding to myosin.

Thick myofilaments are composed of myosin protein complexes, which are composed of six proteins: two myosin heavy chains and four light chain molecules. The heavy chains consist of a tail region, flexible hinge region, and globular head which contains an Actin-

binding site and a binding site for the high energy molecule ATP. The light chains play a regulatory role at the hinge region, but the heavy chain head region interacts with actin and is the most important factor for generating force. Hundreds of myosin proteins are arranged into each thick filament with tails toward the M-line and heads extending toward the Z-discs.

Other structural proteins are associated with the sarcomere but do not play a direct role in active force production. Titin, which is the largest known protein, helps align the thick filament and adds an elastic element to the sarcomere. Titin is anchored at the M-Line, runs the length of myosin, and extends to the Z disc. The thin filaments also have a stabilizing protein, called nebulin, which spans the length of the thick filaments.

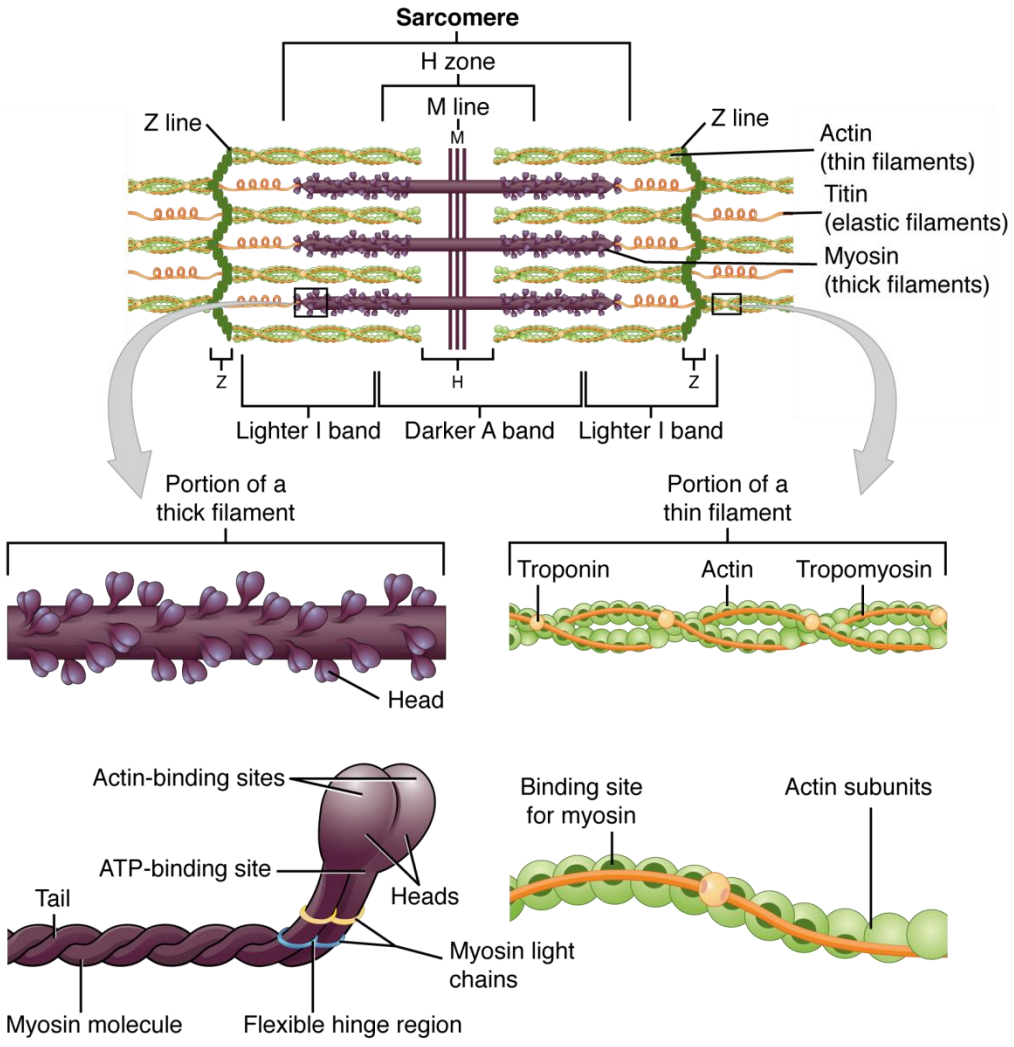


Figure 3 – The Sarcomere: The sarcomere, the region from one Z-line to the next Z-line, is the functional unit of a skeletal muscle fiber.

Physiology of Muscle Contraction

The sequence of events that result in the contraction of an individual muscle fiber begins with a signal—the neurotransmitter, ACh—from the motor neuron innervating that fiber. The local membrane of the fiber will depolarize as positively charged sodium ions (Na^+) enter, triggering an action potential that spreads to the rest of the membrane will depolarize, including the T-tubules. This triggers the release of calcium ions (Ca^{++}) from storage in the sarcoplasmic reticulum (SR). The Ca^{++} then initiates contraction, which is sustained by ATP (Figure 1). As long as Ca^{++} ions remain in the sarcoplasm to bind to troponin, which keeps the actin-binding sites "unshielded," and as long as ATP is available to drive the cross-bridge cycling and the pulling of actin strands by myosin, the muscle fiber will continue to shorten to an anatomical limit.

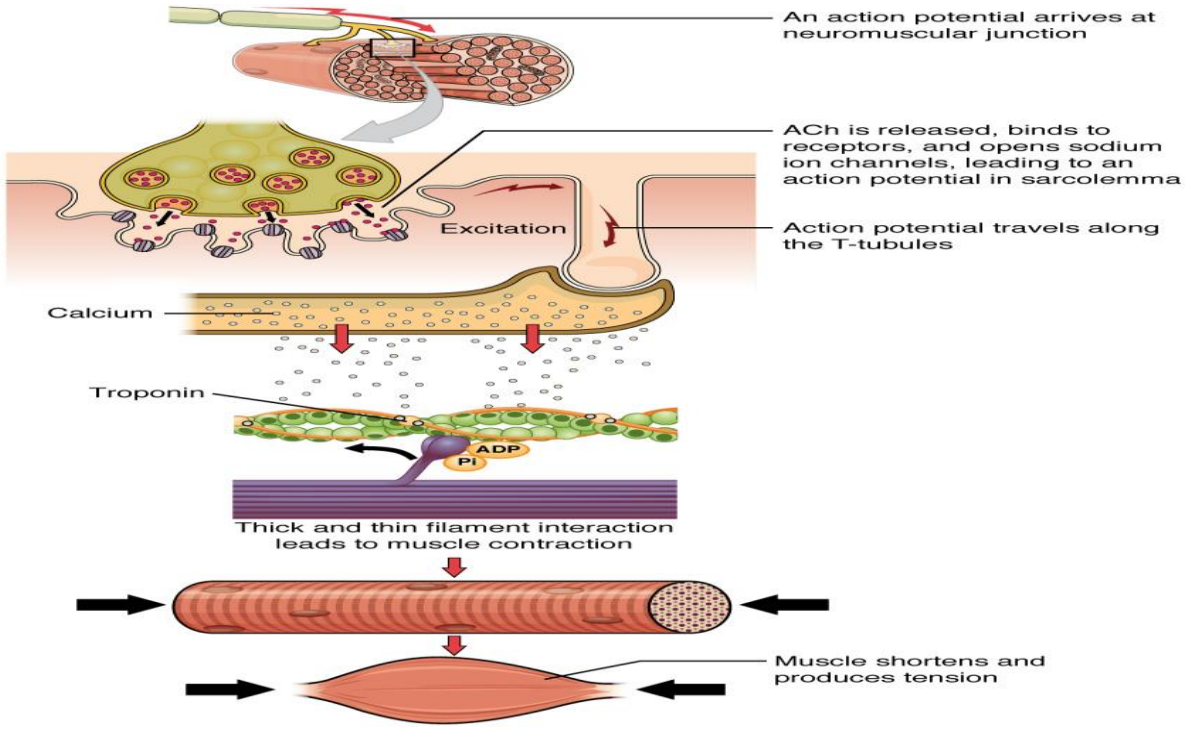


Figure 1. Contraction of a Muscle Fiber. A cross-bridge forms between actin and the myosin heads triggering contraction. As long as Ca++ ions remain in the sarcoplasm to bind to troponin, and as long as ATP is available, the muscle fiber will continue to shorten.

Muscle contraction usually stops when signaling from the motor neuron ends, which repolarizes the sarcolemma and T-tubules, and closes the voltage-gated calcium channels in the SR. Ca^{++} ions are then pumped back into the SR, which causes the tropomyosin to reshield (or re-cover) the binding sites on the actin strands. A muscle also can stop contracting when it runs out of ATP and becomes fatigued.

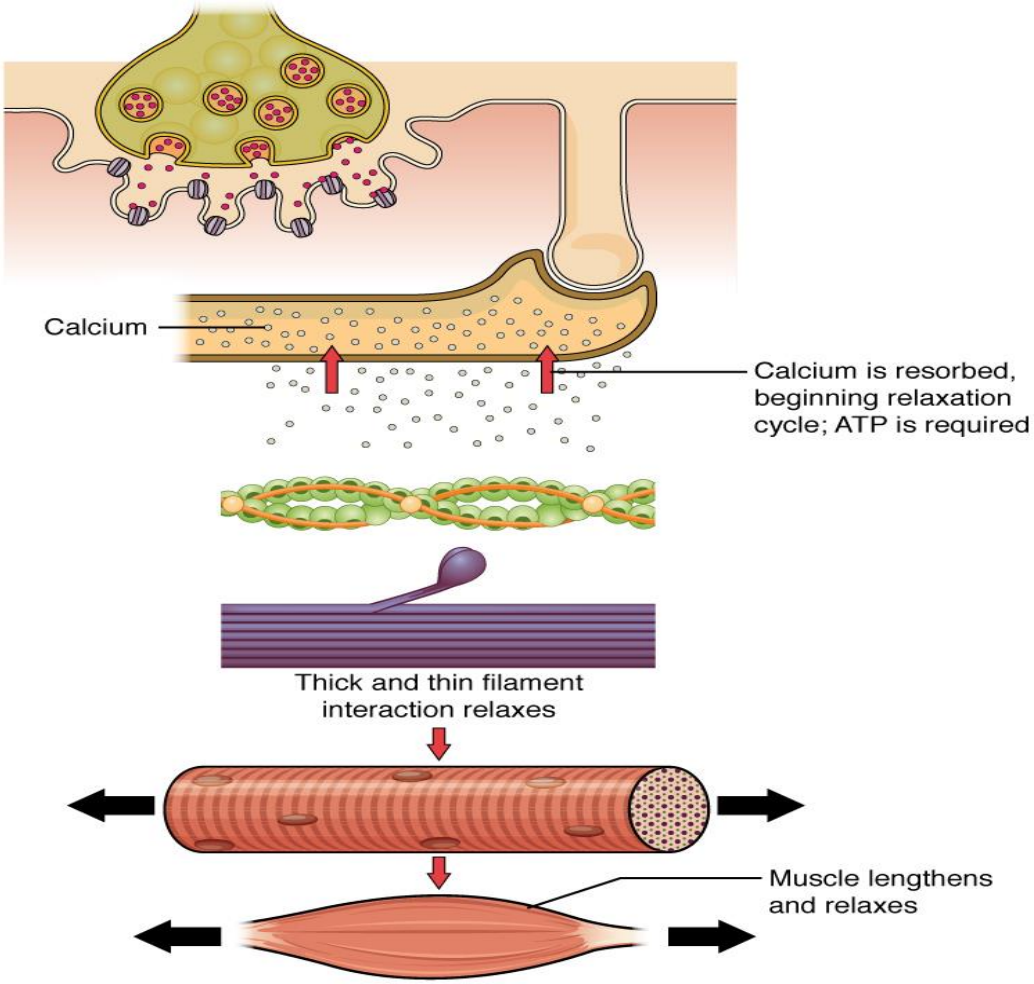


Figure 2. Relaxation of a Muscle Fiber. Ca++ ions are pumped back into the SR, which causes the tropomyosin to reshield the binding sites on the actin strands. A muscle may also stop contracting when it runs out of ATP and becomes fatigued.

The release of calcium ions initiates muscle contractions. The molecular events of muscle fiber shortening occur within the fiber's sarcomeres (see Figure 3). The contraction of a striated muscle fiber occurs as the sarcomeres, linearly arranged within myofibrils, shorten as myosin heads pull on the actin filaments.

The region where thick and thin filaments overlap has a dense appearance, as there is little space between the filaments. This zone where thin and thick filaments overlap is very important to muscle contraction, as it is the site where filament movement starts. Thin filaments, anchored at their ends by the Z-discs, do not extend completely into the central region that only contains thick filaments, anchored at their bases at a spot called the M-line. A myofibril is composed of many sarcomeres running along its length; thus, myofibrils and muscle cells contract as the sarcomeres contract.

THE SLIDING FILAMENT MODEL OF CONTRACTION

When signaled by a motor neuron, a skeletal muscle fiber contracts as the thin filaments are pulled and then slide past the thick filaments within the fiber's sarcomeres. This process is known as the sliding filament model of muscle contraction (Figure 3). The sliding can only occur when myosin-binding sites on the actin filaments are exposed by a series of steps that begins with Ca^{++} entry into the sarcoplasm.

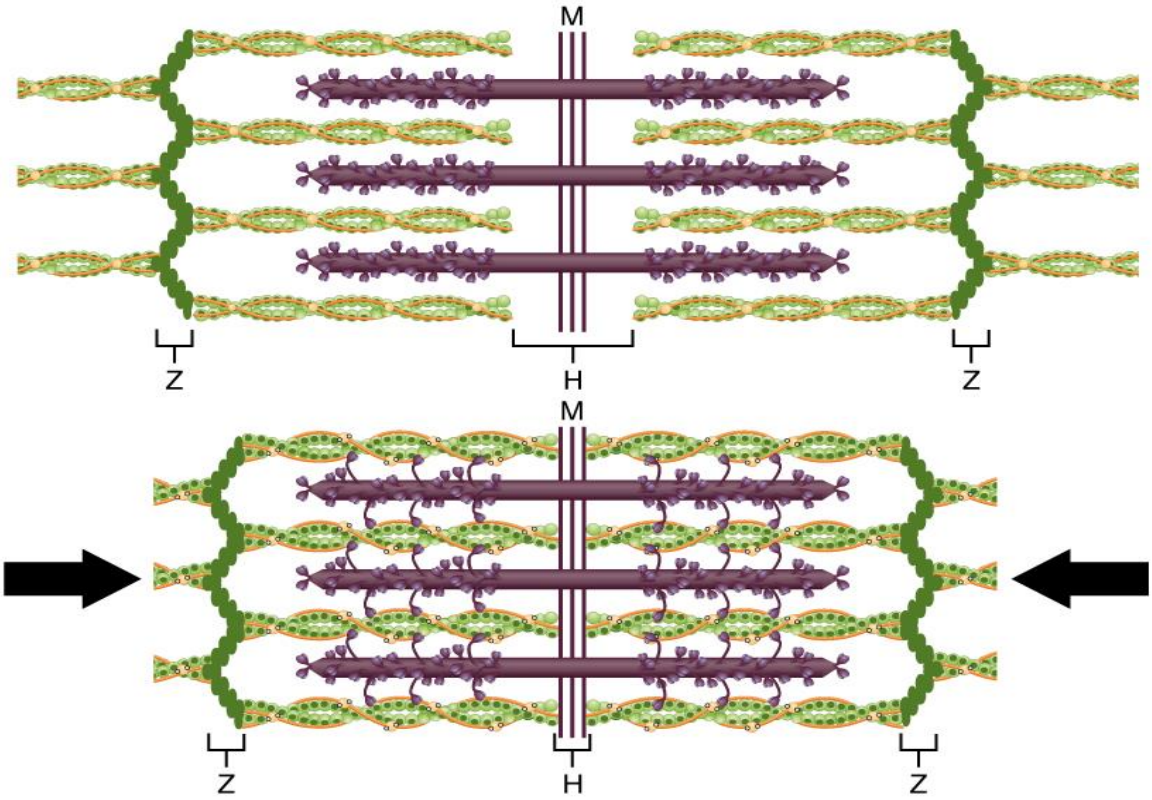


Figure 3. The Sliding Filament Model of Muscle Contraction. When a sarcomere contracts, the Z lines move closer together, and the I band becomes smaller. The A band stays the same width. At full contraction, the thin and thick filaments overlap.

Tropomyosin is a protein that winds around the chains of the actin filament and covers the myosin-binding sites to prevent actin from binding to myosin. Tropomyosin binds to troponin to form a troponin-tropomyosin complex. The troponin-tropomyosin complex prevents the myosin "heads" from binding to the active sites on the actin microfilaments. Troponin also has a binding site for Ca^{++} ions.

To initiate muscle contraction, tropomyosin has to expose the myosin-binding site on an actin filament to allow cross-bridge formation between the actin and myosin microfilaments. The first step in the process of contraction is for Ca^{++} to bind to troponin so that tropomyosin can slide away from the binding sites on the actin strands. This allows the myosin heads to bind to

these exposed binding sites and form cross-bridges. The thin filaments are then pulled by the myosin heads to slide past the thick filaments toward the center of the sarcomere. But each head can only pull a very short distance before it has reached its limit and must be “re-cocked” before it can pull again, a step that requires ATP.

ATP AND MUSCLE CONTRACTION

For thin filaments to continue to slide past thick filaments during muscle contraction, myosin heads must pull the actin at the binding sites, detach, re-cock, attach to more binding sites, pull, detach, re-cock, etc. This repeated movement is known as the cross-bridge cycle. This motion of the myosin heads is similar to the oars when an individual rows a boat: The paddle of the oars (the myosin heads) pull, are lifted from the water (detach), repositioned (re-cocked) and then immersed again to pull (Figure 4). Each cycle requires energy, and the action of the myosin heads in the sarcomeres repetitively pulling on the thin filaments also requires energy, which is provided by ATP.

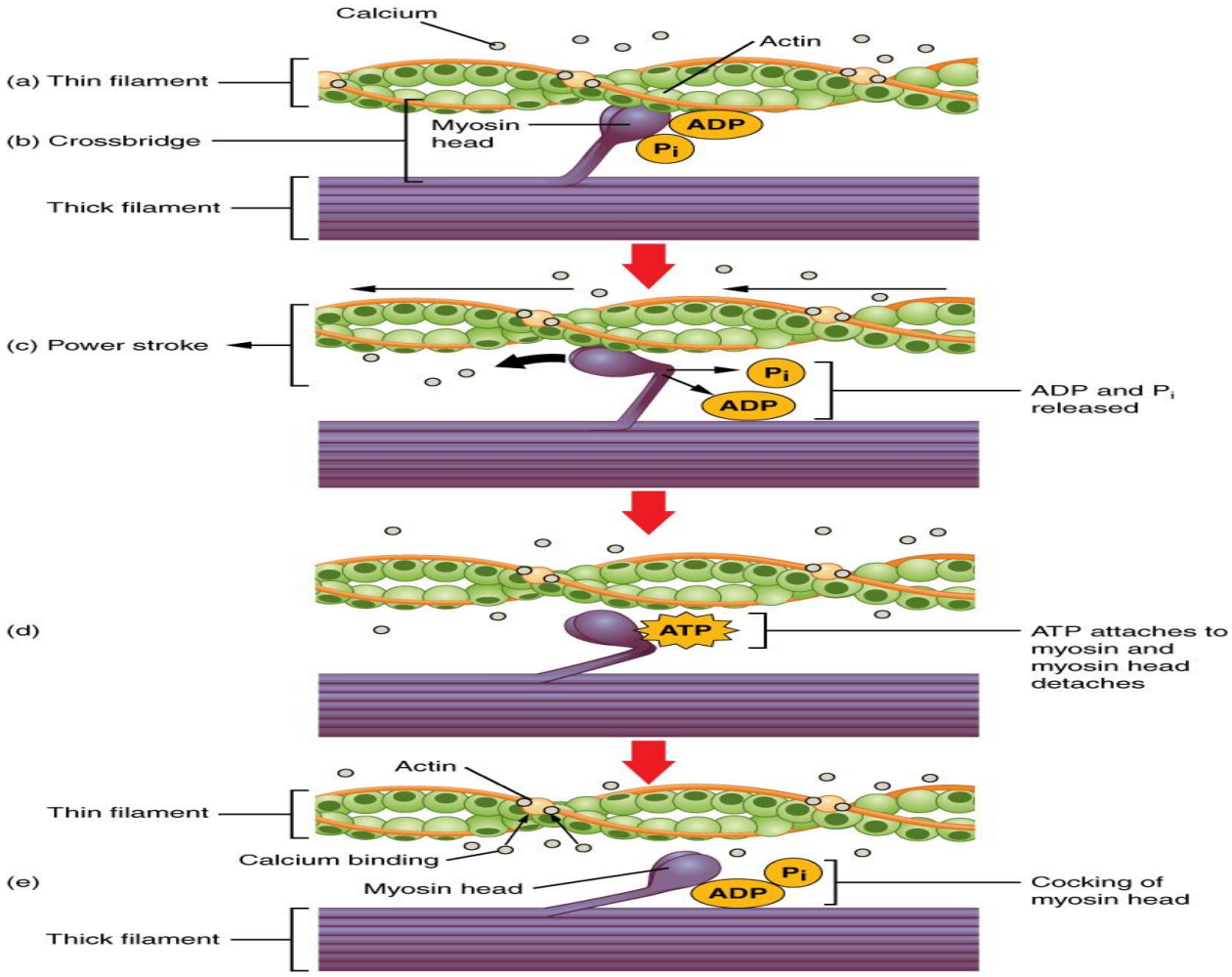


Figure 4. Skeletal Muscle Contraction. (a) The active site on actin is exposed as calcium binds to troponin. (b) The myosin head is attracted to actin, and myosin binds actin at its actin-binding site, forming the cross-bridge. (c) During the power stroke, the phosphate generated in the previous contraction cycle is released. This results in the myosin head pivoting toward the center of the sarcomere, after which the attached ADP and phosphate group are released. (d) A new molecule of ATP attaches to the myosin head, causing the cross-bridge to detach. (e) The myosin head hydrolyzes ATP to ADP and phosphate, which returns the myosin to the cocked position.

Cross-bridge formation occurs when the myosin head attaches to the actin while adenosine diphosphate (ADP) and inorganic phosphate (P_i) are still bound to myosin (Figure 4**a,b**). P_i is

then released, causing myosin to form a stronger attachment to the actin, after which the myosin head moves toward the M-line, pulling the actin along with it. As actin is pulled, the filaments move approximately 10 nm toward the M-line. This movement is called the **power stroke**, as movement of the thin filament occurs at this step (Figure 4**c**). In the absence of ATP, the myosin head will not detach from actin.

One part of the myosin head attaches to the binding site on the actin, but the head has another binding site for ATP. ATP binding causes the myosin head to detach from the actin (Figure 4**d**). After this occurs, ATP is converted to ADP and P_i by the intrinsic **ATPase** activity of myosin. The energy released during ATP hydrolysis changes the angle of the myosin head into a cocked position (Figure 4**e**). The myosin head is now in position for further movement.

When the myosin head is cocked, myosin is in a high-energy configuration. This energy is expended as the myosin head moves through the power stroke, and at the end of the power stroke, the myosin head is in a low-energy position. After the power stroke, ADP is released; however, the formed cross-bridge is still in place, and actin and myosin are bound together. As long as ATP is available, it readily attaches to myosin, the cross-bridge cycle can recur, and muscle contraction can continue.

Note that each thick filament of roughly 300 myosin molecules has multiple myosin heads, and many cross-bridges form and break continuously during muscle contraction. Multiply this by all of the sarcomeres in one myofibril, all the myofibrils in one muscle fiber, and all of the muscle fibers in one skeletal muscle, and you can understand why so much energy (ATP) is needed to keep skeletal muscles working. In fact, it is the loss of ATP that results in the rigor mortis observed soon after someone dies. With no further ATP production possible, there is no ATP available for myosin heads to detach from the actin-binding sites, so the cross-bridges stay in place, causing the rigidity in the skeletal muscles.

Neuromuscular Junction

At its simplest, the neuromuscular junction is a type of **synapse** where **neuronal signals** from the brain or spinal cord interact with **skeletal muscle** fibers, causing them to contract. The activation of many muscle fibers together causes muscles to contract, which in turn can produce movement. The **neuromuscular junction** then, is a key component in the body's ability to produce and control movement. Amazingly, processes at the neuromuscular junction take place at speeds that allow movements to occur with no appreciable delay or lag.

Components

Each muscle is surrounded by a thin sheet of connective tissue or fascia known as **epimysium**. Within the muscle, bundles of muscle fibers or cells, known as **fascicles**, are bound together by another layer of connective tissue known as the **perimysium**. Every muscle fiber or cell within a fascicle is itself encased in a layer of connective tissue called **endomysium**.

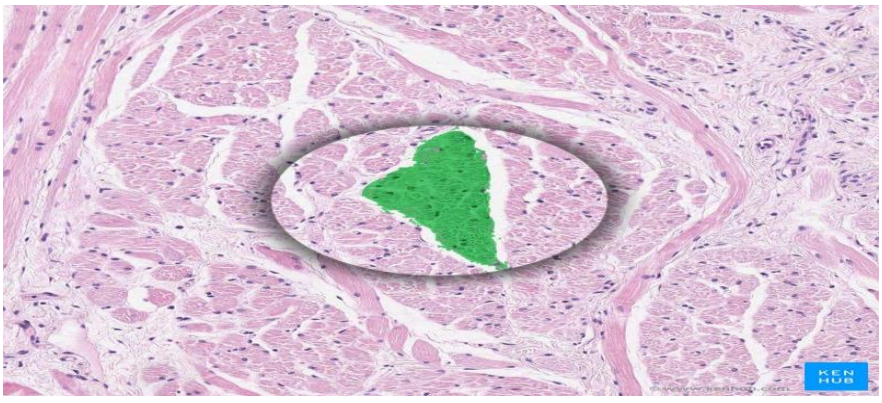


Figure 1: Skeletal muscle fascicle (histological slide)

Each individual muscle fiber is innervated (supplied) and controlled by a motor neuron. This **motor neuron**, which has its cell body located within the central nervous system, will have axons that enter the muscle and penetrate the perimysium.

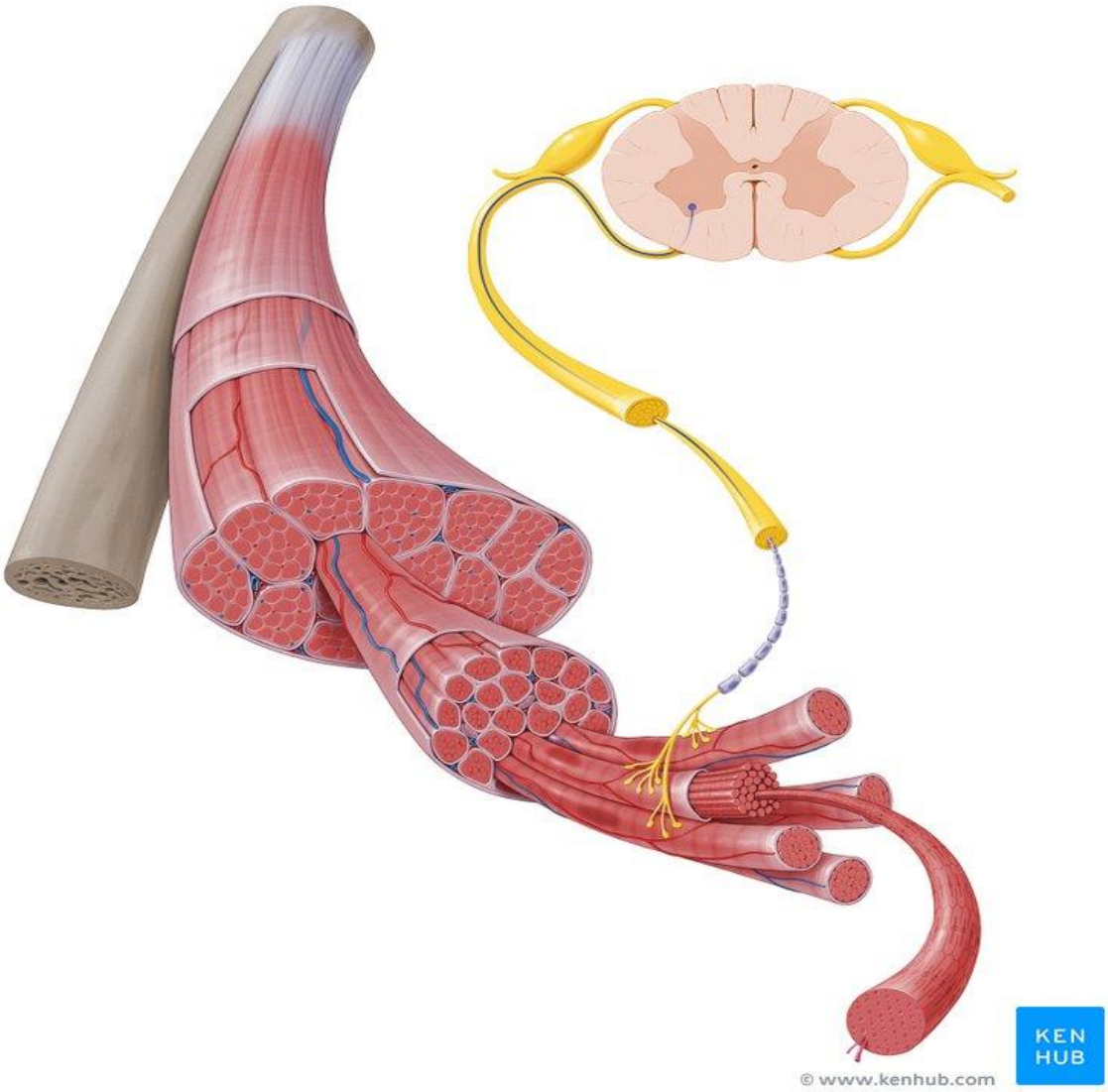


Figure 2: Motor unit

At this point, each axon of the motor neuron will divide into branches called **axon terminals**. Towards the end of the axon terminal, closest to the muscle fiber, the tip of the axon terminal enlarges and becomes known as the **synaptic end bulb**. It is the synaptic end bulb of the motor neuron that comprises the nervous system component of the neuromuscular junction. The muscular component is a region of the muscle fiber referred to as the **motor end plate**. Between the synaptic end bulbs of the neuron and the cell membrane of the muscle fiber (the

sarcolemma) lies a space known as the **synaptic cleft**, which is the final component of the neuromuscular junction.

The synaptic end bulb

The presence of the synaptic cleft between the synaptic end bulb of the neuron and the motor end plate of the muscle fiber, means that the electrical signal or action potential, arriving from the central nervous system, needs to somehow transverse (cross) this space. The neuromuscular junction accomplishes this by turning the electrical signal from the nervous system into a **chemical signal** that can be moved across the synaptic cleft.

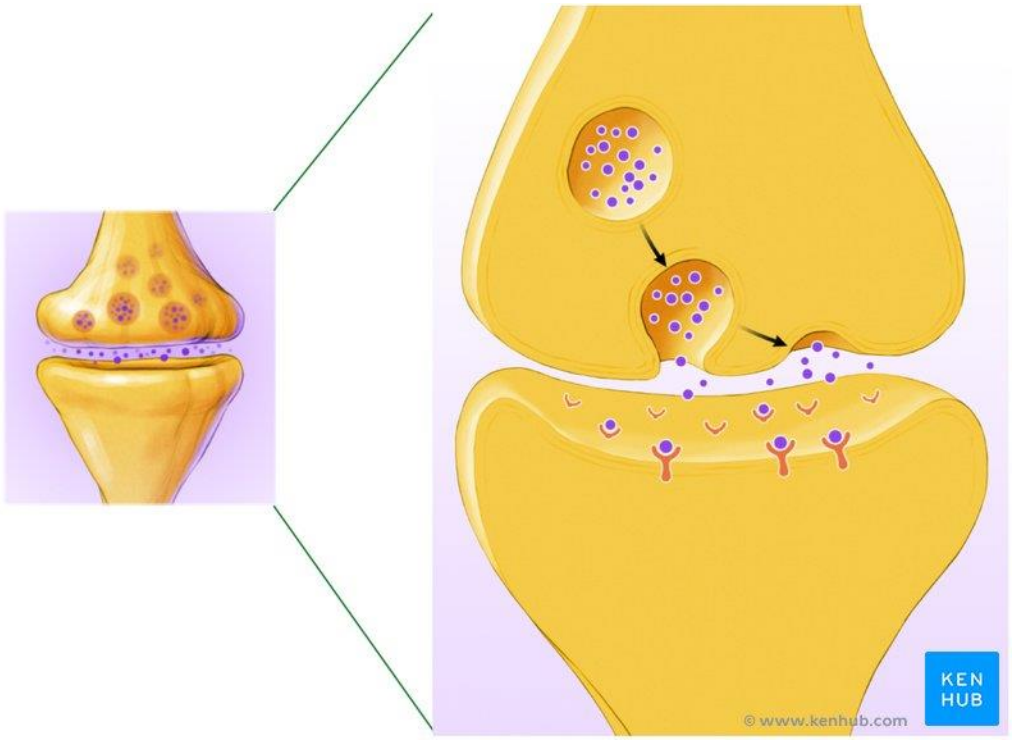


Figure 3: Neurotransmitters

The chemical in this case is **acetylcholine** (ACh), an example of a neurotransmitter that allows neurons to communicate with other cells. ACh is stored inside the synaptic end bulb within membrane-enclosed sacs known as **synaptic vesicles**. As the electrical signal approaches the synaptic end bulb, it stimulates the inflow of **calcium** (Ca2+) by opening voltage-gated channels in the cell membrane of the neuron.

The increase of Ca2+ within the cytosol of the synaptic end bulb causes the synaptic vesicles to move towards and fuse with the neuron's cell membrane. Once fused, the synaptic vesicles **exocytose** (release) their contents – ACh – into the synaptic cleft.

The ACh then moves across the synaptic cleft towards the motor end plate of the muscle fiber.

The motor end plate

Across the synaptic cleft from the synaptic end bulb is a specialized region of the muscle fiber sarcolemma known as the **motor end plate**. There is one neuromuscular junction associated with each muscle fiber, and it is typically located near the middle of the fiber. This means that the motor end plate will also be located near the midpoint of the muscle fiber.

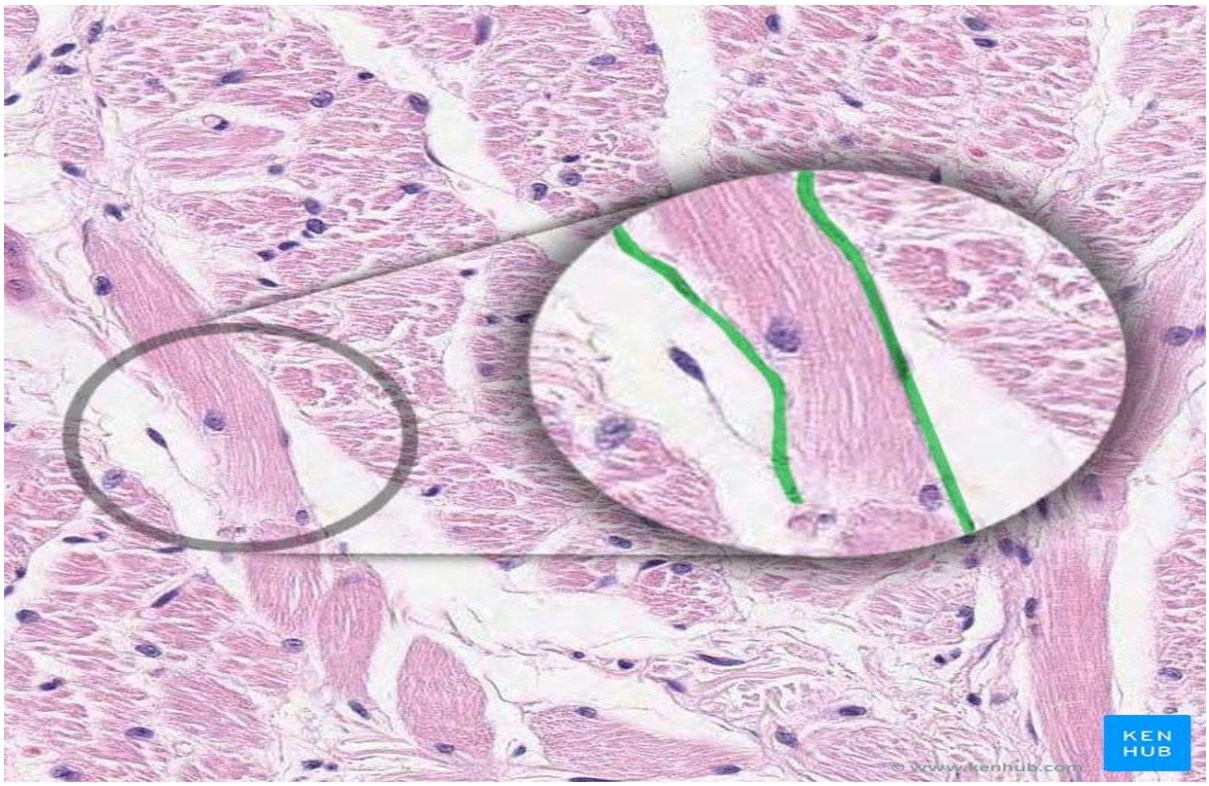


Figure 4: Sarcolemma (histological slide)

The motor end plate has two specializations that make it ideal for receiving ACh released from the synaptic end bulb.

- The first specialization at the motor end plate is the presence of **junctional folds**, which are deep invaginations or grooves of the sarcolemma that provide a large surface area where the ACh from the synaptic end bulb can interact.
- Secondly, within the region of the motor end plate, the sarcolemma of the junctional folds contains 30 to 40 million **acetylcholine receptors**. These receptors are integral transmembrane proteins that function as an ion channel once activated.

  The binding of two molecules of ACh to an acetylcholine receptor, opens the ion channel in the receptor and allows the influx of **sodium** (Na+) into the muscle fiber. It is this influx of Na+ that once again initiates an electrical impulse or action potential that travels outwards from

the motor end plate towards both ends of the muscle fiber causing the muscle fiber to contract and shorten.

The synaptic cleft

Up until now the synaptic cleft has merely been a space between the neural and muscular components of the neuromuscular junction. It does however, house an enzyme that is imperative for the proper function of muscles. If ACh remained within the synaptic cleft, it would continue to bind to acetylcholine receptors in the motor end plate region causing continued muscle contraction. Instead, the synaptic cleft contains **acetylcholinesterase** (AChE), an enzyme that breaks down ACh into **acetyl** and **choline**, neither of which can activate the acetylcholine receptors.

Structural and Functional Classification of Joints

Structural Classification of Joints

There are three structural classifications of joints: fibrous, cartilaginous, and synovial.

A joint, also known as an articulation or articular surface, is a connection that occurs between bones in the skeletal system. Joints provide the means for movement. The type and characteristics of a given joint determines its degree and type of movement. Joints can be classified based on structure and function.

Structural classification of joints categorizes them based on the type of tissue involved in formation. There are three structural classifications of joints: fibrous, cartilaginous, and synovial.

Fibrous Joints

Fibrous joints are connected by dense, tough connective tissue that is rich in collagen fibers. These fixed or immovable joints are typically interlocked with irregular edges. There are three types of fibrous joints.

Sutures are the types of joint found in the cranium (skull). The bones are connected by Sharpey's fibres. The nature of cranial sutures allows for some movement in the fetus. However, they become mostly immovable as the individual ages, although very slight movement allows some necessary cranial elasticity. These rigid joints are referred to as synarthrodial.

Syndesmoses are found between long bones of the body, such as the radio-ulnar and tibio-fibular joints. These moveable fibrous joints are also termed amphiarthrodial. They have a lesser range of movement than synovial joints.

Gomphosis is a type of joint found at the articulation between teeth and the sockets of the maxilla or mandible (dental-alveolar joint). The fibrous tissue that connects the tooth and socket is called the periodontal ligament.

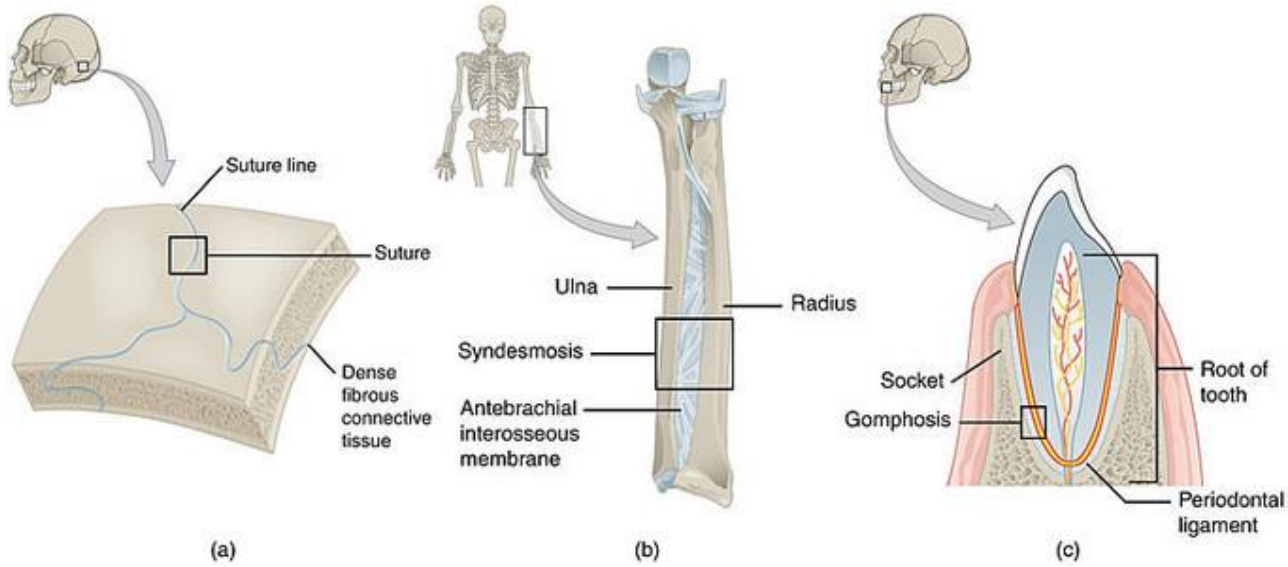


Figure 1: Fibrous joints: Image demonstrating the three types of fibrous joints. (a) Sutures (b) Syndesmosis (c) Gomphosis.

Cartilaginous Joints

Cartilaginous joints are connected by fibrocartilage or hyaline cartilage. They allow more movement than fibrous joints but less than that of synovial joints. These types of joints are further subdivided into primary (synchondroses) and secondary (symphyses) cartilaginous joints. The epiphyseal (growth) plates are examples of synchondroses. Symphyses are found between the manubrium and sternum (manubriosternal joint), intervertebral discs, and the pubic symphysis.

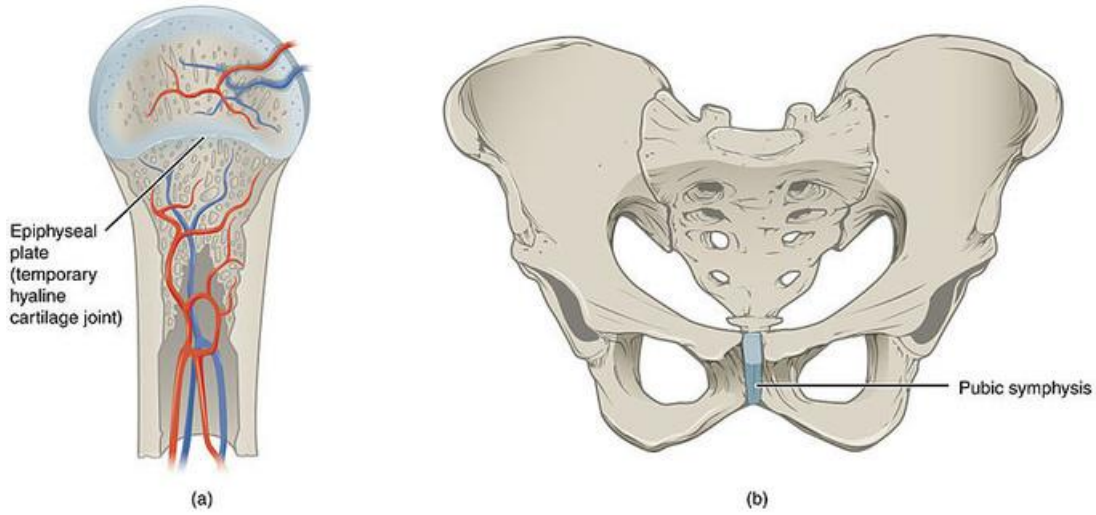


Figure 2: Cartilaginous Joints: Image demonstrates a synchondrosis joint with epiphyseal plate (temporary hyaline cartilage joint) indicated (a) and a symphysis joint (b).

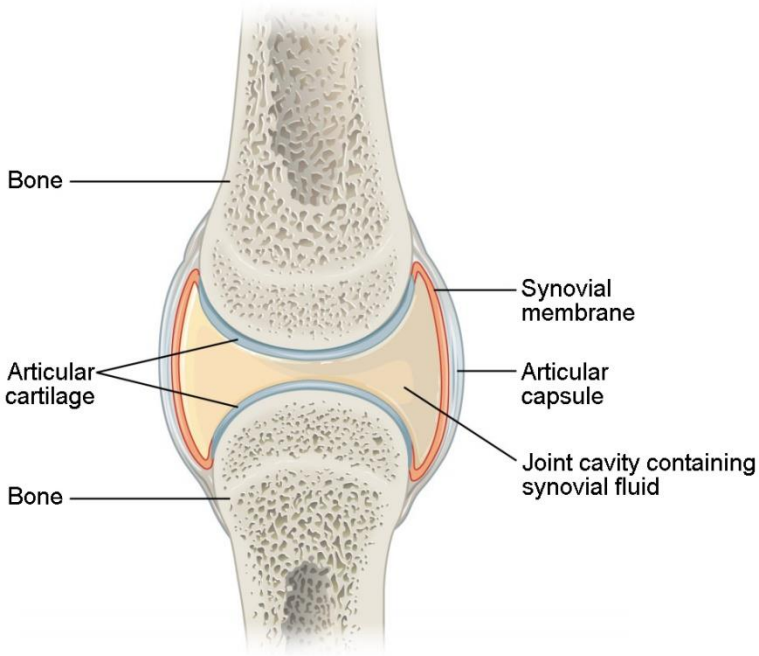


Figure 3: Synovial Joint: This diagram of a synovial joint delineates the articular cartilage, articular capsule, bone, synovial membrane, and joint cavity containing synovial fluid.

Synovial Joints

This is the most common and movable joint type in the body. These joints (also called diarthroses) have a synovial cavity. Their bones are connected by dense irregular connective tissue that forms an articular capsule surrounding the bones' articulating surfaces.

A synovial joint connects bones with a fibrous joint capsule that is continuous with the bones' periosteum. This joint capsule constitutes the outer boundary of a synovial cavity and surrounds the bones' articulating surfaces.

Synovial cavities are filled with synovial fluid. The knees and elbows are examples of synovial joints.

Functional Classification of Joints

Functional classification of joints is based on the type and degree of movement permitted.

Joints or articulations (connections between bones) can be classified in a number of ways. The primary classifications are structural and functional. Functional classification is based on the type and degree of movement permitted.

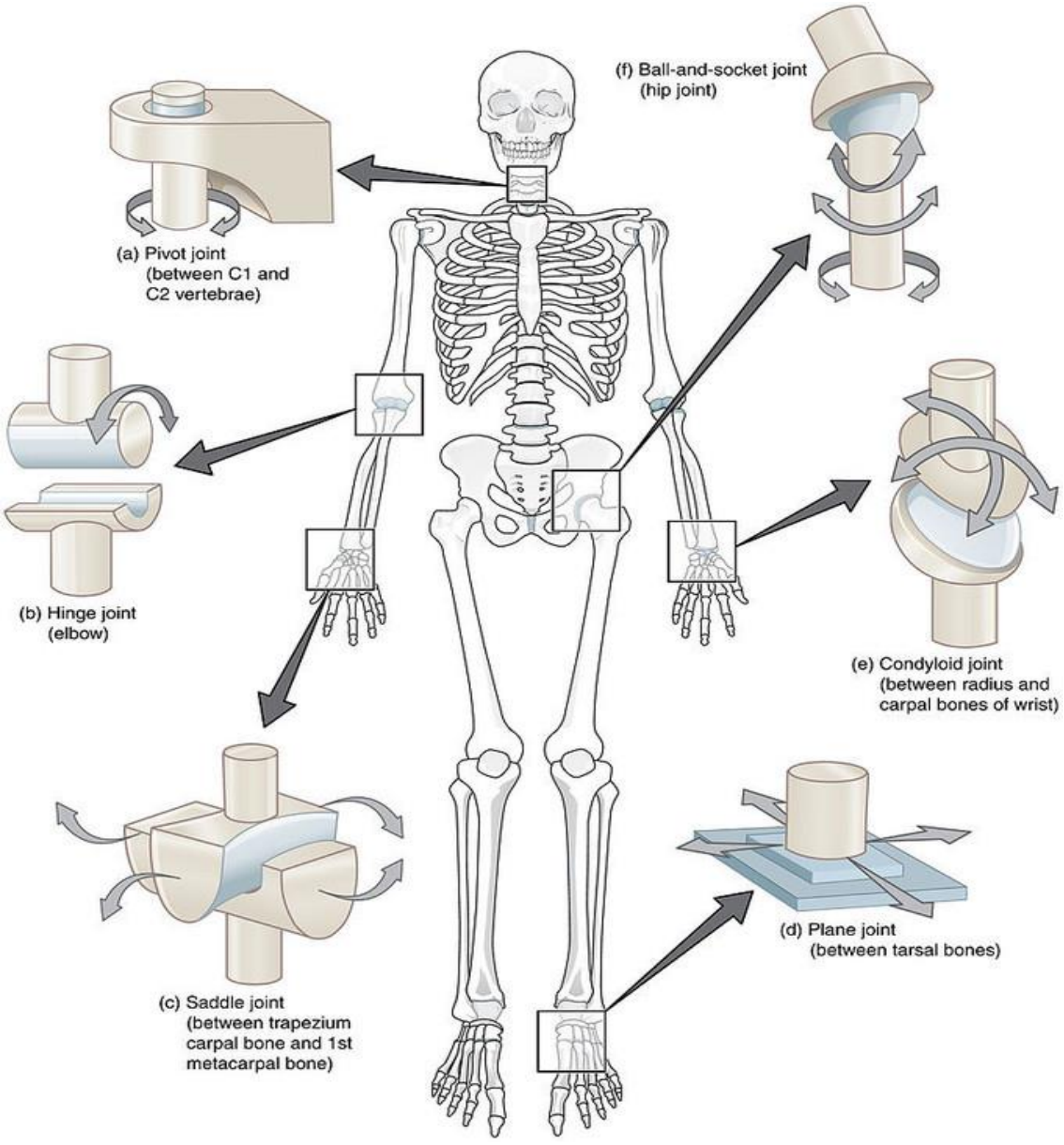


Figure 4: Types of Synovial Joints: Image of a skeleton and skematics of the different classes of synovial joints.

Three Categories of Functional Joints

- Synarthrosis: These types of joints are immobile or allow limited mobility. This category includes fibrous joints such as suture joints (found in the cranium) and gomphosis joints (found between teeth and sockets of the maxilla and mandible).
- Amphiarthrosis: These joints allow a small amount of mobility. Most joints in this category
  include cartilaginous joints such as those found between vertebrae and the pubic symphysis.
- Diarthrosis: These are the freely-movable synovial joints. Synovial joints are further classified based on the different types of movement they provide, including:
  - Plane joint
  - Ball and socket joint
  - Hinge joint
  - Pivot joint
  - Condyloid joint
  - Saddle joint

Types of Joints movements and its articulation

Movement at Synovial Joints

The range of movement allowed by synovial joints is fairly wide. These movements can be classified as: gliding, angular, rotational, or special movement.

Gliding Movement

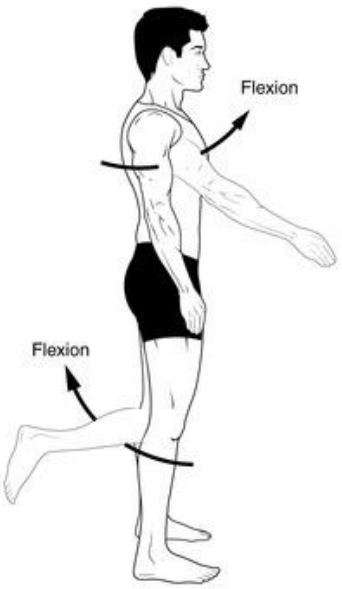
Gliding movements occur as relatively flat bone surfaces move past each other. They produce very little rotation or angular movement of the bones. The joints of the carpal and tarsal bones are examples of joints that produce gliding movements.

Angular Movement

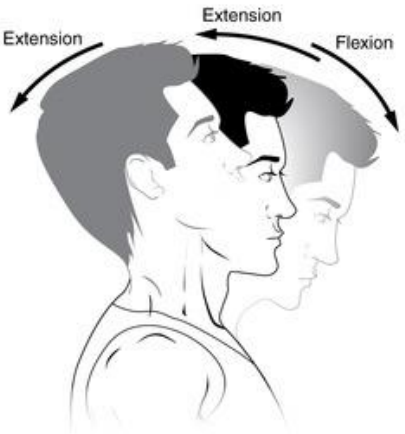
Angular movements are produced by changing the angle between the bones of a joint. There are several different types of angular movements, including flexion, extension, hyperextension, abduction, adduction, and circumduction. Flexion, or bending, occurs when the angle between the bones decreases. Moving the forearm upward at the elbow or moving the wrist to move the hand toward the forearm are examples of flexion. In extension, the opposite of flexion, the angle between the bones of a joint increases. Straightening a limb after flexion is an example of extension. Extension past the normal anatomical position is referred to as hyperextension.

This includes moving the neck back to look upward or bending the wrist so that the hand moves away from the forearm.

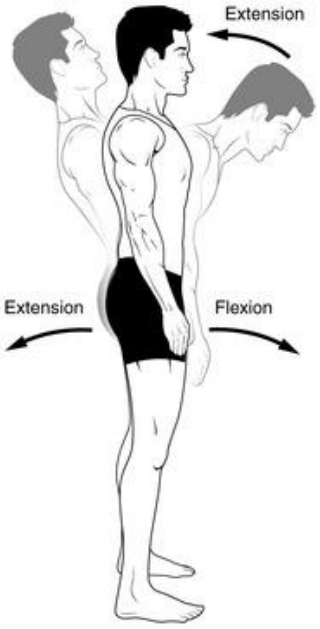
Abduction occurs when a bone moves away from the midline of the body. Examples of abduction include moving the arms or legs laterally to lift them straight out to the side. Adduction is the movement of a bone toward the midline of the body. Movement of the limbs inward after abduction is an example of adduction. Circumduction is the movement of a limb in a circular motion, as in swinging an arm around.



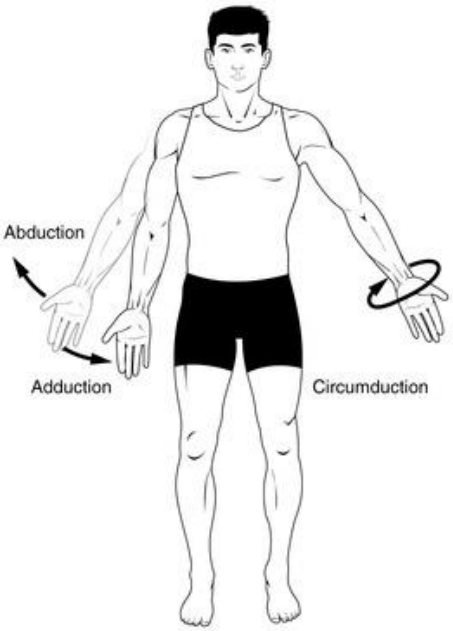
(a) and (b) Angular movements: flexion and extension at the shoulder and knees



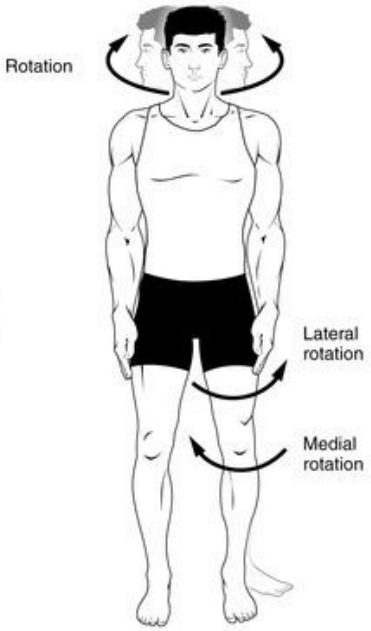
(c) Angular movements: flexion and extension of the neck



(d) Angular movements: flexion and extension of the vertebral column



(e) Angular movements: abduction, adduction, and circumduction of the upper limb at the shoulder



(f) Rotation of the head, neck, and lower limb

Angular and rotational movements: Synovial joints give the body many ways in which to move. (a)–(b) Flexion and extension motions are in the sagittal (anterior–posterior) plane of motion. These movements take place at the shoulder, hip, elbow, knee, wrist,

metacarpophalangeal, metatarsophalangeal, and interphalangeal joints. (c)–(d) Anterior bending of the head or vertebral column is flexion, while any posterior movement of the head is extension. (e) Abduction and adduction are motions of the limbs, hand, fingers, or toes in the coronal (medial–lateral) plane of movement. Moving the limb or hand laterally away from the body, or spreading the fingers or toes, is abduction. Adduction brings the limb or hand toward or across the midline of the body or brings the fingers or toes together. Circumduction is the movement of the limb, hand, or fingers in a circular pattern, using the sequential combination of flexion, adduction, extension, and abduction motions. Adduction/abduction and circumduction take place at the shoulder, hip, wrist, metacarpophalangeal, and metatarsophalangeal joints. (f) Turning of the head side to side or twisting of the body is rotation. Medial and lateral rotation of the upper limb at the shoulder or lower limb at the hip involves turning the anterior surface of the limb toward the midline of the body (medial or internal rotation) or away from the midline (lateral or external rotation).

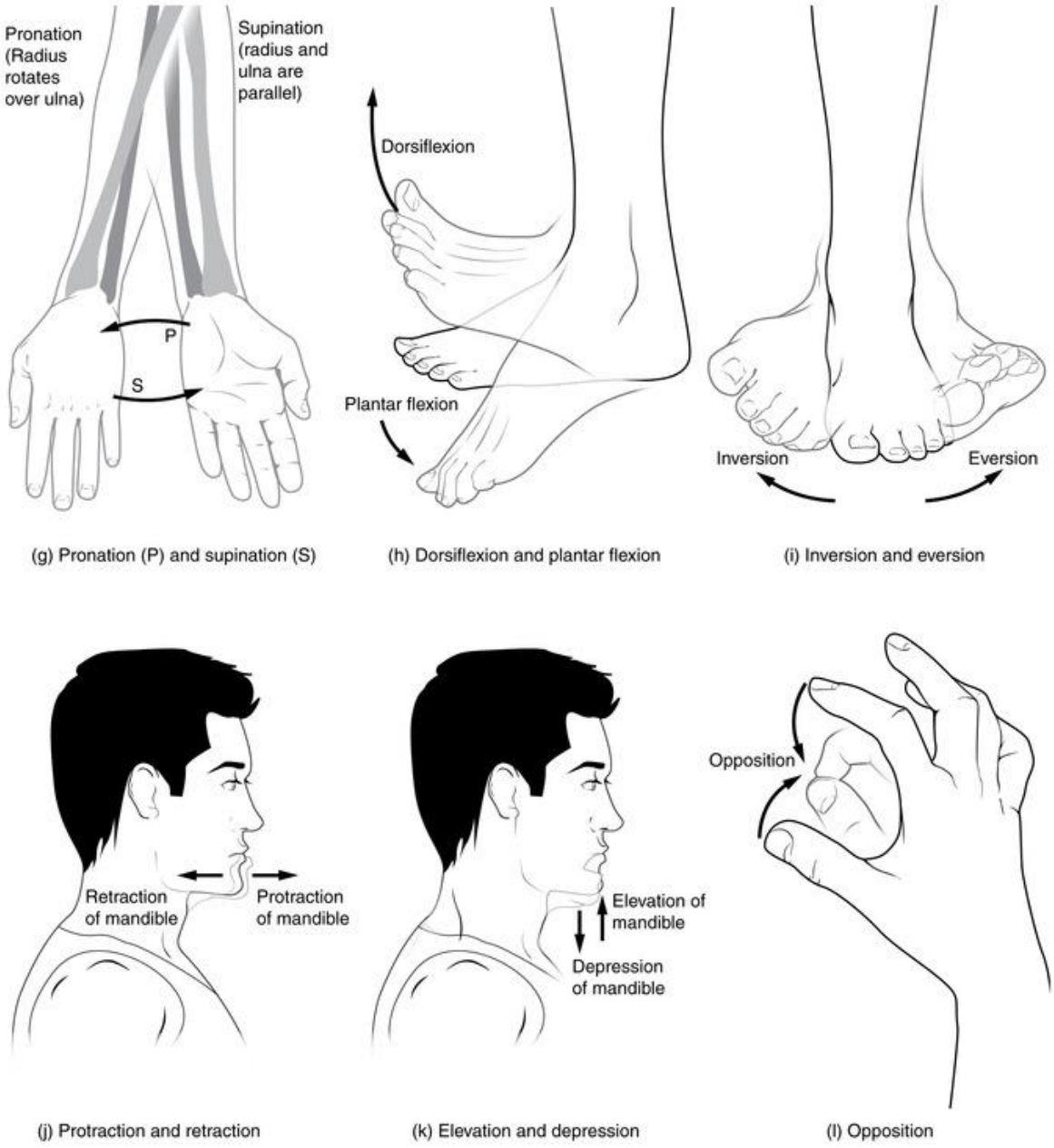
Rotational Movement

Rotational movement is the movement of a bone as it rotates around its longitudinal axis. Rotation can be toward the midline of the body, which is referred to as medial rotation, or away from the midline of the body, which is referred to as lateral rotation. Movement of the head from side to side is an example of rotation.

Special Movements

Some movements that cannot be classified as gliding, angular, or rotational are called special movements. Inversion involves moving the soles of the feet inward, toward the midline of the body. Eversion, the opposite of inversion, involves moving of the sole of the foot outward, away from the midline of the body. Protraction is the anterior movement of a bone in the horizontal plane. Retraction occurs as a joint moves back into position after protraction. Protraction and retraction can be seen in the movement of the mandible as the jaw is thrust outwards and then back inwards. Elevation is the movement of a bone upward, such as

shrugging the shoulders, lifting the scapulae. Depression is the opposite of elevation and involves moving the bone downward, such as after the shoulders are shrugged and the scapulae return to their normal position from an elevated position. Dorsiflexion is a bending at the ankle such that the toes are lifted toward the knee. Plantarflexion is a bending at the ankle when the heel is lifted, such as when standing on the toes. Supination is the movement of the radius and ulna bones of the forearm so that the palm faces forward or up. Pronation is the opposite movement, in which the palm faces backward or down. Opposition is the movement of the thumb toward the fingers of the same hand, making it possible to grasp and hold objects.



(g) Pronation (P) and supination (S) (h) Dorsiflexion and plantar flexion (i) Inversion and eversion

(j) Protraction and retraction (k) Elevation and depression (l) Opposition

Special movements: (g) Supination of the forearm turns the palm upward in which the radius and ulna are parallel, while forearm pronation turns the palm downward in which the radius crosses over the ulna to form an "X." (h) Dorsiflexion of the foot at the ankle joint moves the top of the foot toward the leg, while plantar flexion lifts the heel and points the toes. (i) Eversion of the foot moves the bottom (sole) of the foot away from the midline of the body, while foot inversion faces the sole toward the midline. (j) Protraction of the mandible pushes the chin

forward, while retraction pulls the chin back. (k) Depression of the mandible opens the mouth, while elevation closes it. (l) Opposition of the thumb brings the tip of the thumb into contact with the tip of the fingers of the same hand.

Subject: Human Anatomy and Physiology-I

Unit No: III

Organization of nervous system

The nervous system coordinates voluntary and involuntary actions in the body by sending and receiving information. The nervous system is comprised of an enormous number of cells (over 100 billion), primarily of two types: **neurons** (the signaling units) and **glial cells** (the supporting units). However, nervous system function is mostly a story of the neuron. The neuron is the functional unit of the nervous system and is designed to transmit information between cells. Interestingly, neurons with a particular function are found in a predictable location. This regularity in structure has permitted neurobiologists to categorically organize the nervous system based on location and function.

Thus, the nervous system can first be divided into two major parts: the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS consists of neurons associated with central processing and which are located in the brain and spinal cord. The peripheral nervous system (PNS) consists of neurons associated with sensory input (afferent) and motor output (efferent), and functions to connect the central nervous system to all other parts of the body. Stated another way, if the entire structure of the neuron is contained within the brain and/or spinal cord, the neuron would be considered part of the CNS. In contrast, if any part of the neuronal structure is located outside of the brain and/or spinal cord the neuron would be considered part of the PNS

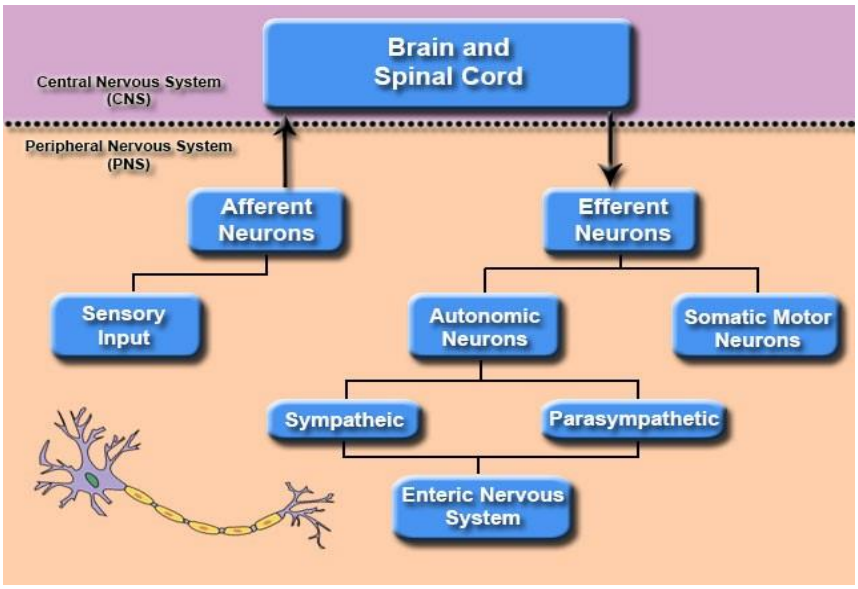


Figure 1: Divisions of Nervous system

The Central Nervous System

The brain and spinal cord are the organs of the central nervous system. Because they are so vitally important, the brain and spinal cord, located in the dorsal body cavity, are encased in bone for protection. The brain is in the cranial vault, and the spinal cord is in the vertebral canal of the vertebral column. Although considered to be two separate organs, the brain and spinal cord are continuous at the foramen magnum.

The Peripheral Nervous System

The organs of the peripheral nervous system are the nerves and ganglia. Nerves are bundles of nerve fibers, much like muscles are bundles of muscle fibers. Cranial nerves and spinal nerves extend from the CNS to peripheral organs such as muscles and glands. Ganglia are collections, or small knots, of nerve cell bodies outside the CNS.

The peripheral nervous system is further subdivided into an afferent (sensory) division and an efferent (motor) division. The afferent or sensory division transmits impulses from peripheral organs to the CNS. The efferent or motor division transmits impulses from the CNS out to the peripheral organs to cause an effect or action.

Finally, the efferent or motor division is again subdivided into the somatic nervous system and the autonomic nervous system. The somatic nervous system, also called the somatomotor or somatic efferent nervous system, supplies motor impulses to the skeletal muscles. Because these nerves permit conscious control of the skeletal muscles, it is sometimes called the voluntary nervous system. The autonomic nervous system, also called the visceral efferent nervous system, supplies motor impulses to cardiac muscle, to smooth muscle, and to glandular epithelium. It is further subdivided into sympathetic and parasympathetic divisions. Because the autonomic nervous system regulates involuntary or automatic functions, it is called the involuntary nervous system.

Neuron and Neuroglia

NEURON STRUCTURE

Neurons have four specialized structures that allow for the sending and receiving of information: the cell body (soma), dendrites, axon and axon terminals (see lowest figure).

Cell body or soma: The cell body is the portion of the cell that surrounds the nucleus and plays a major role in synthesizing proteins.

Dendrites: Dendrites are short, branched processes that extend from the cell body. Dendrites function to receive information, and do so through numerous receptors located in their membranes that bind to chemicals, called neurotransmitters.

Axon: An axon is a large process that extends from the cell body at a point of origin-called the axon hillock-and functions to send information. In contrast to the shorter dendrites, the axon can extend for more than a meter. Because of this length, the axon contains microtubules and is surrounded by myelin. Microtubules are arranged inside the axon as parallel arrays of long strands that act as highways for the movement of materials to and from the soma. Specialized motor proteins "walk" along the microtubules, carrying material away from the soma (anterograde transport) or back to the soma (retrograde transport). This system can move materials down the axon at rates of 400mm/day (see lowest figure). Myelin consists of totally separate cells that coil and wrap their membranes around the outside of the axon. These are essential for electrical insulation and to speed up action potential propagation.

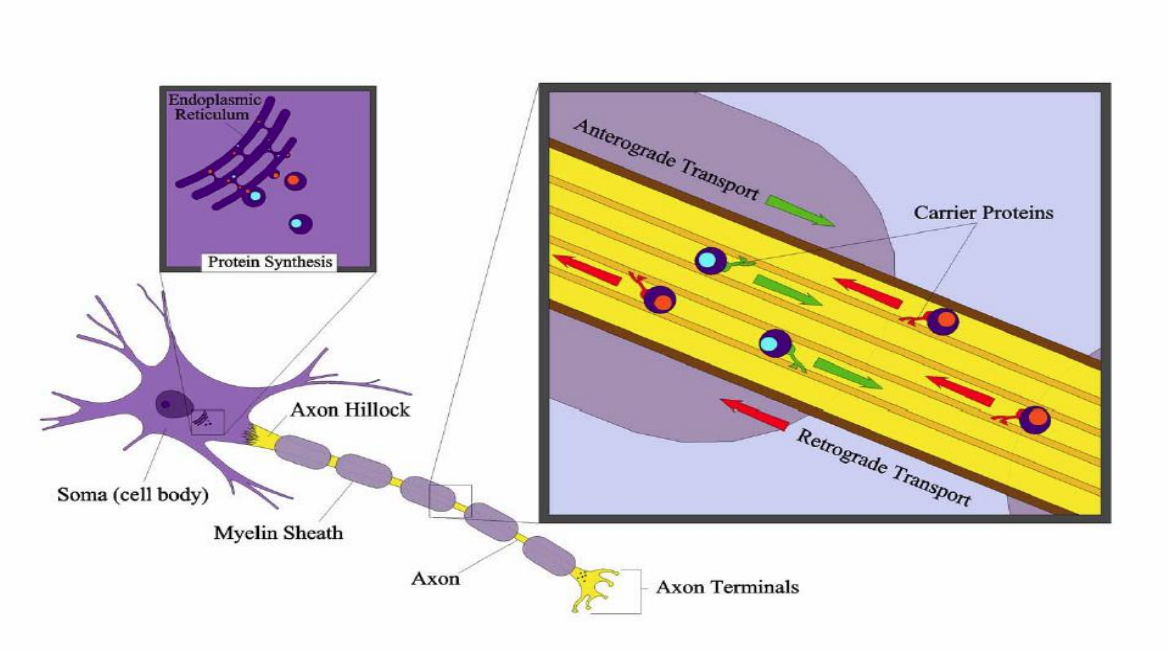


Figure 1: Structure of a Neuron

Axon terminals: Once an axon reaches a target, it terminates into multiple endings, called axon terminals. The axon terminal is designed to convert the electrical signal into a chemical signal in a process called synaptic transmission (further explained in the section "Physiology of the Neuron").

Most neurons are amitotic or lose their ability to divide. Exceptions to this rule are found in olfactory neurons (those associated with smell) and hippocampal regions of the brain. Fortunately, lifespans of amitotic neurons is near 100 years. Still, if a neuron is damaged or lost, it is not easily replaced. For this reason, there is usually limited recovery from serious brain or spinal cord injuries. Perhaps the slow recovery rate or lack of regeneration is to ensure that learned behavior and memories are preserved throughout life. Neurons also have exceptionally high metabolic rates and subsequently require high levels of glucose and oxygen. The body will go to great lengths to ensure that neurons are adequately fed; in fact, if for some reason the brain detects that it is not receiving adequate amounts of nutrition, the body will shut down immediately (i.e., faint).

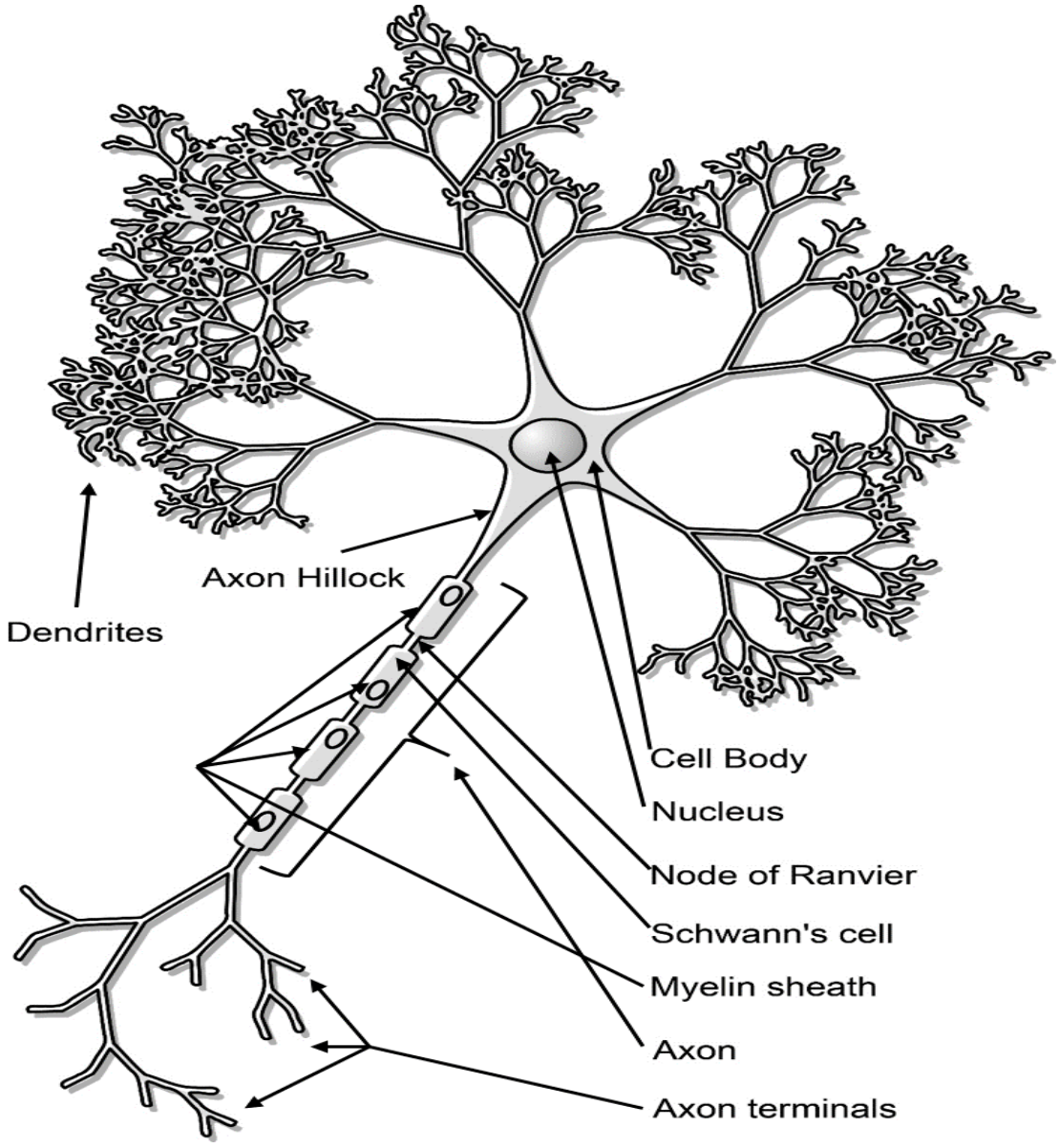


Figure 2: Illustration of key components of a Neuron

Neuroglia: Neuroglia (glia) are cells that support and protect neurons. The following four neuroglia are found in the CNS

- **Astrocytes** have numerous processes that give the cell a star-shaped appearance. Astrocytes maintain the ion balance around neurons and control the exchange of materials between blood vessels and neurons.
- ***Oligodendrocytes*** have fewer processes than astrocytes. They wrap these cytoplasmic processes around neurons to create an insulating barrier called a myelin sheath.

- ***Microglia*** are phagocytic macrophages that provide a protective function by engulfing microorganisms and cellular debris.
- ***Ependymal cells*** line the fluid-filled cavities of the brain and spinal cord. Many are ciliated.

Two kinds of neuroglia are found in PNS:

- ***Schwann cells*** (neurolemmocytes) wrap around axons to produce an insulating myelin sheath. Schwann cells provide the same function in the PNS as oligodendrocytes provide in the CNS.
- ***Satellite cells*** are located in ganglia, where they surround the cell bodies of neurons.

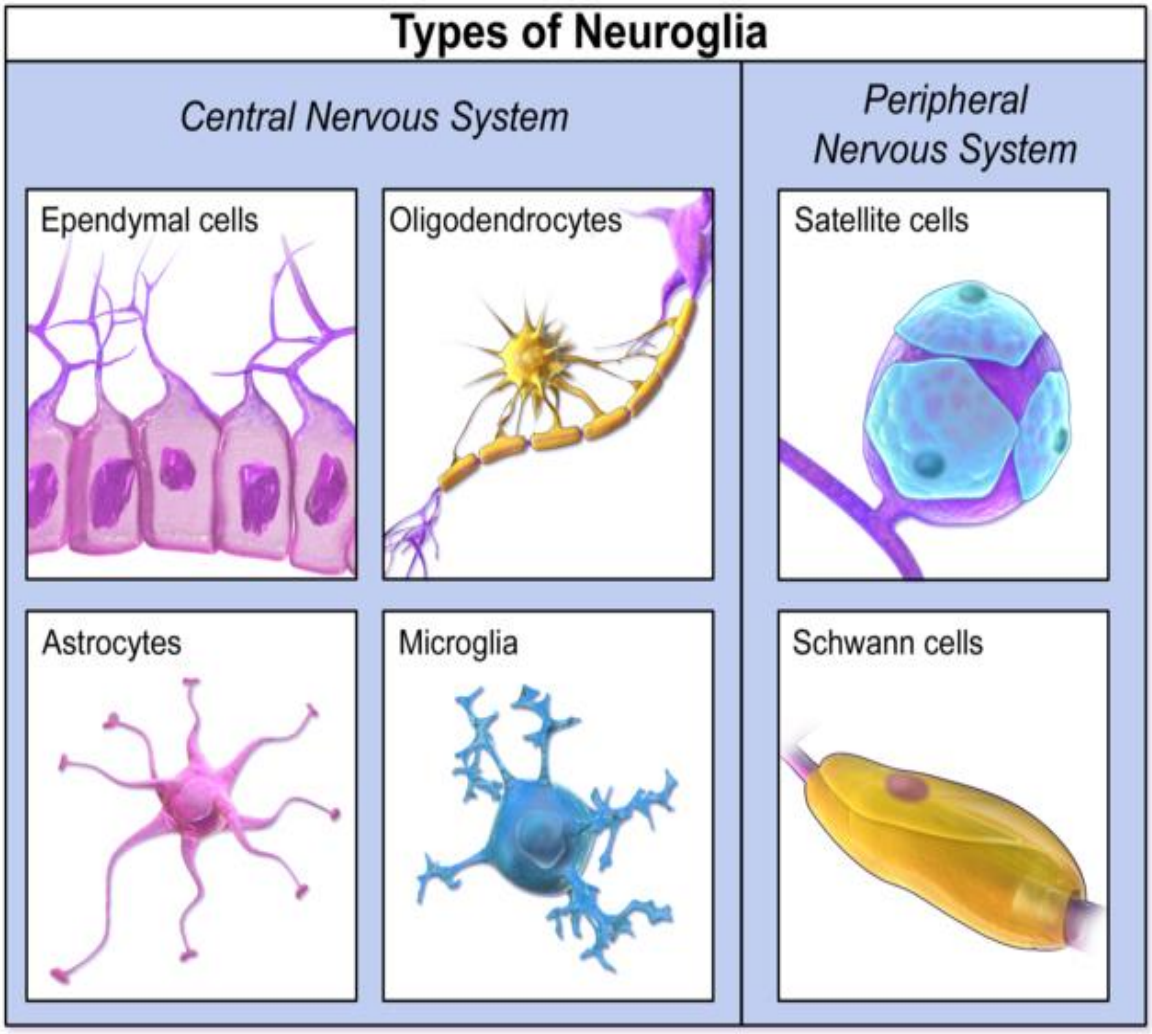


Figure 1: Types of Neuroglia in CNS and PNS

Classification and properties of Nerve fiber

Neurones can be classified by structure or by function. Neurones with different functions have differing structures, which is visible histologically.

Structural Classification

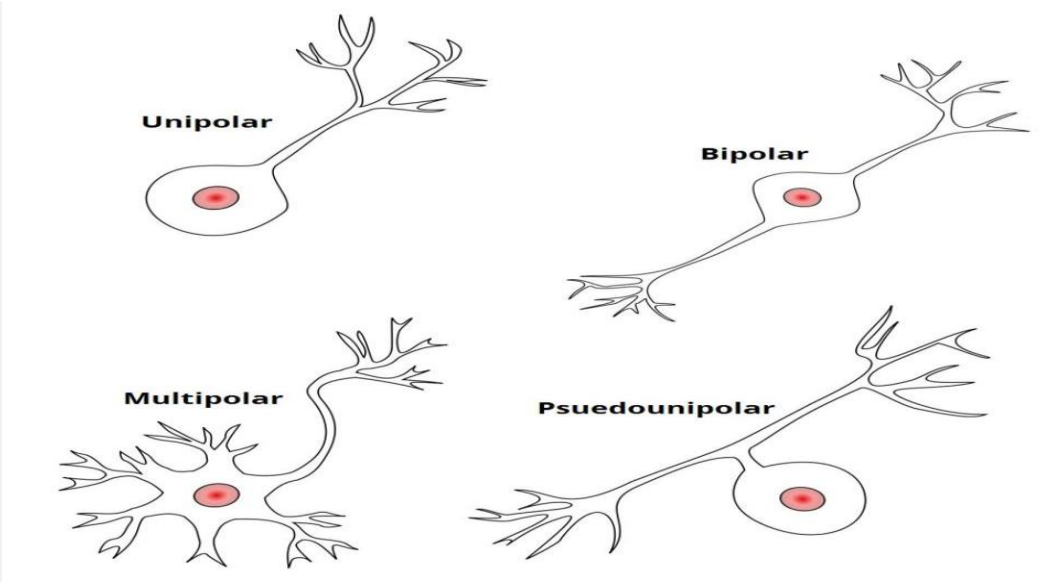


Fig 1 – Structural classification of neurones.

Neurones can be either unipolar, pseudounipolar, bipolar or multipolar.

- **Unipolar** – Here the cell body is at one end of a single unbranched axon, and there are no dendrites. These can be found in the cochlear nucleus of the brain.
- **Pseudounipolar** – They have one axon which is divided into two branches by the presence of the cell body. Sensory neurones are all pseudounipolar.
- **Bipolar** – These neurones have two processes arising from a central cell body – typically one axon and one dendrite. These cells are found in the retina.
- **Multipolar** – They have one axon and many dendrites, with a cell body displaced to one side of the axon. Motor neurones are a prime example of this.

Functional Classification

There are three broad functional classifications of nerves – **sensory** (afferent), **intermediate** and **motor** (efferent). There are key structural differences between these three types:

- **Sensory nerves** – small axons and psuedounipolar structure.
- **Motor nerves** – larger axons and multipolar structure.
- **Intermediate neurones** – central cell body and many dendrites.

Sensory and motor nerves are located within the PNS, whereas intermediate nerves are found in the CNS.

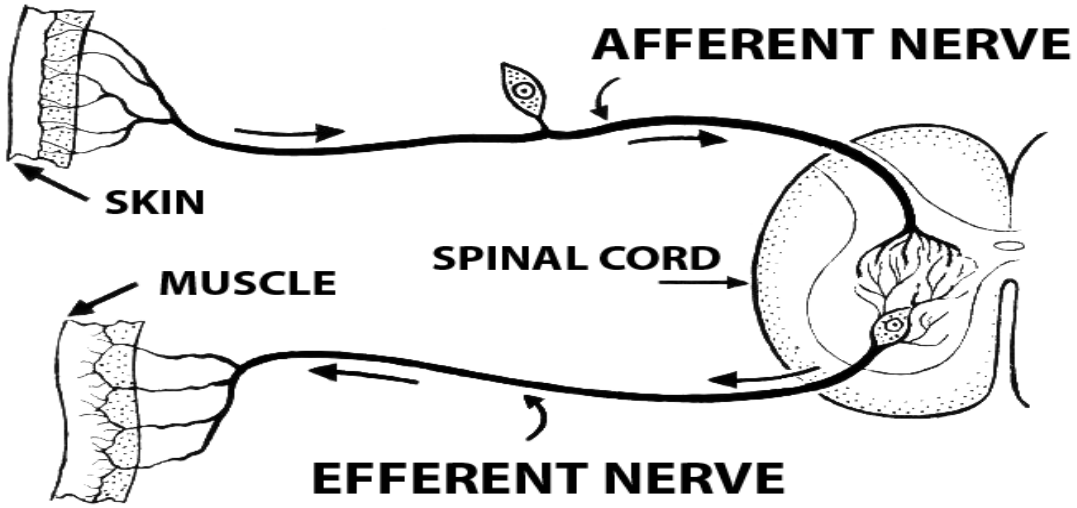


Figure 2: Functional Classification of Neurons

Histological Classification: Histologically, as myelinated or non-myelinated

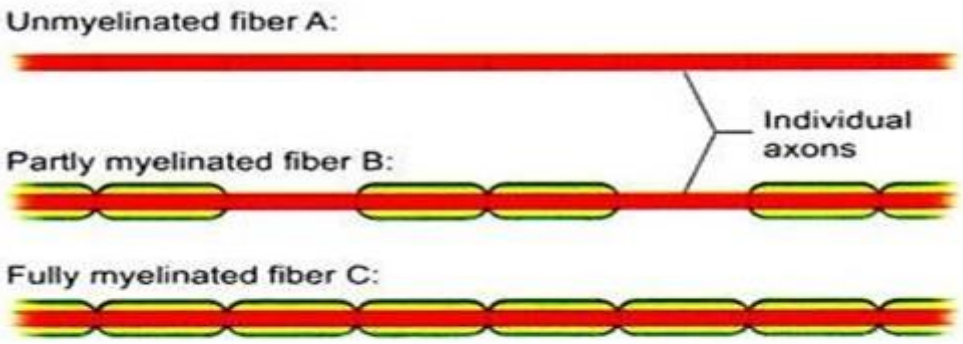


Fig. 3 : A typical non-myelinated and myelinated nerve fiber

Functions of the Myelin Sheath:

1. In myelinated nerve fibers, the velocity of impulse transmission is faster because the process of depolarization occurs only at the nodes of Ranveir and, therefore, it appears as if the impulses are jumping from one node to the successive node.

This type of impulse transmission is known as saltatory or leaping type of conduction. Because of this type of impulse transmission, the energy required for conduction is markedly reduced.

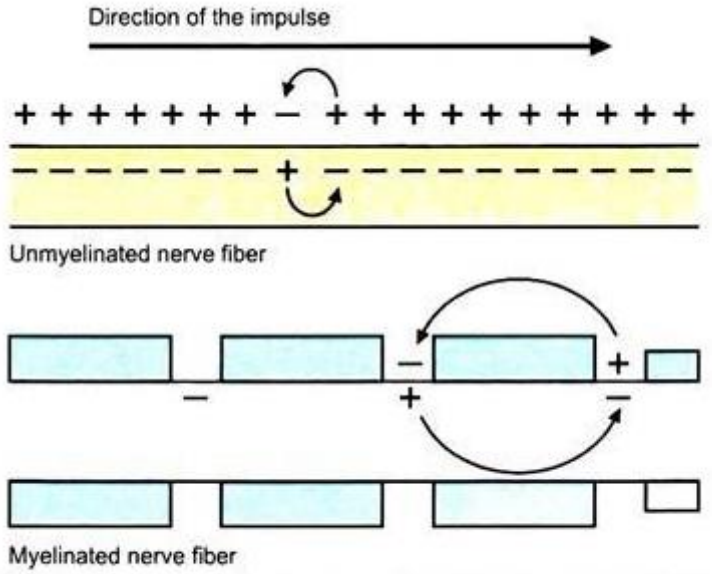


Fig.4 The process of impulse conduction in unmyelinated and myelinated nerve fibers. In myelinated nerve fiber, the impulse jumps from one node of Ranvier to the next

2. It acts as a protective sheath minimizing injury to the nerve fiber.

3. It acts as an insulator and prevents cross transmission of impulses from one fiber to the other in a mixed nerve.

Properties of Nerve Fiber:

i. Excitability:

When a stimulus is applied, the nerve fiber demonstrates a change in its electrical activity from its resting state.

ii. Conductivity:

It is the ability of the nerve fiber to transmit impulses all along the whole length of axon without any change in the amplitude of the action potential. This type of conduction is termed as decrementless conduction.

iii. Refractory period

It is the duration after an effective stimulus, when a second stimulus is applied, there will be no response for the second stimulus.

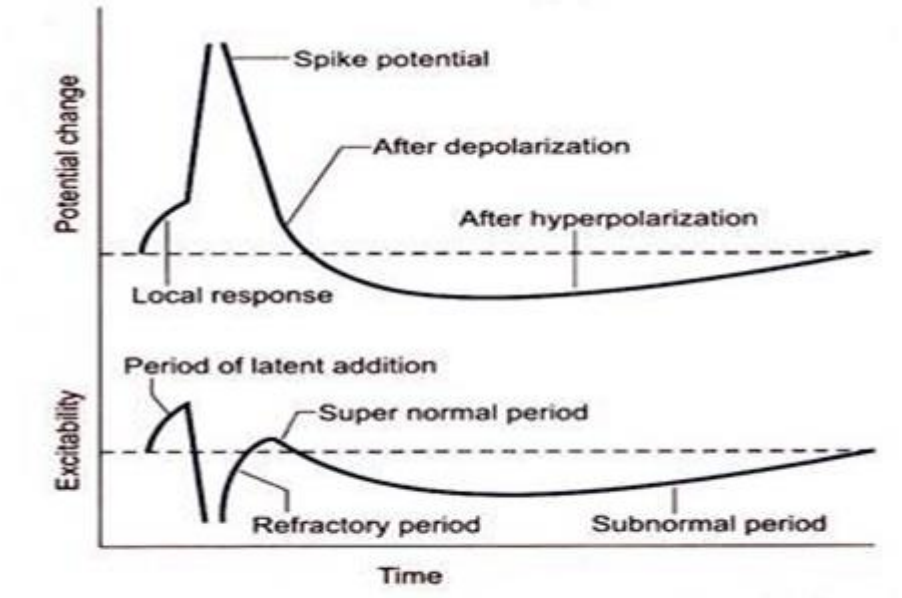


Fig: 5 Excitability of the nerve fiber during absolute and relative refrectory periods

a. From the time of the application of the stimulus till the initial one-third of the repolarization phase, the nerve fiber excitability will be zero and is completely refractory for the second stimulus. This duration is known as absolute refractory period.

b. Relative refractory period is the duration after an effective stimulus, when a second stimulus, which is slightly above threshold, is applied there will be response for the second stimulus as well.

iv. All or none law:

It states that, when the tissue is stimulated with threshold or more than threshold strength, the amplitude of response will remain the same but for a stimulus of less than threshold strength, there will not be any response.

All or none is obeyed by:

a. A single nerve fiber.

b. A single skeletal muscle fiber.

c. A motor unit.

d. Whole of cardiac muscle.

e. A single fiber of multi-unit smooth muscle.

f. Whole of visceral smooth muscle

Electrophysiology of nerve fiber and action potential

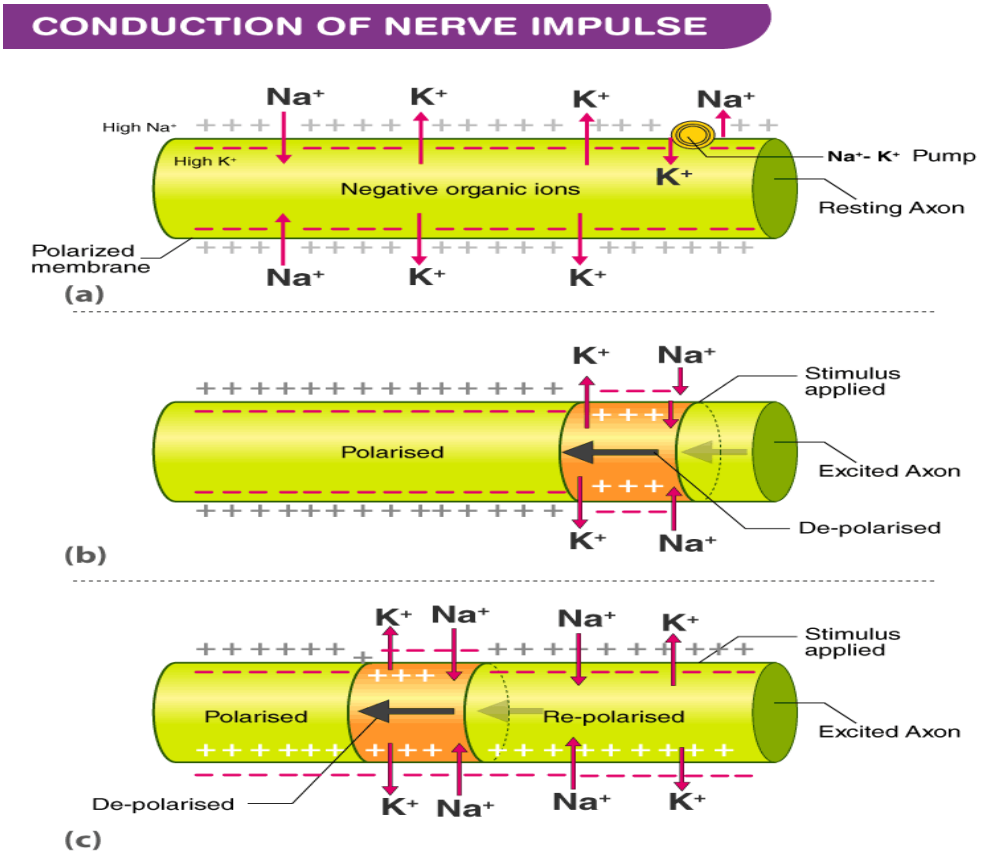


Figure 1: Conduction of Nerve impulse

A nerve impulse is the electric signals that pass along the dendrites to generate a nerve impulse or an action potential. An action potential is the movement of ions in and out of the cell. It specifically involves sodium and potassium ions. They are moved in and out of the cell through sodium and potassium channels and sodium-potassium pump.

Conduction of nerve impulse occurs due to the presence of active and electronic potentials along the conductors. Transmission of signals internally between the cells is achieved through a synapse. Nerve conductors comprise of relatively higher membrane resistance and low axial resistance. The electrical synapse has its application in escape reflexes, heart and in the retina of vertebrates. They are mainly used whenever there is a requirement of fast response and timing being crucial. The ionic currents pass through the two cell membrane when the action potential reaches the stage of such synapse.

Mechanism of Transmission of Nerve Impulse

The axon or nerve fibers are in the form of a cylinder wherein the interior of the axon is filled with axoplasm and the exterior is covered with axolemma. The nerve fibers are immersed in ECF. The solution is in ionic form that is present in axoplasm and extracellular fluid or ECF.

Outside the axon, the negatively charged chloride ions are neutralized in the presence of positively charged sodium ions. Negatively charged protein molecules are neutralized in the presence of potassium ions within the axoplasm. The membrane of a neuron -ve inside and +ve outside. Resting potential would be the difference in charge. The difference in charge might vary from seventy to ninety millivolts, as a result, the membrane would be polarized. Sodium potassium metallic pump operates to keep resting potential in equilibrium.

The pump is placed on the axon membrane. Now the potassium ions are pumped from ECF to axoplasm and sodium ions are placed from axoplasm to ECF. The concentration level of sodium ions would be between twenty-eight to thirty times more inside the neuron membrane and the concentration level of sodium ions would be fourteen times more in outside the neuron membrane.

The sodium-potassium pump stops operating when a stimulus is applied to a membrane of a nerve fiber. The stimulus could be either electrical, chemical or mechanical. The potassium ions rush outside the membrane and sodium ions rush inside the membrane as a result negative charges are present outside and positive charges are present inside.

The nerve fibers are either depolarized or they are said to be in action potential. The action potential traveling along the membrane would be the nerve impulse. It is around + 30 mV. The sodium-potassium pump starts to operate once the action potential is completed. As a result, the axon membrane will obtain a resting potential by repolarization.

Now the process takes place in a reverse order. It is a reversal of the process that has taken place during an action potential. Here, potassium ions will be rushed inside and sodium ions will be rushed outside. Impulse would not be transmitted through the nerve fiber during the refractory period.

In a case of white fibers, saltatory propagation takes place. That is impulse jumps from node to node and it increases with increase in speed of nerve impulse. It is around twenty times faster compared to that of the non-medullated nerve fibers. The transmission of nerve impulse would rely upon the diameter of the fiber. For instance, the nerve impulse of a mammal is one twenty meters per second whereas nerve impulse of a Frog is 30 meters per second.

An action potential (AP) is the mode through which a neuron transports electrical signals. It is defined as a brief change in the voltage across the membrane due to the flow of certain ions into and out of the neuron.

The Resting Membrane Potential

The resting membrane potential of cells varies depending on the cell type, the resting potential for neurons typically sits between -50 and -75mV. This value depends on the types of ion channels that are open and the concentrations of different ions in the intracellular and extracellular fluids. In neurons **K+** and organic anions are typically found at a higher

concentration within the cell than outside, whereas Na+ and Cl- are typically found in higher concentrations outside the cell.

This difference in concentrations provide a concentration gradient for ions to flow down when their channels are open. At rest, most neurons are permeable to K+, Na+ and Cl-, as such they will all readily flow down their concentration gradients, with K+ moving out of the cells and Na+ and Cl- moving in to the cell. However the cell is most permeable to K+, as such this exerts the greatest influence on the resting membrane potential – and the value is closest to the **equilibrium potential** of K+ (the membrane potential at which the concentration gradient for an ion is balanced) out of the three ions.

These concentration gradients are maintained by the action of the **Na+/K+ ATPase** via active transport, which in turn allows the membrane potential to be maintained.

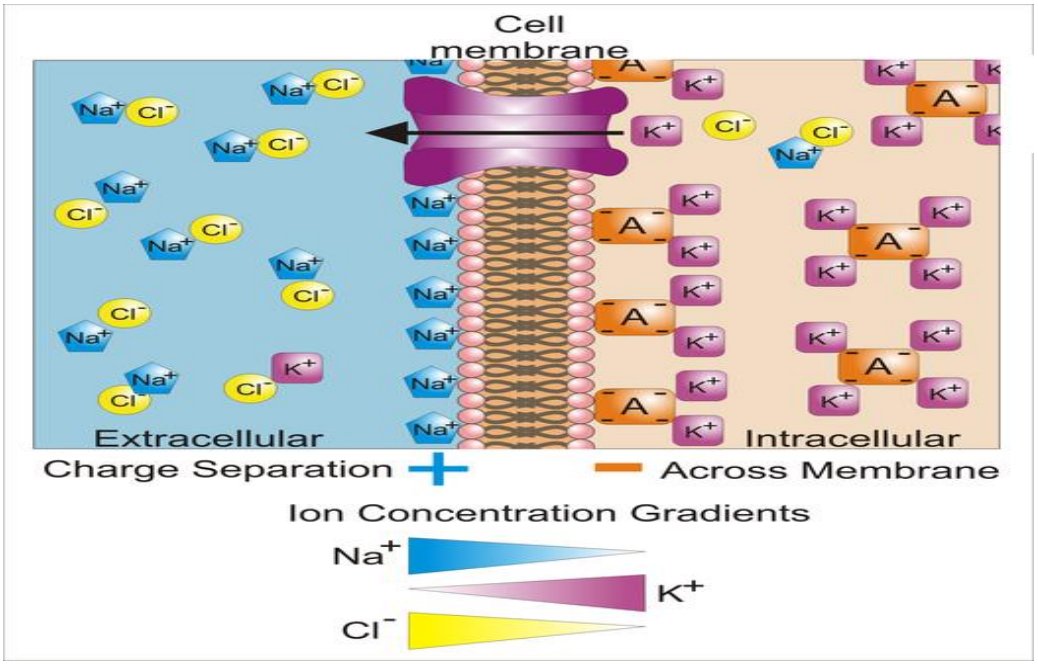


Fig 2 – Diagram demonstrating the ions involved in setting the resting membrane potential, as well as the direction of the ion concentration gradients.

Generation of Action Potentials

During the resting state the membrane potential arises because the membrane is selectively permeable to K+. An action potential begins at the axon hillock as a result of depolarisation. During **depolarisation** voltage gated sodium ion channels open due to an electrical stimulus. As the sodium rushes back into the cell the positive sodium ions raise the charge inside the cell from negative to positive.

If a threshold is reached, then an action potential is produced. Action potentials will only occur if a threshold is reached, as such they are described as "**all or nothing**". If the threshold is reached then the maximum response will be elicited.

Once the cell has been depolarised the voltage gated sodium ion channels close. The raised positive charge inside the cell causes potassium channels to open, K+ ions now move down their **electrochemical gradient** out of the cell. As the K+ moves out of the cell the membrane potential falls and starts to approach the resting potential.

Typically, repolarisation overshoots the resting membrane potential, making the membrane potential more negative. This is known as **hyperpolarisation.** It is important to note that the Na+/K+ ATPase is not involved in the repolarisation process following an action potential.

Every action potential is followed by a **refractory period.** This period can be further divided into the absolute refractory period and the relative refractory period. This period occurs as once the sodium channels close after an AP, they enter an inactive state during which they cannot be reopened regardless of the membrane potential. This is known as the absolute refractory period.

Slowly the sodium channels come out of inactivation. This is known as the **relative refractory period.** During this period the neuron can be excited with stimuli stronger than one normally needed to initial an AP. Early on in the relative refractory period the strength of the stimulus

required is very high and gradually it becomes smaller throughout the relative refractory period as more sodium channels recover from inactivation.

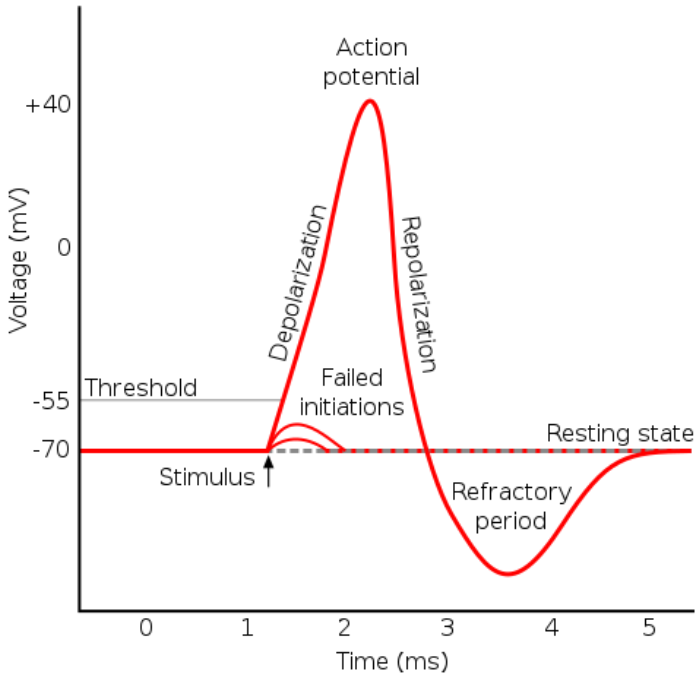


Fig 3 – Diagram showing the phases of an action potential in relation to the membrane voltage over time.

Propagation of Action Potentials

Action potentials are propagated along the axons of neurons via local currents. Local current flow following depolarisation results in depolarisation of the adjacent axonal membrane and where this reaches threshold, further action potentials are generated. The areas of membrane that have recently depolarised will not depolarise again due to the refractory period – meaning that the action potential will only travel in one direction.

These local currents would eventually decrease in charge until threshold is no longer reached. The distance that this would take depends on the membrane capacitance and resistance:

- Membrane capacitance – the ability to store charge, lower capacitance results in a greater distance before threshold is no longer reached
- Membrane resistance – depends on the number of ion channels open, the lower the number the more channels are open. A higher membrane resistance results in a greater distance before threshold is no longer reached.

Myelinated Axons

In order to allow rapid conduction of electrical signals through a neuron and make them more energy efficient certain neuronal axons are covered by a **myelin** sheath. The myelin sheath surrounds the axon to form an insulating layer. Further information on the myelin sheath can be found here.

Myelination improves conduction by increasing the membrane resistance and decreasing the membrane **capacitance.**

There are periodic gaps along a myelinate axon where there is no myelin and the axonal membrane is exposed. This gaps are called **Nodes of Ranvier.** Myelinated sections of the axon lack voltage gated ion channels where as there is a high density of ion channels in the Nodes of Ranvier. For this reason, action potential can only occur at the nodes.

The myelin sheath acts as good insulator so the action potential is able to propagate along the neurone at a higher rate than would be possible in unmyelinated neurons. The electrical signals are rapidly conducted from one node to the next, where is causes depolarisation of the membrane above the threshold and initiates another action potential which is conducted to the next node. In this manner an action potential is rapidly conducted down a neuron. This is known as **saltatory conduction.**

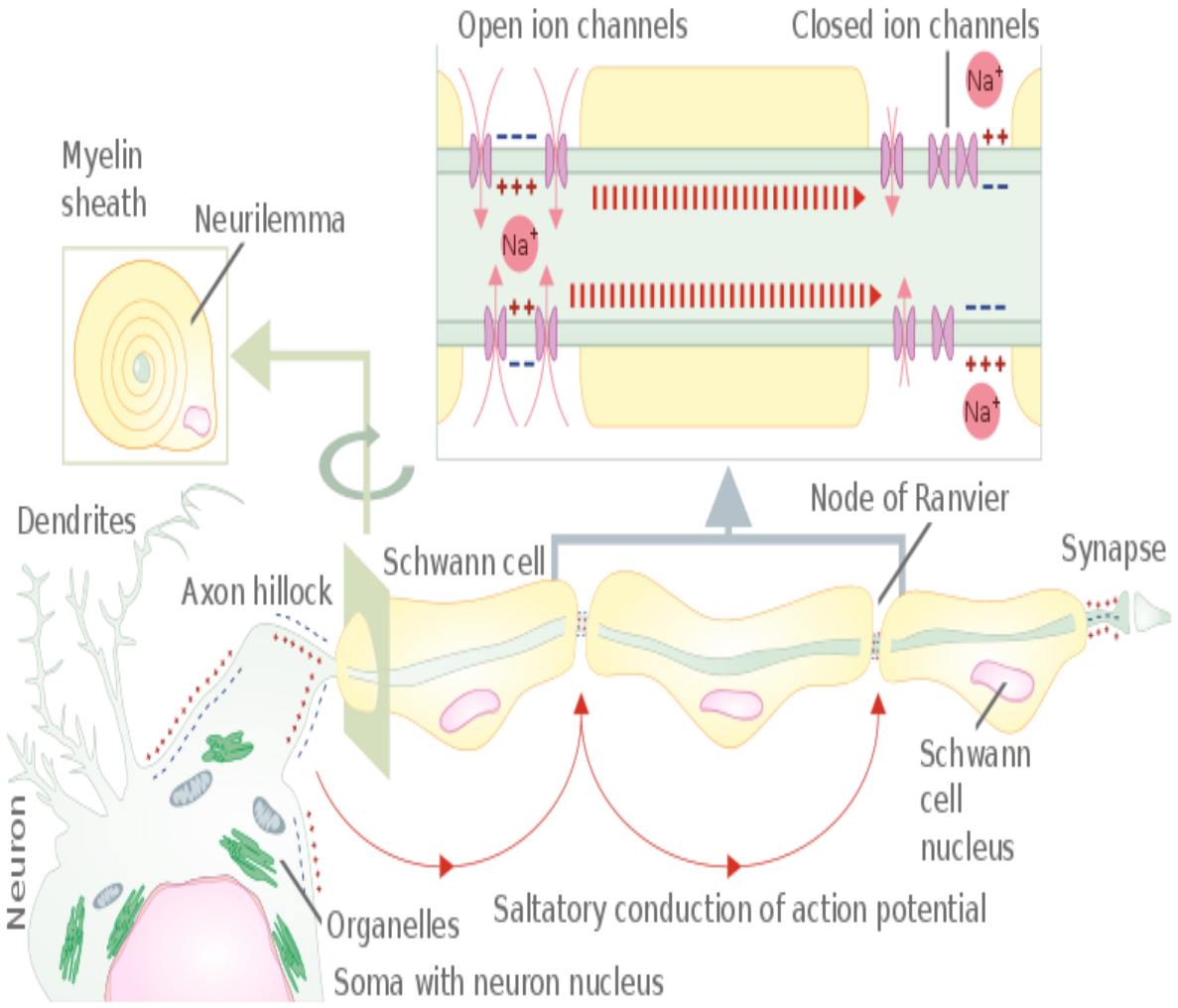


Fig 4 – Diagram to show how the myelin sheath results in saltatory conduction of an action potential along an axon.

Nerve impulse, receptors and synapse

Nerve impulses are electrical in nature. They result from a difference in electrical charge across the plasma membrane of a neuron. How does this difference in electrical charge come about? The answer involves **ions**, which are electrically charged atoms or molecules.

Resting Potential

When a neuron is not actively transmitting a nerve impulse, it is in a resting state, ready to transmit a **nerve impulse**. During the resting state, the **sodium-potassium pump** maintains a difference in charge across the cell membrane (see **Figure** below). It uses energy in ATP to pump positive sodium ions (Na^+) out of the cell and potassium ions (K^+) into the cell. As a result, the inside of the neuron is negatively charged compared to the extracellular fluid surrounding the neuron. This is due to many more positively charged ions outside the cell compared to inside the cell. This difference in electrical charge is called the **resting potential.**

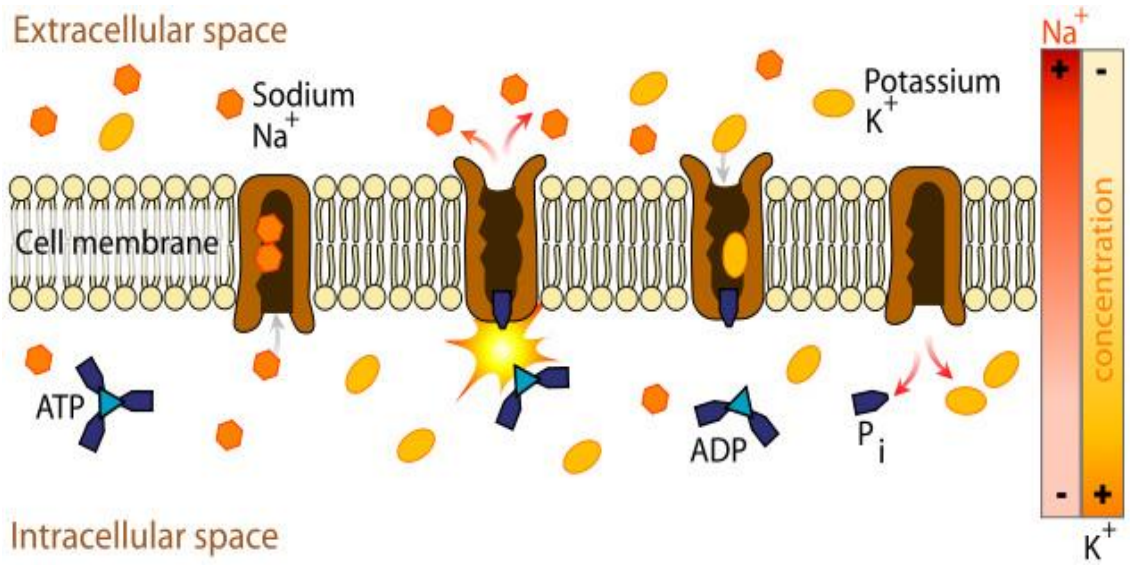


Figure 1: The sodium-potassium pump maintains the resting potential of a neuron

Action Potential

A **nerve impulse** is a sudden reversal of the electrical charge across the membrane of a resting neuron. The reversal of charge is called an **action potential.** It begins when the neuron receives a chemical signal from another cell. The signal causes gates in sodium ion channels to open, allowing positive sodium ions to flow back into the cell. As a result, the inside of the cell becomes positively charged compared to the outside of the cell. This reversal of charge ripples down the axon very rapidly as an electric current (see **Figure** below).

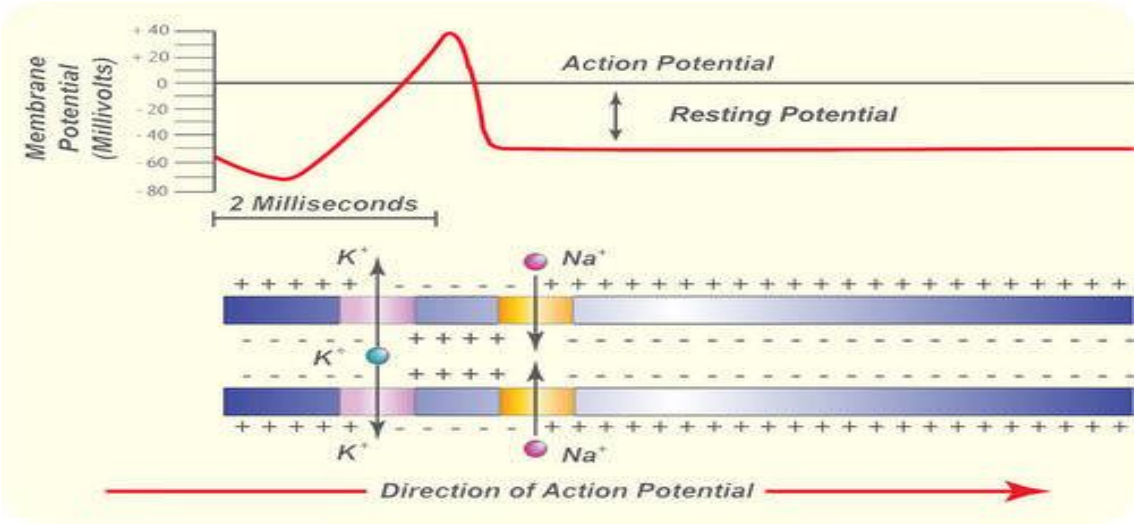


Figure 2: An action potential speeds along an axon in milliseconds

In neurons with myelin sheaths, ions flow across the membrane only at the nodes between sections of myelin. As a result, the action potential jumps along the axon membrane from node to node, rather than spreading smoothly along the entire membrane. This increases the speed at which it travels.

The place where an axon terminal meets another cell is called a **synapse**. The axon terminal and other cell are separated by a narrow space known as a **synaptic cleft** (see **Figure** below). When an action potential reaches the axon terminal, the axon terminal releases molecules of a chemical called a **neurotransmitter**. The neurotransmitter molecules travel across the synaptic cleft and bind to receptors on the membrane of the other cell. If the other cell is a neuron, this starts an action potential in the other cell.

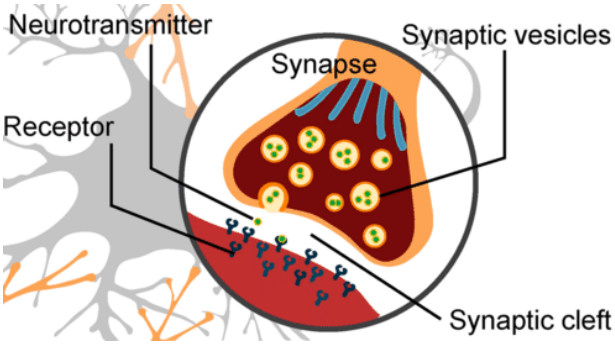


Figure 3: At a synapse, neurotransmitters are released by the axon terminal. They bind with receptors on the other cell

Neurotransmitters

Neurotransmitter Definition

"Neurotransmitter is a type of chemical messenger that transmits signals across a chemical synapse, from one neuron to another."

What is Neurotransmitter?

A neurotransmitter is the body's chemical messenger. They are molecules that transmit signals from neurons to muscles, or between different neurons. The transmission of signals between two neurons occurs in the synaptic cleft. The electrical signals that travel along the axon are briefly converted into chemical signals through neurotransmitters.

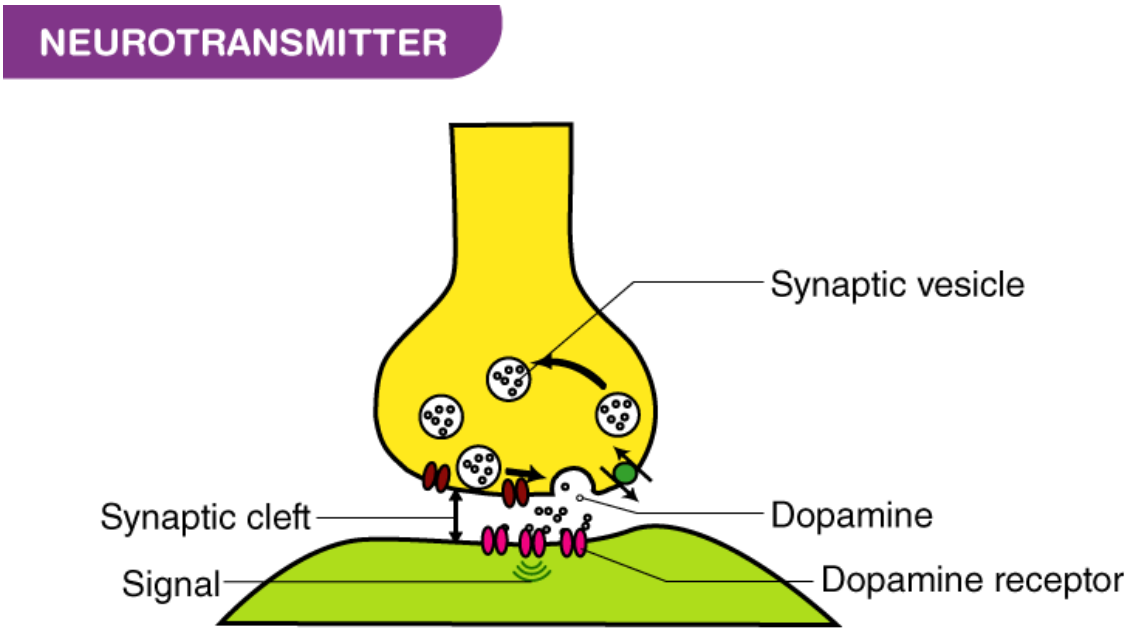


Figure 1: Neurotransmitter and its release

Types of Neurotransmitter

There are the following different types of neurotransmitter:

Excitatory Neurotransmitters

These type of neurons increase the chances of the neuron firing an action potential. Epinephrine and norepinephrine are the two excitatory neurotransmitters.

Inhibitory Neurotransmitters

These have inhibitory effects on the neurons and have fewer chances of the neuron firing an action potential. For eg., serotonin and gamma-aminobutyric acid (GABA).

Modulatory Neurotransmitter

These can affect a large number of neurotransmitters at the same time. These can also influence the effect of other chemical messengers.

Other Types of Neurotransmitter

Types	Examples
Amino acids	Gama amino-butyric acid Glutamate
Peptides	Oxytocin Endorphins
Monoamines	Epinephrine Norepinephrine

	Histamine Dopamine Serotonin
Purines	Adenosine Adenosine Triphosphate
Gasotransmitters	Nitric oxide Carbon monoxide
Acetylcholine	Acetylcholine

Central nervous system: Meninges

The meninges refer to the **membranous** coverings of the brain and spinal cord. There are three layers of meninges, known as the **dura** mater, **arachnoid** mater and **pia** mater.

These coverings have two major functions:

- Provide a **supportive framework** for the cerebral and cranial vasculature.
- Acting with cerebrospinal fluid to **protect** the CNS from mechanical damage.

The meninges are often involved cerebral pathology, as a common site of **infection** (meningitis), and **intracranial bleeds**.

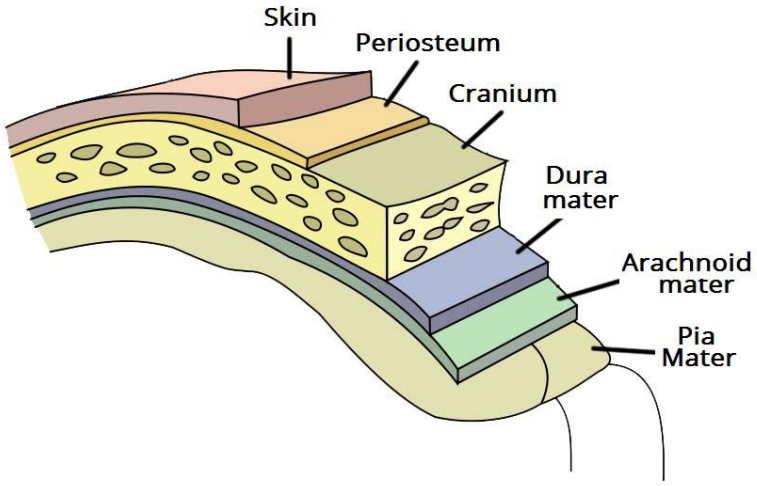


Fig 1 – Overview of the meninges, and their relationship to the skull and brain

Dura Mater

The dura mater is the **outermost** layer of the meninges, lying directly underneath the bones of the skull and vertebral column. It is thick, tough and inextensible.

Within the cranial cavity, the dura contains two connective tissue sheets:

- **Periosteal layer** – lines the inner surface of the bones of the cranium.
- **Meningeal layer** – deep to the periosteal layer inside the cranial cavity. It is the only layer present in the vertebral column.

Between these two layers, the **dural venous sinuses** are located. They are responsible for the venous vasculature of the cranium, draining into the **internal jugular** veins.

In some areas within the skull, the meningeal layer of the dura mater folds inwards as **dural reflections**. They partition the brain, and divide the cranial cavity into several compartments. For example, the **tentorium cerebelli** divides the cranial cavity into supratentorial and infratentorial compartments.

The dura mater receives its own vasculature; primarily from the **middle meningeal** artery and vein. It is innervated by the **trigeminal nerve** (V1, V2 and V3).

Arachnoid Mater

The arachnoid mater is the middle layer of the meninges, lying directly underneath the dura mater. It consists of layers of connective tissue, is **avascular**, and does not receive any innervation.

Underneath the arachnoid is a space known as the **sub-arachnoid space**. It contains cerebrospinal fluid, which acts to cushion the brain. Small projections of arachnoid mater into the dura (known as **arachnoid granulations**) allow CSF to re-enter the circulation via the dural venous sinuses.

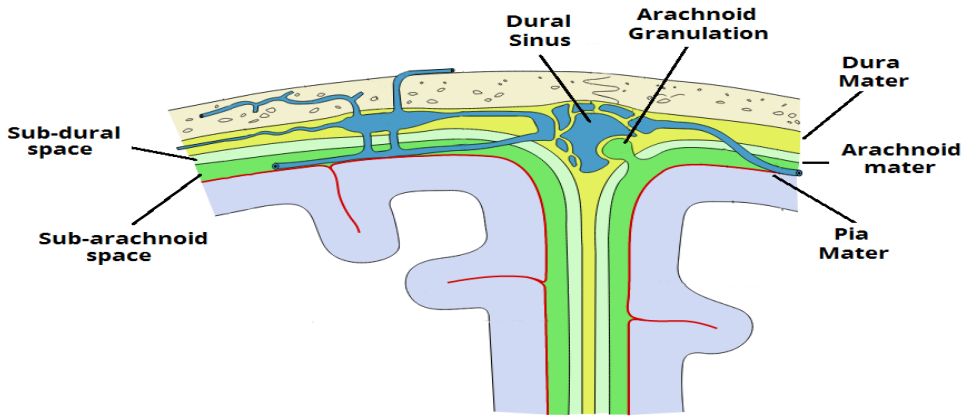


Fig 2 – Coronal section of the skull, meninges and cerebrum. An arachnoid granulation is visible in the centre

Pia Mater

The pia mater is located underneath the sub-arachnoid space. It is very thin, and **tightly adhered** to the surface of the brain and spinal cord. It is the only covering to follow the contours of the brain (the gyri and fissures).

Like the dura mater, it is **highly vascularised**, with blood vessels perforating through the membrane to supply the underlying neural tissue.

Ventricles of the brain and Cerebrospinal fluid

The **ventricular system** is a set of communicating **cavities** within the brain. These structures are responsible for the production, transport and removal of **cerebrospinal fluid**, which bathes the central nervous system.

The Ventricles of the Brain

The ventricles are structures that produce **cerebrospinal fluid**, and transport it around the cranial cavity. They are lined by **ependymal cells**, which form a structure called the choroid plexus. It is within the **choroid plexus** that CSF is produced.

Embryologically, the ventricular system is derived from the lumen of the **neural tube**.

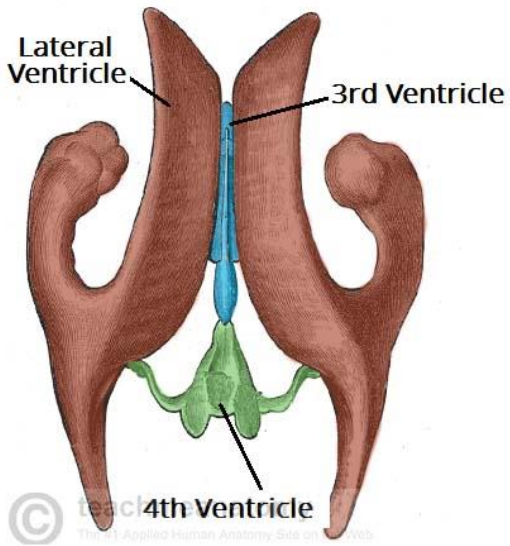


Fig 1.0 – Bird's eye view of a cast of the ventricular system of the brain.

In total, there are four ventricles; right and left lateral ventricles, third ventricle and fourth ventricle.

Lateral Ventricles

The left and right **lateral ventricles** are located within their respective hemispheres of the cerebrum. They have 'horns' which project into the frontal, occipital and temporal lobes. The volume of the lateral ventricles increases with age.

Third Ventricle

The lateral ventricles are connected to the **third ventricle** by the **foramen of Monro**. The third ventricle is situated in between the right and the left thalamus. The anterior surface of the ventricle contains two protrusions:

- **Supra-optic recess** – located above the optic chiasm.
- **Infundibular recess** – located above the optic stalk.

Fourth Ventricle

The fourth ventricle is the last in the system – it receives CSF from the third ventricle via the **cerebral aqueduct.** It lies within the brainstem, at the junction between the **pons** and **medulla oblongata**.

From the 4th ventricle, the fluid drains into two places:

- **Central spinal canal** – bathes the spinal cord
- **Subarachnoid cisterns** – bathes the brain, between arachnoid mater and pia mater. Here the CSF is reabsorbed back into the circulation.

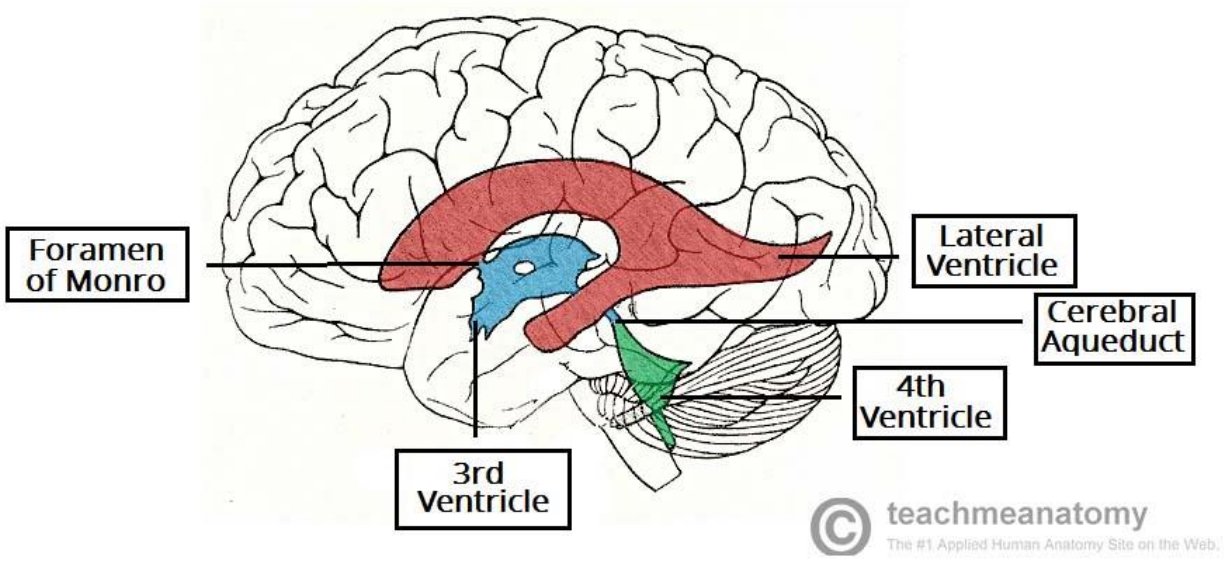


Fig 2. – The anatomical positioning of the ventricles of the brain

Production and Reabsorption of Cerebrospinal Fluid

Cerebrospinal fluid is produced by the **choroid plexus**, located in the lining of the ventricles. It consists of capillaries and loose connective tissue, surrounded by **cuboidal epithelial** cells. Plasma is filtered from the blood by the epithelial cells to produce CSF. In this way, the exact chemical composition of the fluid can be controlled.

Drainage of the CSF occurs in the **subarachnoid cisterns** (or space). Small projections of arachnoid mater (called arachnoid granulations), protrude into the dura mater. They allow the fluid to drain into the **dural venous sinuses**.

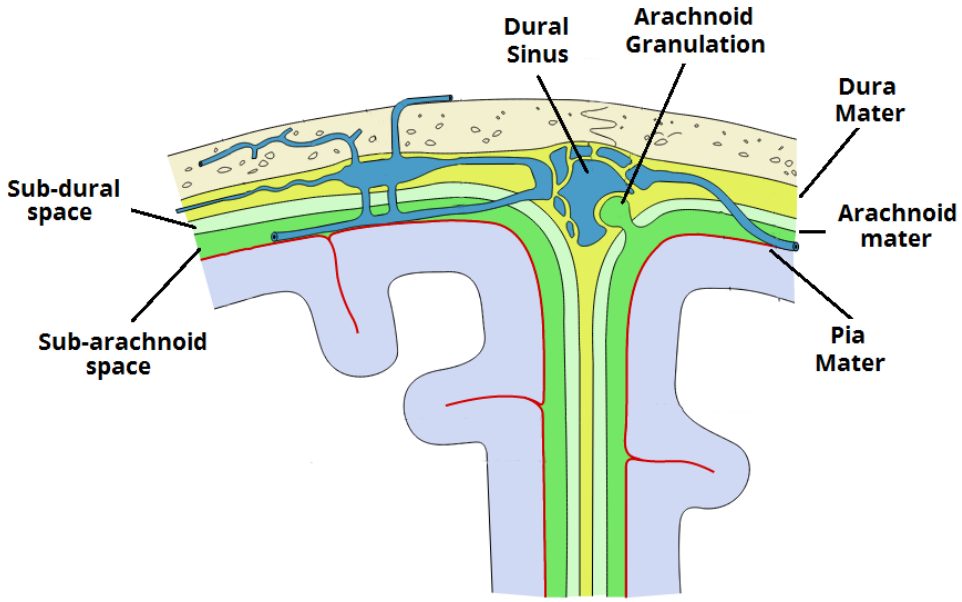


Fig 3 – Coronal section of the skull, meninges and cerebrum. An arachnoid granulation is visible in the centre

Functions of Cerebrospinal Fluid

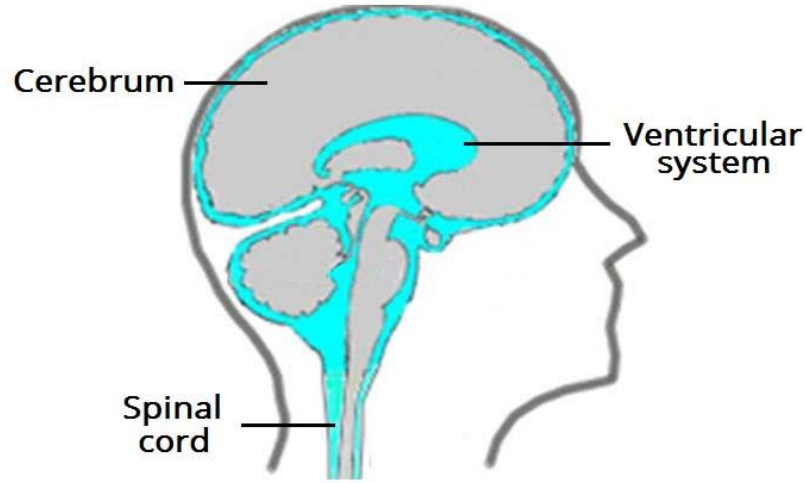


Fig 4 .0 – Overview of the cerebrospinal fluid distribution in the brain

Cerebrospinal fluid is an ultrafiltrate of plasma that surrounds the brain and spinal cord.

It serves three main functions:

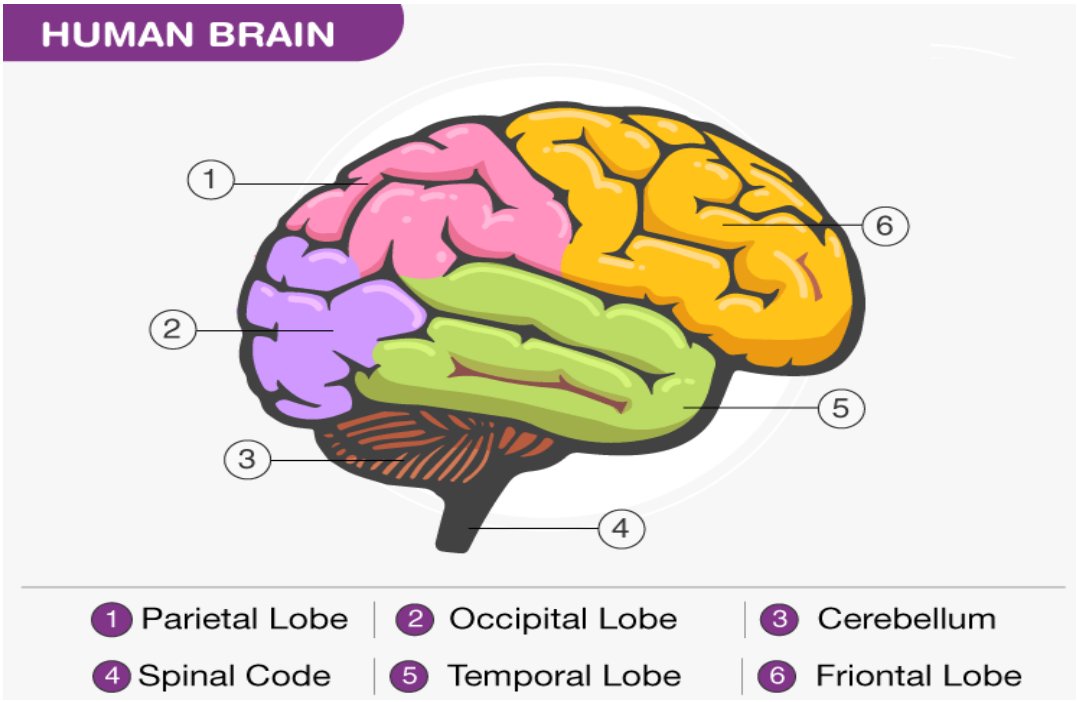
- **Protection** – acts as a cushion for the brain, limiting neural damage in cranial injuries.
- **Buoyancy** – by being immersed in CSF, the net weight of the brain is reduced to approximately 25 grams. This prevents excessive pressure on the base of the brain.
- **Chemical stability** – the CSF creates an environment to allow for proper functioning of the brain, e.g. maintaining low extracellular K+ for synaptic transmission.

Structure and functions of the Brain

The human brain controls nearly every aspect of the human body ranging from physiological functions to cognitive abilities. It functions by receiving and sending signals via neurons to different parts of the body. The human brain, just like most other mammals, has the same basic structure, but it is better developed than any other mammalian brain.

On average, an adult brain weighs between 1.0 kg – 1.5 kg. It is mainly composed of neurons – the fundamental unit of the brain and nervous system. Recent estimates have suggested that the brain contains anywhere between 86 billion to 100 billion neurons.

The **brain**, along with the **spinal cord**, constitutes the central nervous system. It is responsible for thoughts, interpretation and origin of control for body movements.



Where is the Brain located?

The brain is enclosed within the skull, which provides frontal, lateral and dorsal protection. The skull consists of 22 bones, 14 of which form the facial bones and the remaining 8 forms the cranial bones. Anatomically, the brain is contained within the cranium and is surrounded by the cerebrospinal fluid.

The Cerebrospinal Fluid (CSF) is a fluid that circulates within the skull and spinal cord, filling up hollow spaces on the surface of the brain. Every day, the specialised ependymal cells produce around 500mL of cerebrospinal fluid.

The primary function of the CSF is to act as a buffer for the brain, cushioning mechanical shocks and dampening minor jolts. It also provides basic immunological protection to the brain.

Furthermore, CSF provides buoyancy for the brain. i.e., the brain is suspended in a layer of CSF, wherein, the weight of the brain is nearly negated. If the brain is not suspended in CSF, it would be impeded by its weight, consequently cutting off the blood supply in the lower half of the brain. It would lead to the death of neurons in the affected area

Forebrain – Largest part of the brain

It is the anterior part of the brain. The fore brain parts include:

- Cerebrum
- Hypothalamus
- Thalamus

Forebrain Function: *Controls the reproductive functions, body temperature, emotions, hunger and sleep.*

Fact*: The largest among the forebrain parts is the cerebrum. It is also the largest part of all vertebrate brains.*

Midbrain: Smallest and central part of the brain

The mi*dbrain* consists of:

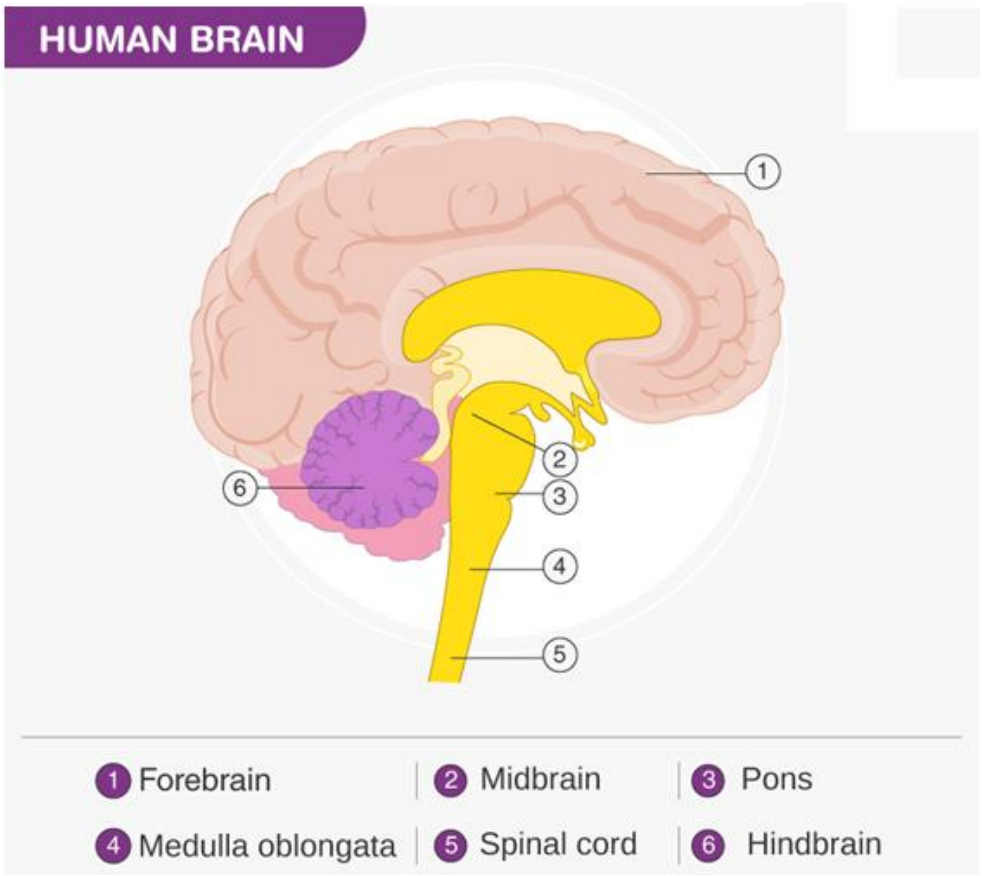
- Tectum
- Tegmentum

Hindbrain: The central region of the brain

The *hindbrain* is composed of:

- Cerebellum
- Medulla
- Pons

Hindbrain function: *The three regions of the hindbrain coordinates all processes necessary for survival. These induce breathing, heartbeat, sleep, wakefulness and motor learning.*



Brain diagram highlighting various parts of human brain

Cerebrum

The cerebrum is the largest part of the brain. It consists of the cerebral cortex and other subcortical structures. It is composed of two cerebral hemispheres that are joined together by heavy, dense bands of fibre called the corpus callosum. The cerebrum is further divided into four sections or lobes:

1. **Frontal lobe**: It is associated with parts of speech, planning, reasoning, problem-solving and movements.
2. **Parietal lobe**: Help in movements, the perception of stimuli and orientation.
3. **Occipital lobe**: It is related to visual processing.

4. **Temporal lobe**: This region is related to perception and recognition of memory, auditory stimuli, and speech.

The brain consists of two types of tissues: Grey matter and White matter**.**

1. **Grey matter** mainly consists of various types of cells, which make up the bulk of the brain.
2. **White matter** is primarily composed of axons, which connect various grey matter areas of the brain with each other.

The exterior portion of the cerebrum is called the cortex or the cerebral mantle. The cortex is extremely convoluted, due to which, it has a large surface area. The cerebrum also includes:

1. **Sensory areas**: To receive the messages.
2. **Association areas**: These areas integrate the incoming sensory information. It also forms a connection between sensory and motor areas.
3. **Motor areas**: This area is responsible for the action of the voluntary muscles.

Cerebrum Function

The cerebrum is responsible for thinking, intelligence, consciousness and memory. It is also responsible for interpreting touch, hearing and vision.

Thalamus

The thalamus is a small structure, located right above the brain stem responsible for relaying sensory information from the **sense organs**. It is also responsible for transmitting motor information for movement and coordination. Thalamus is found in the limbic system within the cerebrum. This limbic system is mainly responsible for the formation of new memories and storing past experiences.

Hypothalamus

The hypothalamus is a small and essential part of the brain, located precisely below the thalamus. It is considered the primary region of the brain, as it is involved in the following functions:

1. Receives impulses
2. Regulates body temperature
3. Controls the mood and emotions
4. Controls the sense of taste and smell
5. Synthesises the body's essential hormones
6. Coordinates the messages from the autonomous nervous system
7. Controls appetite, peristalsis, the rate of heartbeat, and blood pressure
8. Forms an axis with the pituitary gland which is the main link between the nervous and the endocrine systems

Tectum

The tectum is a small portion of the brain, specifically the dorsal part of the midbrain. It serves as a relay centre for the sensory information from the ears to the cerebrum. It also controls the reflex movements of the head, eye and neck muscles. It provides a passage for the different neurons moving in and out of the cerebrum.

Tegmentum

Tegmentum is a region within the brainstem. It is a complex structure with various components, which is mainly involved in body movements, sleep, arousal, attention, and different necessary reflexes. It forms the platform for the midbrain and connects with the thalamus, cerebral cortex, and the spinal cord.

Cerebellum

The cerebellum is the second largest part of the brain, located in the posterior portion of the medulla and pons. The cerebellum and cerebrum are separated by tentorium cerebelli and transverse fissure. Cortex is the outer surface of the cerebellum, and its parallel ridges are called the foila. Apart from this, the cerebellum has the cerebellar peduncles, cerebellar nuclei, anterior and posterior lobes. The cerebellum consists of two hemispheres, the outer grey cortex and the inner white medulla. It is mainly responsible for coordinating and maintaining the body balance during walking, running, riding, swimming, and precision control of the voluntary movements. The main functions of the cerebellum include:

1. It senses equilibrium.
2. Transfers information.
3. Coordinates eye movement.
4. It enables precision control of the voluntary body movements.
5. Predicts the future position of the body during a particular movement.
6. Both anterior and posterior lobes are concerned with the skeletal movements.
7. The cerebellum is also essential for making fine adjustments to motor actions.
8. Coordinates and maintains body balance and posture during walking, running, riding, swimming.

Medulla Oblongata

The medulla oblongata is a small structure present in the lowest region of the brain. It mainly controls the body's autonomic functions such as heartbeat, breathing, and digestion. It plays a primary role in connecting the spinal cord, pons and the cerebral cortex. Also, it helps us in maintaining our posture and controlling our reflexes.

Pons

The pons is the primary structure of the brain stem present between the midbrain and medulla oblongata. It serves as a relay signals between the lower cerebellum, spinal cord, the midbrain, cerebrum and other higher parts of the brain. The main functions of the pons include:

1. Controlling sleep cycles.
2. Regulating the magnitude and frequency of the respiration.
3. Transfers information between the cerebellum and motor cortex.
4. Pons is also involved in sensations, such as the sense of taste, hearing, and balance.

Structure and functions of the Spinal Cord

The spinal cord is a part of the central nervous system. It is a long pipe-like structure arising from the medulla oblongata part of the brain consisting of a collection of nerve fibres, running through the vertebral column of the backbone. It is segmented with a pair of roots (dorsal and ventral roots) consisting of nerve fibres joining to form the spinal nerves.

Spinal Cord Anatomy

In adults, the spinal cord is usually 40cm long and 2cm wide. It forms a vital link between the brain and the body.

The spinal cord is divided into five different parts.

- Sacral cord
- Lumbar cord
- Thoracic cord
- Cervical cord
- Coccygeal

Several spinal nerves emerge out of each segment of the spinal cord. There are 8 pairs of cervical, 5 lumbar, 12 thoracic, 5 sacral and 1 coccygeal pair of spinal nerves

It performs the primary processing of information as it carries sensory signals from all parts of the body to the Central Nervous System through afferent fibres.

Nerve tissue consists of the grey and white matter spread across uniformly.

The smooth muscles and the skeletal system carrying nerve fibres liaise different reflexes when ventral horn projects axons which carry motor neurons.

It also helps intercede autonomic control for visceral functions which consist of neurons with descending axons. It is a sensitive site, which is severely affected in case of a traumatic injury.

Understanding the physiology of the spinal cord helps in detecting and determining the various methods to deal with diseases and damage related to the spinal cord.

Structure of Spinal Cord

The Spinal cord runs through a hollow case from the skull enclosed within the vertebral column. Spinal nerves arise from different regions of the vertebral column and are named accordingly, the regions are – Neck, chest, pelvic and abdominal.

Cross-section of spinal cord displays grey matter shaped like a butterfly surrounded by a white matter.

Grey matter consists of the central canal at the centre and is filled with a fluid called CSF (Cerebrospinal fluid). It consists of horns (four projections) and forms the core mainly containing neurons and cells of the CNS. There are two dorsal and two ventral horns.

The white matter consists of a collection of axons permitting communication between different layers of CNS. A tract is a collection of axons and carries specialized information. Ascending tracts and descending tracts send and transmit signals from the brain respectively to various nerve cells across the body.

Spinal nerves act as mediators, communicating information to and from the rest of the body and the spinal cord. We have 31 pairs of spinal nerves.

Three layers of meninges surround the spinal cord and spinal nerve roots.

- Dura mater
- Arachnoid mater
- Pia mater

Dura mater consists of two layers- periosteal and meningeal. Epidural space is present between the two layers.

Subarachnoid space lies between the arachnoid mater and pia mater. It is filled with cerebrospinal fluid.

Spinal Cord Injuries

Damage to any part of the spinal cord or spinal nerves results in permanent and life-long damage to the spinal cord affecting the normal functioning of the spinal cord without any replacements.

It often causes long-term changes in the strength, body posture and reflexing of the body. Voluntary control of limbs post an injury depends on the severity and location of the injury.

One has a complete injury when he loses the ability to move or sense below the injury. The incomplete injury allows the injured to perform some sensory and motor functions.

Spinal cord injury not only has an impact on the spinal nerves and the vertebral column but affects other muscles and vital organs as well.

Paralysis from an injury can be of two types:

- Tetraplegic
- Paraplegic

Tetraplegia is a paralysis that results in total or partial loss of use of all four limbs and torso.

Paraplegia, on the other hand, is similar to tetraplegia, except it doesn't affect the arms.

These injuries result in the inability to voluntarily move limbs, lose sensation, delayed or exaggerated reflexes, changes in sexual functions, intense shooting pain due to damaged nerve fibres. It also causes shortness of breath, cough and muscle spasms.

Spinal Cord Nerves

The spinal nerves consist of a group of 31 nerves. These nerves are attached to the spinal cord by two roots- dorsal sensory root and ventral motor root.

The sensory root fibers carry sensory impulses to the spinal cord. The motor roots, on the contrary, carry impulses from the spinal cord.

The spinal nerves carry messages to and from the skin of specific regions of the body called dermatomes.

The spinal cord nerves can be grouped as:

- Cervical
- Thoracic
- Sacral
- Lumbar
- Coccygeal

Cervical Nerves

Cervical means of the neck. There are 8 cervical nerves that emerge from the cervical spine (C1-C8).

Thoracic Nerves

Thoracic means of the chest. There are 12 thoracic nerves that emerge from the thoracic spine (T1-T12).

Lumbar Nerves

Lumbar means from the lower back region. There are 5 lumbar nerves that emerge from the lumbar spine (L1-L5).

Sacral Nerves

Sacral means of the sacrum. The sacrum is a bony plate at the base of the vertebral column.

There are 5 sacral nerves that emerge from the sacral bone (S1-S5).

Coccygeal Nerves

Coccygeal means of the tailbone. There is 1 nerve that emerges from the coccygeal bone.

Function of Spinal Cord

Important functions of Spinal Cord are mentioned below:

- Forms a connecting link between the brain and the PNS
- Provides structural support and builds a body posture
- Facilitates flexible movements
- Myelin present in the white matter acts as an electrical insulation
- Communicates messages from the brain to different parts of the body
- Coordinates reflexes
- Receives sensory information from receptors and approaches towards the brain for processing.

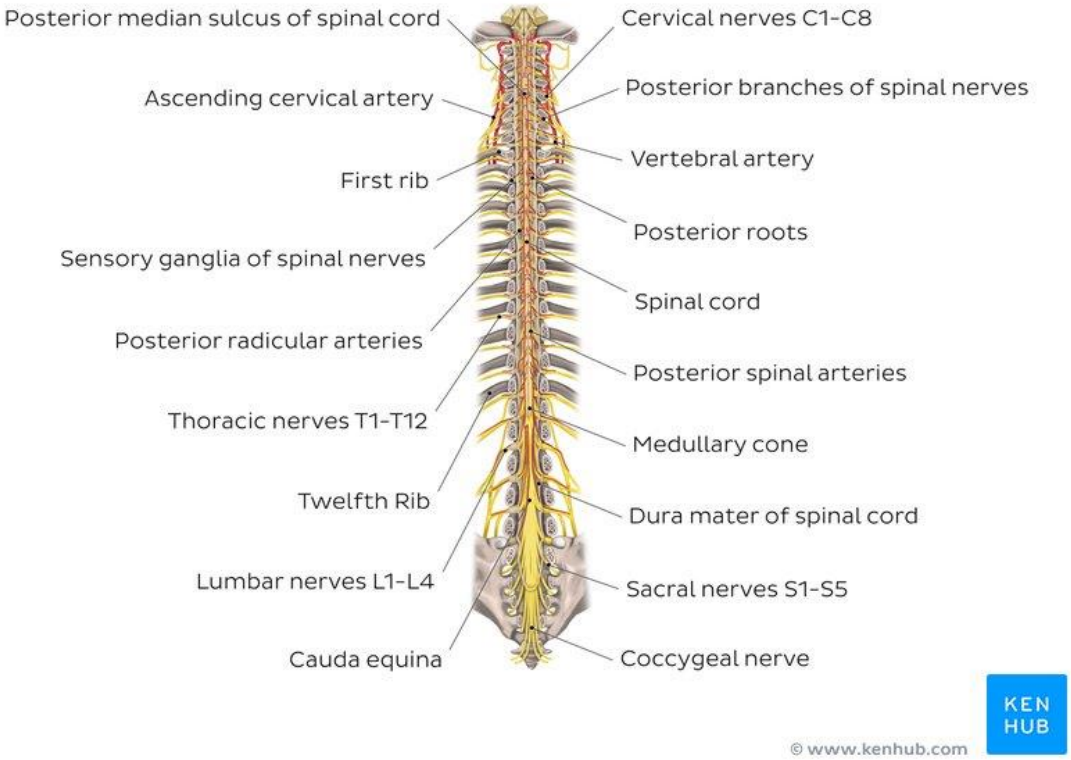


Figure 1: Anatomy of the Spinal Cord

What is Reflex Action?

Reflex is an involuntary and sudden response to stimuli. It happens to be an integral component of the famed survival instinct.

Most of the common reflexes are a response to all the well trained, accumulated knowledge of caution that we have internalized. It could be anything and ranges from the reflex action of abruptly withdrawing the hand as it comes in contact with an extremely cold or hot object. This action is termed as the reflex action. It has a subtle relation to instinct.

A point to be thought upon is that we all have our instincts differently depending on our past experience and understanding. A reflex is a reaction triggered by this instinct. At times, we have no prior knowledge if the pan is hot or not. In other words, instinct has little to do with reflex.

REFLEX ACTION

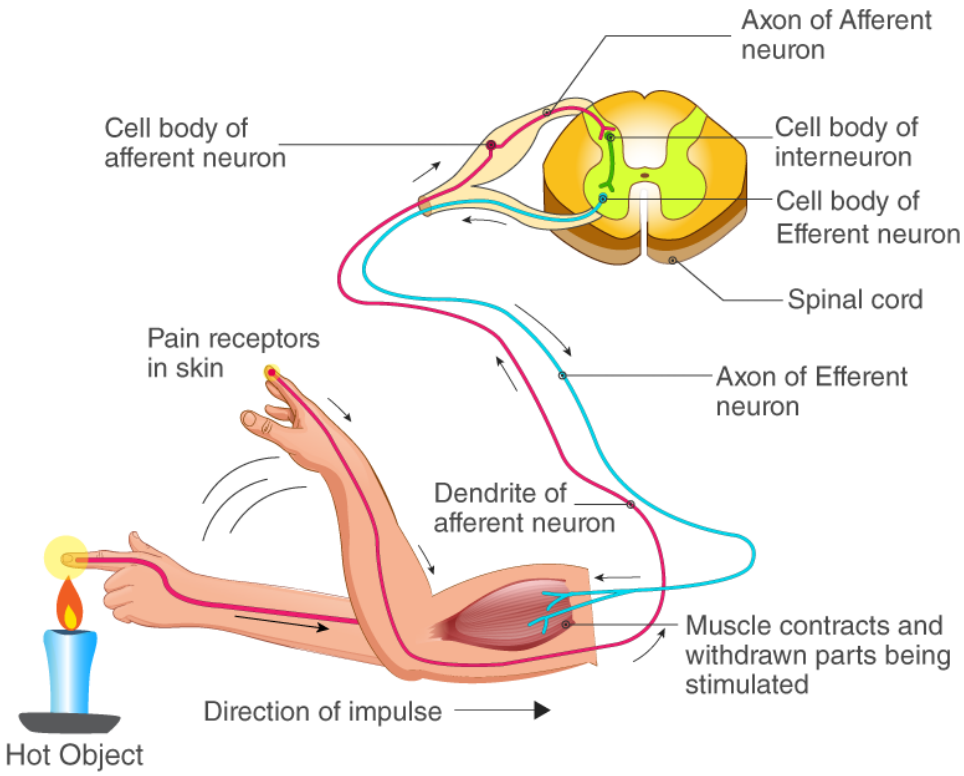


Figure 1: Reflex arc diagram

The Action of Neuron

Two neurons dominate the pathway, afferent nerves (receptor) and the efferent nerves (effector or excitor).

Below is a brief description of the events that take place:

- Firstly, it begins with receptor detecting the stimulus or a sudden change in the environment, where the instinct again has a role to play. The stimulus is received from a sensory organ.

- Then, the sensory neuron sends a signal to the relay neuron.
- This is followed with the relay neuron sending the signal to the motor neuron.
- Further, the motor neuron sends a signal to the effector.
- The effector produces an instantaneous response, for example, pulling away of the hand or a knee-jerk reaction.

From the above explanations, it can be clearly summarized that the moment the afferent neuron receives a signal from the sensory organ; it transmits the impulse via a dorsal nerve root into the Central Nervous System**.** The efferent neuron then carries the signal from the CNS to the effector. The stimulus thus forms a reflex arc.

In a reflex action, the signals do not route to the brain – instead, it is directed into the synapse in the spinal cord, hence the reaction is almost instantaneous.

Subject: Human Anatomy and Physiology-I Unit No: IV

Classification of Peripheral Nervous system

The nervous system is classified into the central and peripheral nervous system. The central nervous system (CNS) consists of the brain and spinal cord, leaving everything else in the peripheral nervous system (PNS).

Structure

The peripheral nervous system is itself classified into two systems: the somatic nervous system and the autonomic nervous system. Each system contains afferent and efferent components.

The **afferent** arm consists of sensory (or afferent) neurons running from receptors for stimuli to the CNS. Afferent nerves detect the external environment via receptors for external stimuli such as sight, hearing, pressure, temperature etc. Afferent nerves exist in both the somatic and autonomic nervous systems as both can use sensory signals to alter their activity.

The **efferent** arm consists of motor (or efferent) neurons running from the CNS to the effector organ. Effector organs can either be muscles or glands.

The efferent nerves of the **somatic nervous system** of the PNS is responsible for voluntary, conscious control of skeletal muscles (effector organ) using motor (efferent) nerves.

The efferent nerves of the **autonomic (visceral) nervous system** control the visceral functions of the body. These visceral functions include the regulation of heart rate, digestion, salivation, urination, digestion and many more. The efferent arm of this system can be further subdivided into parasympathetic motor or sympathetic motor.

The **enteric nervous system** is sometimes classified as a separate component of the autonomic nervous system and is sometimes even considered a third independent branch of the PNS.

Following are the important functions of the peripheral nervous system:

1. The peripheral nervous system connects the brain and the spinal cord to the rest of the body and the external environment.
2. It regulates the internal homeostasis.
3. It can regulate the strength of the muscle contractility.
4. It controls the release of secretions from most exocrine glands

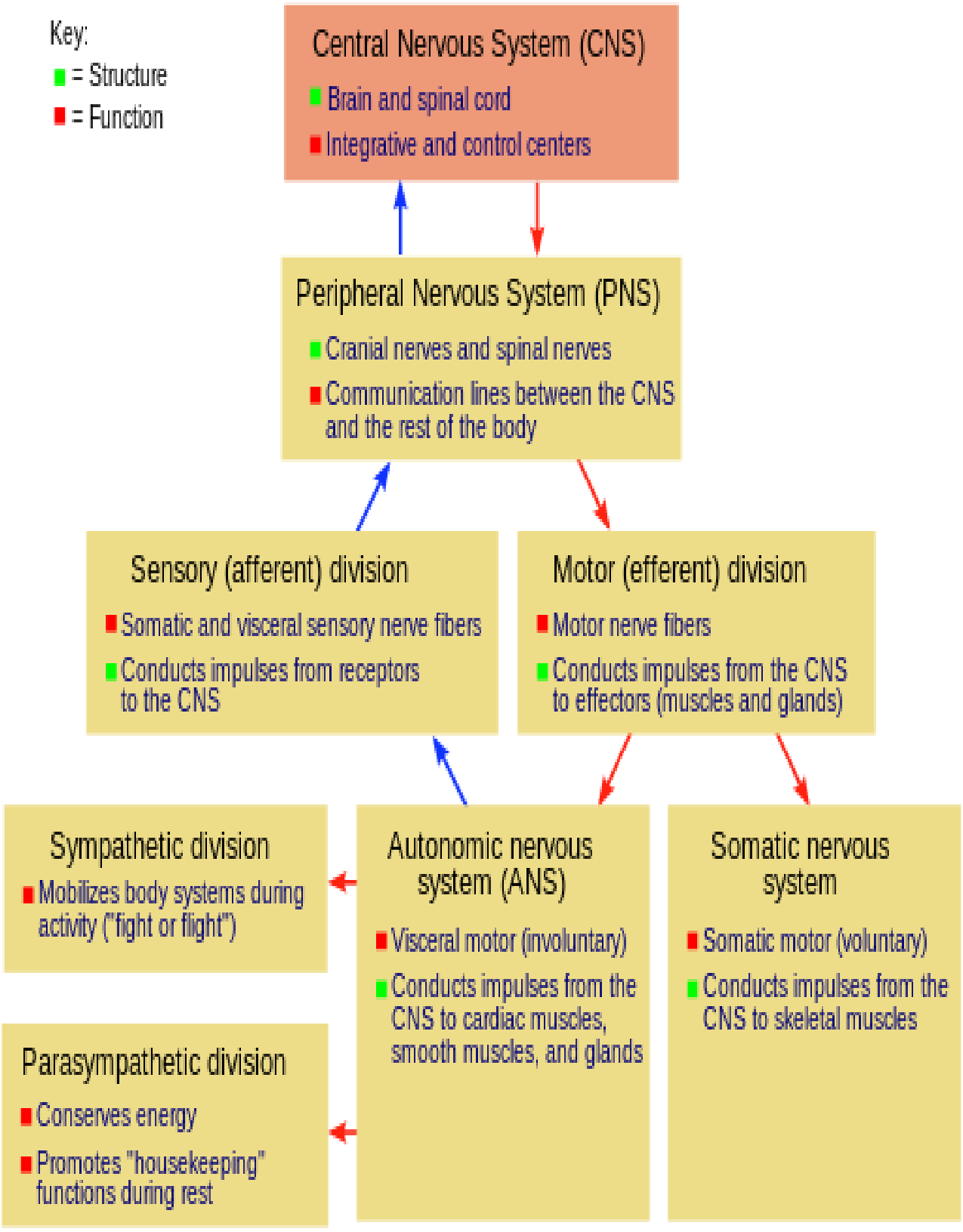

Key:
= Structure
= Function
Central Nervous System (CNS)
Brain and spinal cord
Integrative and control centers
Peripheral Nervous System (PNS)
Cranial nerves and spinal nerves
Communication lines between the CNS and the rest of the body
Sensory (afferent) division
Somatic and visceral sensory nerve fibers
Conducts impulses from receptors to the CNS
Motor (efferent) division
Motor nerve fibers
Conducts impulses from the CNS to effectors (muscles and glands)
Sympathetic division
Mobilizes body systems during activity ("fight or flight")
Autonomic nervous system (ANS)
Visceral motor (involuntary)
Conducts impulses from the CNS to cardiac muscles, smooth muscles, and glands
Somatic nervous system
Somatic motor (voluntary)
Conducts impulses from the CNS to skeletal muscles
Parasympathetic division
Conserves energy
Promotes "housekeeping" functions during rest

Figure 1: Divisions of Nervous system

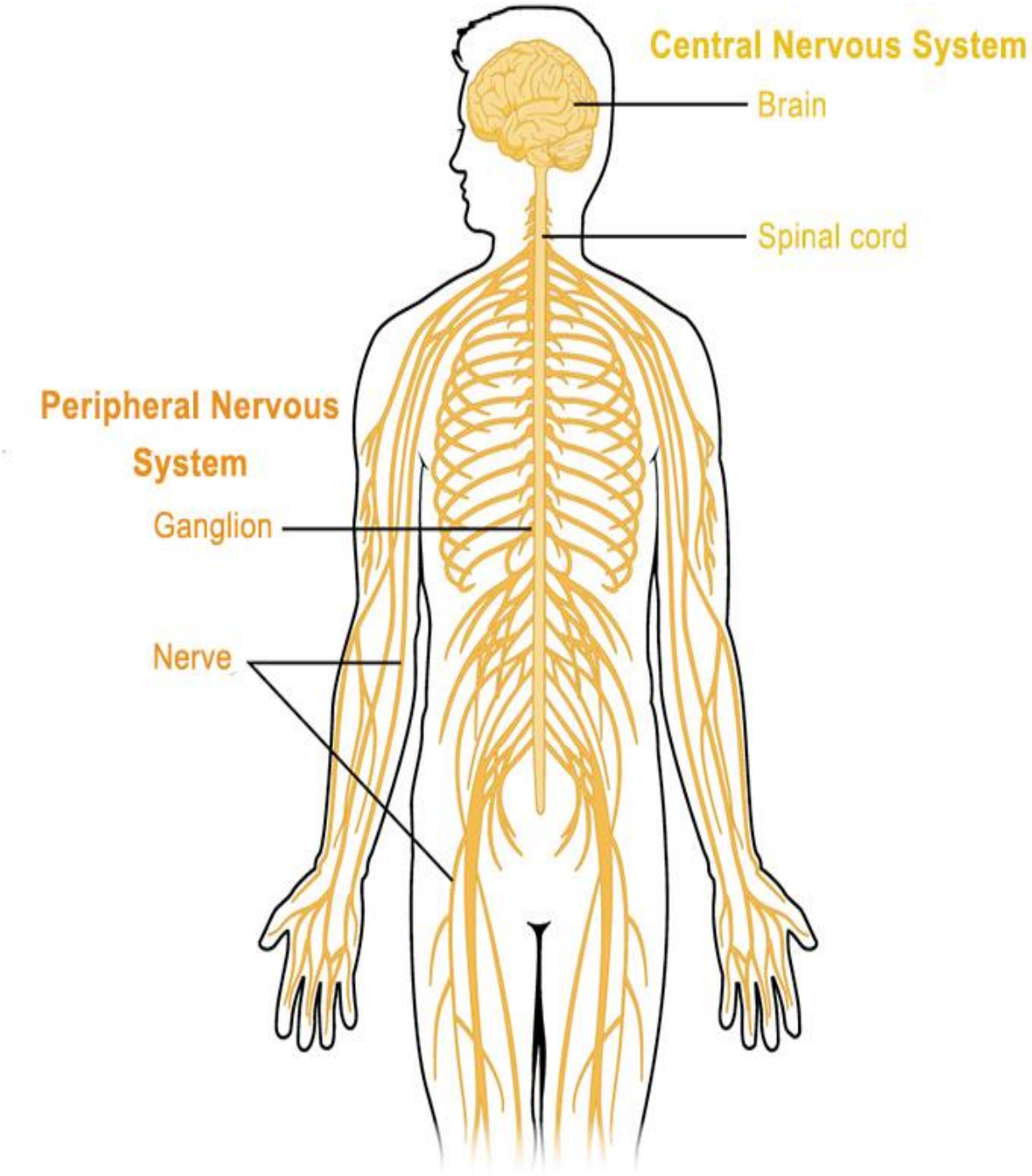


Figure 2: Location of CNS and PNS

Structure of Sympathetic and Parasympathetic nervous system

What is Sympathetic and Parasympathetic Nervous System?

Sympathetic Autonomic Nervous System: It is the part of the autonomic nervous system, located near the thoracic and lumbar regions in the spinal cord. Its primary function is to stimulate the body's fight or flight response. It does this by regulating the heart rate, rate of respiration, pupillary response and more.

Parasympathetic Autonomic Nervous System: It is located in between the spinal cord and the medulla. It primarily stimulates the body's "rest and digest" and "feed and breed" response.

Difference between Sympathetic and Parasympathetic Nervous System

The sympathetic nervous system prepares the body for the "fight or flight" response during any potential danger. On the other hand, the parasympathetic nervous system inhibits the body from overworking and restores the body to a calm and composed state. The difference between the sympathetic and parasympathetic nervous system are differentiated based on the way the body responds to environmental stimuli.

The major difference between sympathetic and parasympathetic nervous system are summarised below:

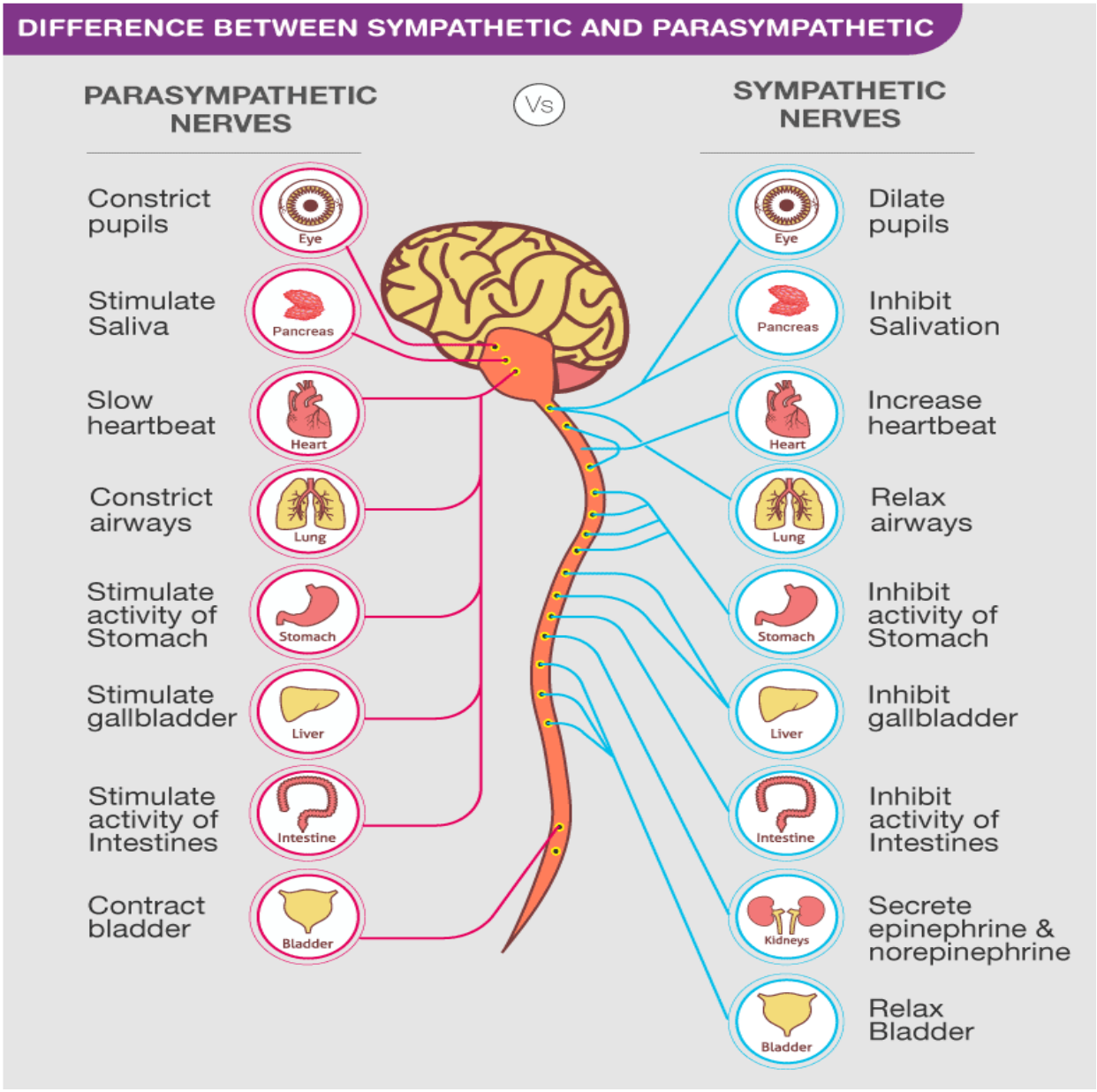


Figure 1: Difference between Sympathetic and Parasympathetic Nervous system

Sympathetic	Parasympathetic
Involved in the fight or flight response.	Involved in maintaining homeostasis and also, permits the rest and digest response.
The sympathetic system prepares the body for any potential danger.	The parasympathetic system aims to bring the body to a state of calm.
Sympathetic system has shorter neuron pathways, hence a faster response time.	Has comparatively longer neuron pathways, hence a slower response time.
Increases heartbeat, muscles tense up.	Reduces heartbeat, muscles relaxes.
The pupil dilates to let in more light.	The pupil contracts.
Saliva secretion is inhibited.	Saliva secretion increases, digestion increases.
On “fight and flight” situations, Adrenaline is released by the adrenal glands; more glycogen is converted to glucose.	No such functions exist in “fight or flight” situations.

The autonomic nervous system comprises of two parts- the sympathetic and parasympathetic nervous system. The sympathetic nervous system activates the fight or flight response during a threat or perceived danger, and the parasympathetic nervous system restores the body to a state of calm.

Functions of Sympathetic and Parasympathetic nervous system

The Parasympathetic System

"Rest and digest" response:

- Increase in blood flow to the gastrointestinal tract, which helps to meet the greater metabolic demands placed on the body by the GI tract
- Constriction of the bronchioles when oxygen levels are normalized
- Control of the heart via the Vagus nerve cardiac branches and spinal accessory nerves of the thoracic spinal cord
- Constriction of the pupil allowing for near vision control
- Stimulation of salivary gland production and speeds up peristalsis to aid digestion
- Relaxation/contraction of the uterus and erection/ejaculation in men

In order to understand the functioning of the parasympathetic nervous system, it is helpful to use a real example:
The male sexual response is under direct control of the CNS. Erections are controlled by the parasympathetic system through excitatory pathways. Excitatory signals originate in the brain, through thought, sight or direct stimulation. Regardless of the origin of the excitatory signal, penile nerves respond by releasing acetylcholine and nitric oxide, which in turn signal the smooth muscles of the arteries of the penis to relax and fill with blood. This cascade of events results in erection.

The Sympathetic System

"Fight or Flight" response:

- Stimulation of the sweat glands
- Constriction of peripheral blood vessels to shunt blood to the core, where it is needed
- Increased in supply of blood to skeletal muscles that may be needed for activity
- Dilation of the bronchioles under conditions of low oxygen in the blood
- Reduction in blood flow to the abdomen; decreased peristalsis and digestive activities
- Release of glucose stores from the liver to increase glucose in the bloodstream

As with the parasympathetic system, it is helpful to look at a real example to understand how the sympathetic nervous system functions:

Extreme heat is a stressor that many of us have experienced. When we are exposed to excessive heat, our bodies respond in the following manner: thermal receptors convey stimuli to sympathetic control centers located in the brain. Inhibitory messages are sent along the sympathetic nerves to the blood vessels in the skin, which dilate in response. This dilation of the blood vessels increases the flow of blood to the body's surface so that heat can be lost through radiation from the body surface. In addition to the dilation of blood vessels in the skin, the body also reacts to excessive heat by sweating. This occurs through the rise in body temperature, which is sensed by the hypothalamus, which sends a signal via the sympathetic nerves to the sweat glands, which increase the amount of sweat produced. Heat is lost by evaporation of the sweat produced.

Autonomic Neurons

Neurons that conduct impulses away from the central nervous system are known as efferent (motor) neurons. They differ from somatic motor neurons in that Efferent neurons are not under conscious control. Somatic neurons send axons to skeletal muscle, which is usually under conscious control.

- Visceral efferent neurons- motor neurons whose job it is to conduct impulses to cardiac muscle, smooth muscles and glands. They may originate in the brain or spinal cord (CNS). Two visceral efferent neurons are required to conduct an impulse from the brain or spinal cord to the target tissue.

- Preganglionic (presynaptic) neurons- the cell body of the neuron is located in the grey matter of the spinal cord or brain. It ends in a sympathetic or parasympathetic ganglion.
- Preganglionic autonomic fibers- may begin in the hindbrain, midbrain, upper thoracic spinal cord, or fourth sacral level of the spinal cord. Autonomic ganglia may be found in the head, neck or abdomen. Chains of autonomic ganglia also run parallel to each side of the spinal cord.
- Postganglionic (postsynaptic) neurons- cell body is located in the autonomic ganglion (sympathetic or parasympathetic). The neuron ends in a visceral structure (the target tissue)

Where preganglionic fibers originate and autonomic ganglia are found helps in differentiating between the sympathetic nervous system and the parasympathetic nervous system.

Origin and Functions of Spinal Nerves

Spinal nerve, in vertebrates, any one of many paired peripheral nerves that arise from the spinal cord. In humans there are 31 pairs: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal. Each pair connects the spinal cord with a specific region of the body. Near the spinal cord each spinal nerve branches into two roots. One, composed of sensory fibres, enters the spinal cord via the dorsal root; its cell bodies lie in a spinal ganglion that is outside the spinal cord. The other, composed of motor fibres, leaves the spinal cord via the ventral root; its cell bodies lie in specific areas of the spinal cord itself.

Spinal nerves are essential for the control of body parts by the higher centers of the nervous system. If any spinal nerve is cut, trapped, injured, or is involved in a disease process, the areas of the body supplied by that nerve escape the control of CNS.

When any area of the body escapes the **control of the CNS**, its functions are not regulated. As a result, that particular area of the body loses its functional ability and dies soon.

Functions

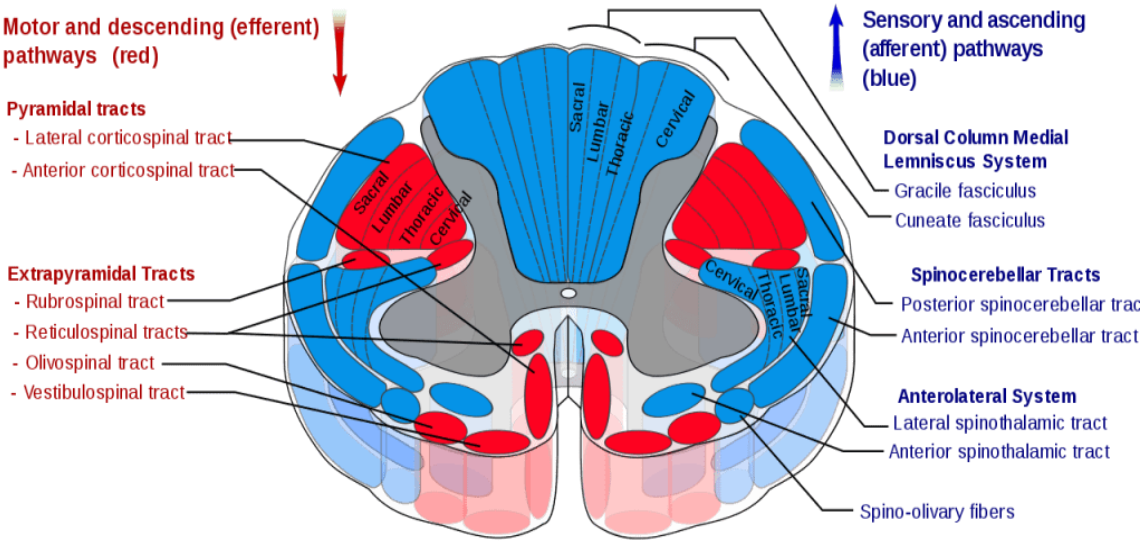
As we have studied the **formation of spinal nerves**, we know that the spinal nerve contains both sensory as well as motor fibers. That's why spinal nerves are called mixed nerves. In addition, they also contain autonomic fibers. The functions performed by the spinal nerves are dependent on these nerve fibers.
Thus, a spinal nerve performs the following functions.

Transmission of Sensory Information

The spinal nerves carry sensory information from the peripheral body parts to the spinal cord. The sensory neurons are located in the dorsal root ganglia. The peripheral fibers of these sensory neurons form the sensory fibers present in the spinal cord.

The nerve endings of these fibers perceive stimuli such as heat and cold, touch, etc. This information is carried in the form of nerve impulses to the **dorsal root ganglia** and from there to the spinal cord via the central process of these neurons.

Figure 1: Conduction of Motor Impulses

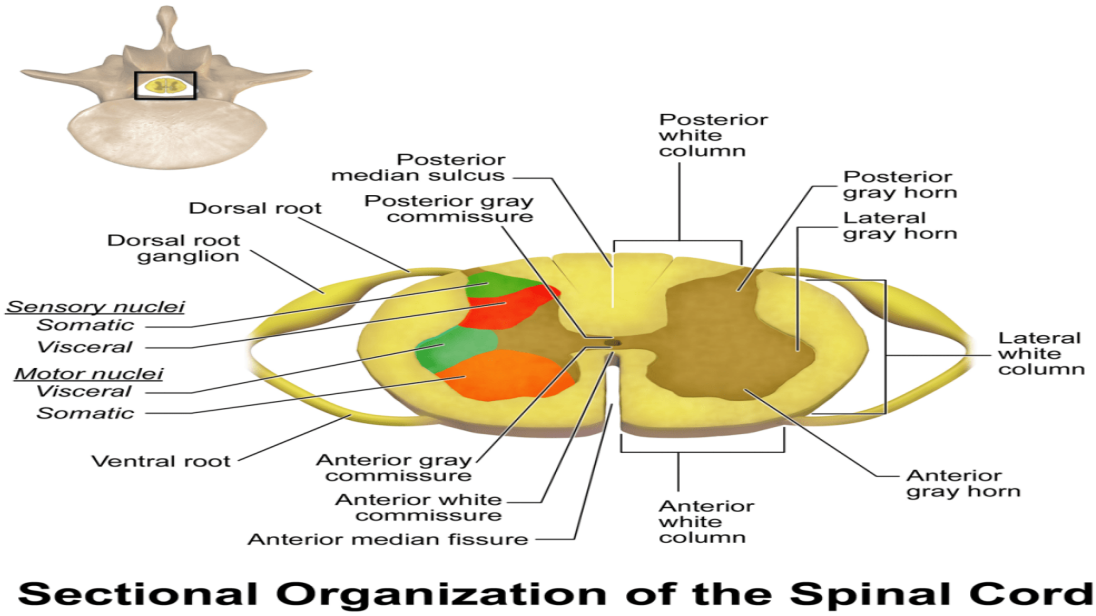


The spinal nerves carry motor impulses to the **muscles of the body**. This function is dependent on the motor fibers present in spinal nerves. These motor fibers are the axons of the motor neurons and originate from the spinal cord in the form of the anterior root of spinal nerve. The motor impulses are generated by these motor neurons and are carried by spinal nerves to the muscles of peripheral body parts.

Conduction of Autonomic Signals

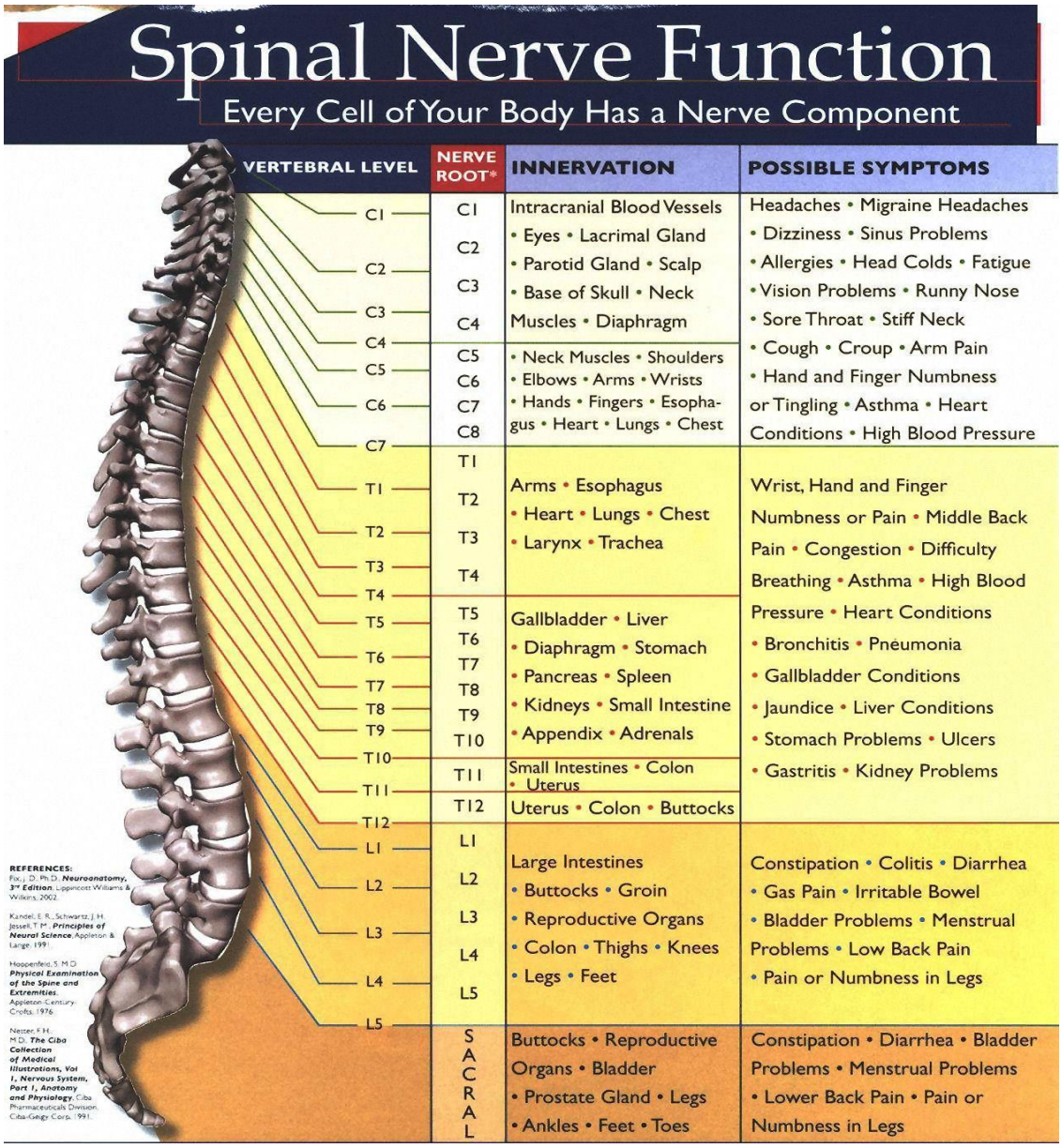
The spinal nerves also carry **autonomic signals** to the peripheral body parts. The autonomic fibers enter the spinal nerves in the form of gray rami and are carried by the spinal nerves to the visceral organs of the body. This function is essential for the regulation of physiological signals performed by the body.

Figure 2: Reflex Action



This is very interesting and i**mportant function** performed by the spinal nerves. In this action, both the motor and the sensory fibers of the spinal nerve are involved. A reflex action is an involuntary response to a painful stimulus. For example, when you touch a hot object, the temperature sensations are carried by the sensory fibers to the spinal cord. The **interneurons** in the gray matter of spinal cord receive this information and pass a nerve impulse to motor neurons of the same spinal nerve. The motor fibers in the spinal nerve carry the motor impulse to the muscles of the arm and the hand is pulled away from the hot object. The pathway in this action involves both sensory and motor fibers and is called reflex arc.

Figure 3: Spinal Nerve Function Anatomical Chart



Origin and Functions of Cranial Nerves

Cranial Nerves:

"Nerves that extend throughout the body on both sides emerging directly from brain and brain stem are called cranial nerves." Cranial nerves carry information from the brain to

all parts of the body, primarily to the head and neck. These nerves are paired and present on both sides of the body. They are mainly responsible for facilitating smell, vision, hearing, and movement of muscles. Cranial nerves are concerned with the head, neck, and other facial regions of the body. Cranial nerves arise directly from the brain in contrast to spinal nerves and exit through its foramina. Most of the cranial nerves originate in the brain stem and pass through the muscles and **sense organs** of head and neck.

Traditionally, there are twelve cranial nerves which are numbered using roman numerals according to the order in which they emerge from the brain (from front to back). Cranial nerves are considered as a part of the peripheral nervous system, although olfactory and optic nerves are considered to be part of the Central nervous system. Most of the cranial nerves belong to the somatic system. Some of the cranial nerves are responsible for sensory and motor functions as they contain only sensory fibres and motor fibres. Others are mixed nerves because they include both sensory and motor fibres.

Only cranial nerves I and II are purely sensory and are responsible for the sense of smell and vision (optic nerve II). The rest of the cranial nerves contain both afferent and efferent fibres and are therefore referred to as the mixed cranial nerves. However, the vagus nerve has branches to most of the internal organs and is the part of the autonomic nervous system.

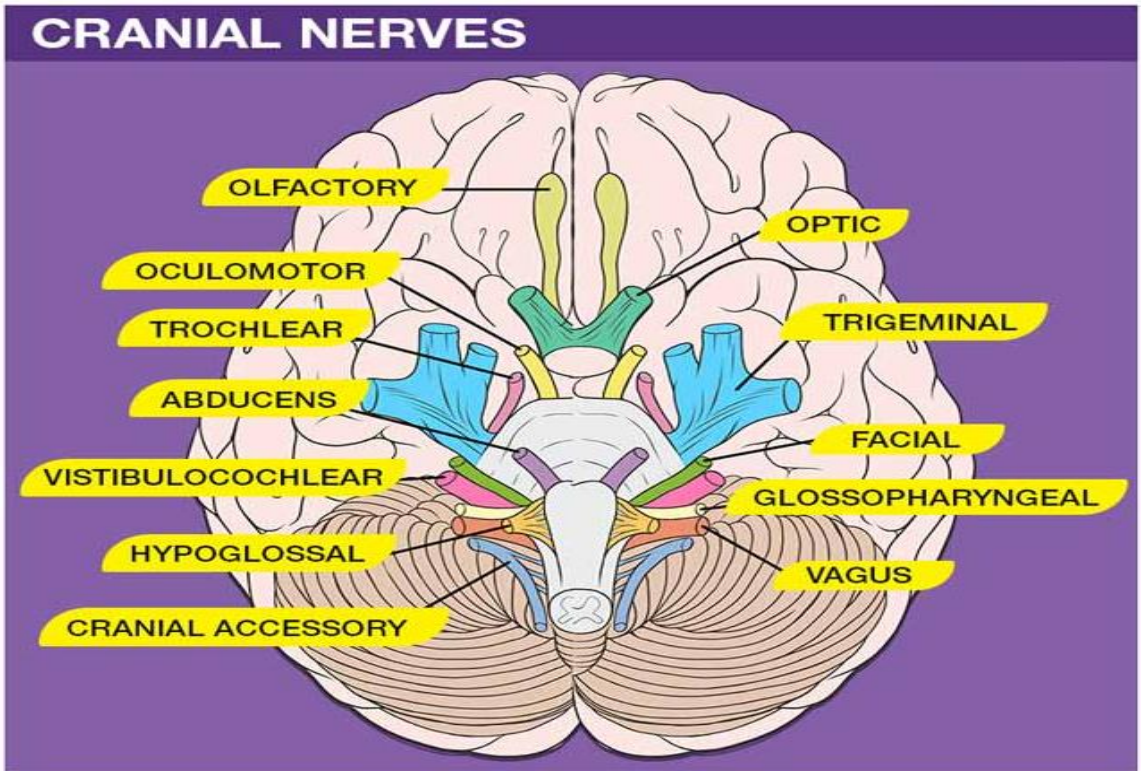


Figure 1: Location of Cranial Nerves

The below table provides the list of cranial nerves along with their location and functions.

Cranial Nerves List	**Location**	**Type**	**Function**
Olfactory (I)	Cribriform plate	Sensory	Smell
Optic (II)	Optic foramen	Sensory	Vision
Oculomotor (III)	Superior orbital fissure	Motor	Eye movement
Trochlear (IV)	Superior orbital fissure	Motor	Eye movement
Trigeminal (V)	Superior orbital fissure	Mixed	Facial sensation
Abducens (VI)	Superior orbital fissure	Motor	Eye movement
Facial (VII)	Internal auditory canal	Mixed	Facial expression

Vestibulocochlear nerve (VIII) (auditory vestibular nerve)	Internal auditory canal	Sensory	Hearing and balance
Glossopharyngeal (XI)	Jugular foramen	Mixed	Oral sensation and taste
Vagus (X)	Jugular foramen	Sensory	Vagus nerve
Accessory (XI)	Jugular foramen	Motor	Shoulder elevation and head turning
Hypoglossal (XII)	Hypoglossal	Motor	Tongue movement

Mnemonics

If we take the first letter of each nerve, we can build a mnemonic to help remember the cranial nerve names!

Oh, **O**h, **O**h, **T**o **T**ouch **A**nd **F**eel **V**ery **G**ood **V**elvet, **S**uch **A** **H**eaven

- **O**lfactory nerve (CN I)
- **O**ptic nerve (CN II)
- **O**cculomotor nerve (CN III)
- **T**rochlear nerve (CN IV)
- **T**rigeminal nerve (CN V)
- **A**bducens nerve (CN VI)
- **F**acial nerve (CN VII)
- **V**estibulocochlear nerve (CN VIII)

- **G**lossopharyngeal nerve (CN IX)
- **V**agus nerve (CN X)
- **A**ccessory nerve (CN XI)
- **H**ypoglossal nerve (CN XII)

In addition, to remember if a nerve is sensory, motor or both in numerical order, remember this:

*"**S**ome **s**ay **m**oney **m**atters, **b**ut **m**y **b**rother **s**ays **b**ig **b**rains **m**atter **m**ost"*

- **S**ensory (CN I)
- **S**ensory (CN II)
- **M**otor (CN III)
- **M**otor (CN IV)
- **B**oth (CN V)
- **M**otor (CN VI)
- **B**oth (CN VII)
- **S**ensory (CN VIII)
- **B**oth (CN IX)
- **B**oth (CN X)
- **M**otor (CN XI)
- **M**otor (CN XII)

Functions of Cranial Nerves

Following is the cranial nerves list along with the important functions they perform:

Olfactory nerve: This nerve helps to feel the sense of smell. This is the primary nerve that is responsible for the smell. Damage to this nerve may result in distortion of smell and taste.

Optic nerve: The optic nerve II is the agent of vision. This transmits visual information from eyes to the brain and vice versa. Any damage to this nerve results in problems related to sight and vision.

Oculomotor nerve: Oculomotor nerve helps in the movement of the eye. Damage to this nerve leads to distortion in vision or double vision and even problem in the coordination of eyes.

Trochlear and Abducens nerves: These nerves also help in eye movement. Damage to the Trochlear nerve might cause inability to move eyeball downwards and damage to abducens nerve might result in diplopia.

Trigeminal nerve: This nerve helps you to have facial sensation. This nerve comprises of three parts namely ophthalmic, maxillary and mandibular.

Facial nerve: This nerve is responsible for facial expression. Due to the damage to this nerve, it might cause the inability to move face parts on one or more sides.

Vestibulocochlear nerve (auditory vestibular nerve): Vestibulocochlear (auditory vestibular nerve) is responsible for hearing and balance. This helps eyes to keep track of moving objects while your head is stable. The sensation of spinning and dizziness are the symptoms of damage to this nerve. This nerve branches into the vestibular nerve and cochlear nerve.

Glossopharyngeal: Oral sensation and sense of taste are stimulated by this nerve. Damage to this nerve disables the sense of taste.

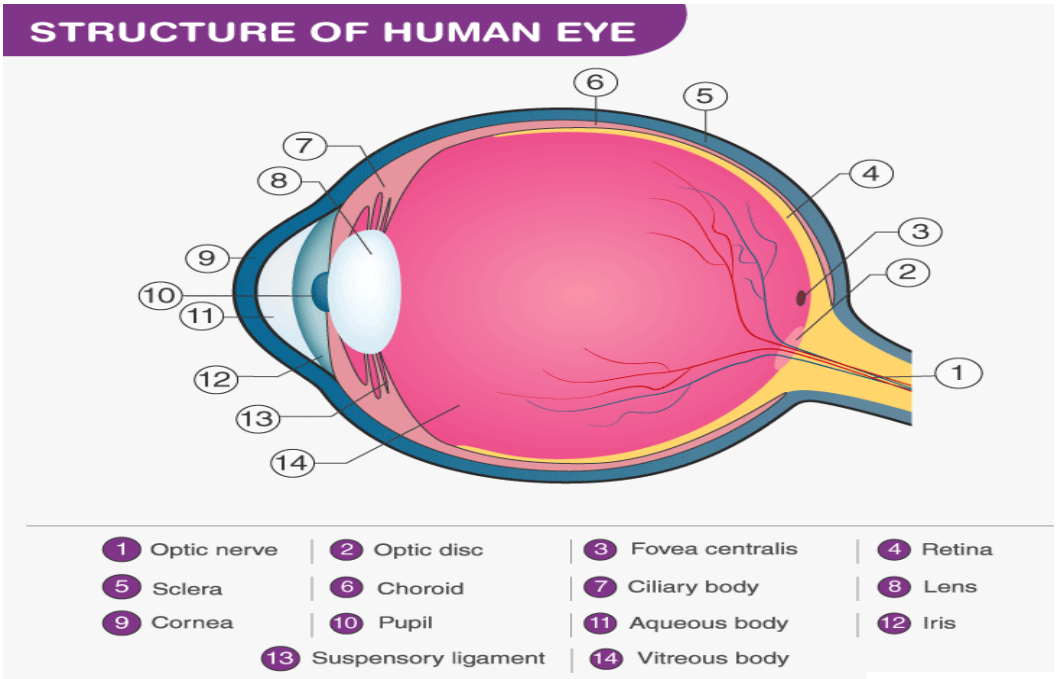
Vagus nerve: This nerve monitors the level of oxygen and helps us to feel the sensation of heat or cold near the throat area. Damage to this nerve leads to the inability to swallow. Major damage to the vagus nerve might result in hypertension or high blood pressure and heart attack.

Accessory nerve: This nerve is also known as nerve XI and arises from two roots namely the cranial and spinal bones. This nerve controls swallowing movements and helps in the movement of head and shoulders.

Hypoglossal nerve: This nerve facilitates the movement of the tongue and helps to talk, swallowing etc.

Structure and functions of Eye and Ear

Structure of the eye is essential to understand as it one of the important sensory organs in the human body. It is mainly responsible for vision, differentiation of colour (the human eye can differentiate approximately 10 – 12 million colours) and maintaining the biological clock of the human body. The human eye can be compared to a camera as both functions by gathering, focusing, and transmitting the light through the lens for creating an image of an object.



Structure and Functions of the Human Eye

The human eyes are the most complicated sense organs in the human body. From the muscles and tissues to nerves and blood vessels, every part of the human eye is responsible for a certain action. Furthermore, contrary to popular belief, the eye is not perfectly spherical; instead, it is two separate segments fused together. It is made up of several muscles and tissues

that come together to form a roughly spherical structure. From an anatomical perspective, the human eye can be broadly classified into the external structure and internal structure.

The External Structure of an Eye

The parts of the eye that are visible externally comprise the external structure of the eye.These include the following:-

Sclera: It is a tough and thick white sheath that protects the inner parts of the eye. We know it as the 'White of the eye'.

Conjunctiva: It is a thin transparent membrane that is spread across the sclera. It keeps the eyes moist and clear by secreting small amounts of mucus and tears.

Cornea: It is the transparent layer of skin that is spread over the pupil and the iris. The main role of the cornea is to refract the light that enters the eyes.

Iris: It is a pigmented layer of tissues that make up the coloured portion of the eye. Its primary function is to control the size of the pupil, depending on the amount of light entering it.

Pupil: It is the small opening located in the middle of the Iris. It allows light to come in.

The Internal Structure of an Eye

The internal structure of the eye includes the following parts:

Lens: It is a transparent, biconvex, and an adjustable part of an eye. The lens with the help of the cornea refracts light focused on the retina, therefore creating images on it.

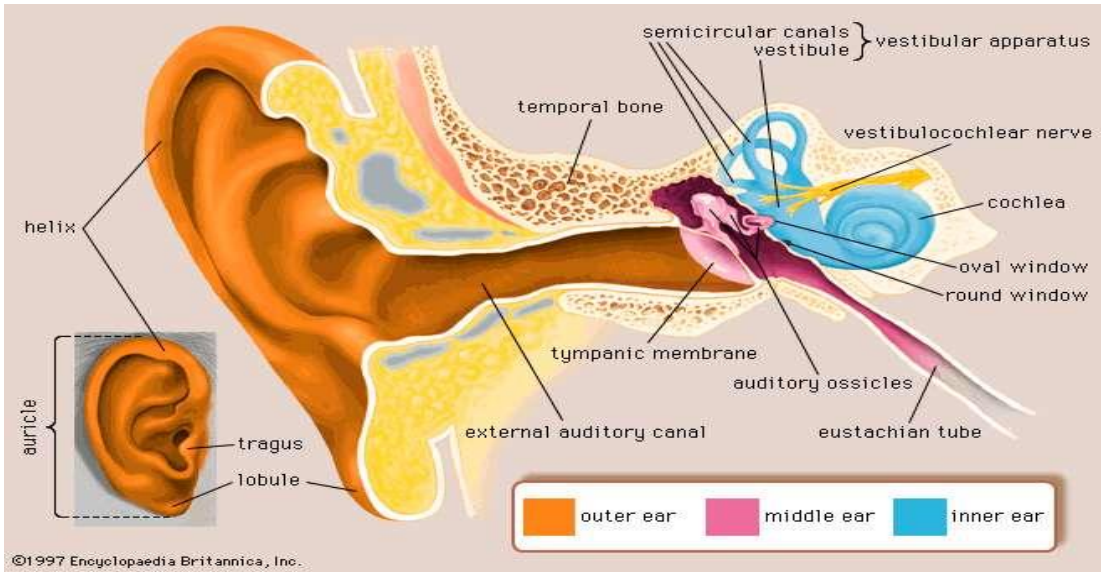
Retina: It is the layer present at the back of the eye where all the images are formed. It is the third and inner coat of the eye which is very sensitive towards the light because of the presence of Photoreceptors. The retina functions by converting the light rays into impulses and sending the signals to the brain through the optic nerve.

Optic nerve: It is located at the end of the eyes, behind the retina. The optic nerve is mainly responsible for carrying all the nerve impulses from the photoreceptors to the human brain, without which vision would not be possible.

Aqueous Humour: It is a watery fluid that is present in the area between the lens and the cornea. It is responsible for the nourishment of both the lens and the cornea.

Vitreous Humour: it is a semi-solid, transparent, jelly-like substance that covers the interior portion of the eyes. It plays an important role in maintaining the shape of the eye and also causes refraction of light before it reaches the retina.

Structure of Ear:



The human ear consists of three parts:

- External ear

- Middle ear
- Internal ear

Human Ear Parts

The human ear parts are explained below:

External Ear

The external ear is further divided into the following parts:

Auricle (Pinna)

The auricle comprises a thin plate of elastic cartilage covered by a layer of skin. It consists of funnel-like curves that collect sound waves and transmits them to the middle ear. The lobule consists of adipose and fibrous tissues supplied with blood capillaries.

External Auditory Meatus

It is a slightly curved canal supported by bone in its interior part and cartilage in the exterior part. The meatus or the canal is lined with stratified epithelium and wax glands.

Tympanic Membrane

This membrane separates the middle ear and the external ear. This part receives and amplifies the sound waves. Its central part is known as the umbo.

Middle Ear:

The middle ear comprises the following parts:

Tympanic Cavity

It is a narrow air-filled cavity separated from the external ear by tympanic membrane and from inner ear by the bony wall. The tympanic cavity has an auditory tube known as the eustachian tube in its anterior wall.

Eustachian Tube

The eustachian tube is a 4cm long tube that equalizes air pressure on either side of the tympanic membrane. It connects the tympanic cavity with the nasopharynx.

Ear Ossicles

These are responsible for transmitting sound waves from the eardrum to the middle ear. There are three ear ossicles in the human ear:

- **Malleus:** A hammer-shaped part that is attached to the tympanic membrane through the handle and incus through the head. It is the largest ear ossicle.
- **Incus:** An anvil-shaped ear ossicle connected with the stapes.
- **Stapes:** It is the smallest ossicle and also the smallest bone in the human body.

Inner Ear

It comprises two parts:

- Bony labyrinth
- Membranous labyrinth

Bony Labyrinth

The bony labyrinth comprises a vestibule, three semi-circular canals, and spirally coiled cochlea. It is filled with perilymph.

Membranous labyrinth

The bony labyrinth surrounds the membranous labyrinth. It comprises sensory receptors responsible for balance and hearing. The membranous labyrinth is filled with endolymph and comprises three semi-circular ducts, cochlear duct, saccule and utricle. The sensory receptors include cristae, organ of corti, and ampullaris maculae.

Functions of Ear

Following are the important functions of the ear:

Hearing

The mechanism of hearing involves the following steps:

- The sound waves pass through the auditory canal and reach the eardrum.
- The vibrations produced pass through the tympanic membrane to the tympanic cavity.
- The ear ossicles in the tympanic cavity receive the vibrations and the stapes pushes the oval window in and out.
- This action is passed on to the organ of corti, the receptor of hearing, that contains tiny hair cells that translate the vibrations into electrical impulse that are transmitted to the brain by sensory nerves.

Balance

The eustachian tube and the vestibular complex are the important parts of the ear responsible for balance.

- The eustachian tube equalizes the air pressure in the middle ear and maintains the balance.
- The vestibular complex contains receptors that maintain body balance

STRUCTURE AND FUNCTIONS OF NOSE AND TONGUE

Nose is the primary organ of smell and functions as an important respiratory organ in the body. Besides this, it is also involved in functions such as hearing and tasting.

The air that we breathe in is filtered through the nasal hair. The inhaled air is warmed and humidified before it enters into the lungs.

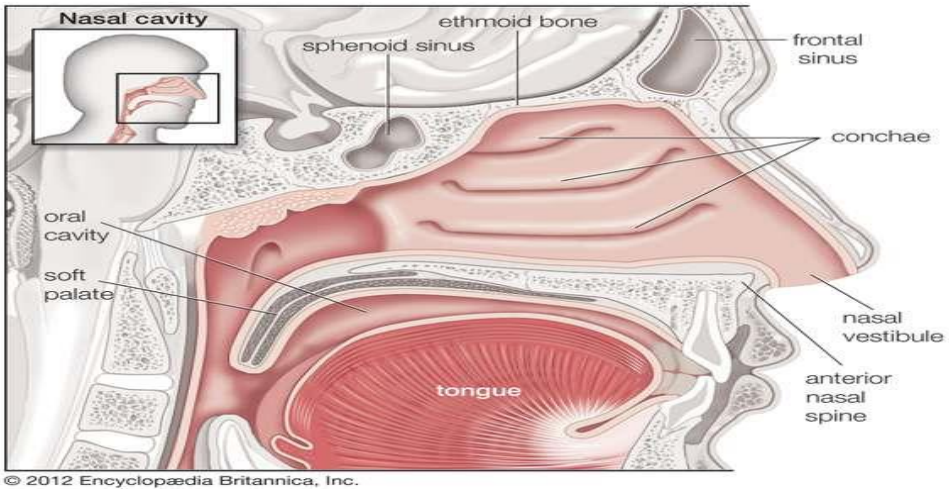


Figure 1: Structure of Human Nose

The shape of the nose is due to the bones and cartilages. The nasal septum separates the nostrils and divides the nasal cavity into two.

The structure and function of the nose are mentioned in detail.

Nose Structure

The structure of nose is explained as follows:

1. **Bone:** It supports the bridge of the nose.
2. **Cartilage:** The upper cartilage provides support to the sides of the nose. The lower cartilage adds width and height to the nose. It provides shape to the nostrils and nose tip.
3. **Nasal Cavity:** It is the hollow space through which the air flows.
4. **Septum:** The septum divides the inside of the nose into two chambers. It is a thin wall made of bones and cartilage.
5. **Mucus Membrane:** The mucus membrane lines the nose, sinuses and throat. It moistens and warms the air we breathe in. It also forms a sticky mucus that prevents dust and other small particles into the nose.
6. **Turbinates:** Each side of the nose contains curved turbinates, and the bony ridges are lined with mucus membrane.

7. **Sinuses:** The bone around the nose contains hollow, air-filled chambers known as sinuses. The mucus flows into the nasal cavity from the sinuses.

Functions of Nose

Following are the important functions of nose:

Helps in Inhalation

The process of respiration starts in the nose. The oxygen enters into the nose through the nostrils and exits the same way during exhalation. The nasal cavities open into a space called choana, which further opens into the nasopharynx. The air then enters the oropharynx and finally reaches the lungs via larynx, trachea and bronchi.

Purification of Inhaled Air

The walls of the nasal cavity are covered with hair or cilia that trap the dust and harmful particles and purify the inhaled air. The back and forth movement of cilia help in moving the dust particles to the throat where they are swallowed, or are excreted through the nasal cavity.

The nose hair also moisturizes and warms the air, so that it resembles the air temperature and moisture within the lungs. During exhalation, the heat and moisture present in the carbon dioxide is absorbed by the nasal hair and then released in the atmosphere.

The nasal conchae, that is spiral in structure, keeps whirling the air for a longer time within the nasal cavity so that it is humidified and purified properly.

Organ of Smell

The inhaled air comes in contact with the olfactory epithelium and the nerve fibres extending from the olfactory receptors accumulate the molecules containing the odour to send the signals to the olfactory bulbs through the receptors. These signals are carried to the olfactory region of the brain and are decoded so that the smell is identified.

Sense of Taste

While chewing, the food releases certain chemicals that travel up to the nose and activate the olfactory receptors inside the nose. They work in coordination with the taste buds to identify the actual flavour of the food.

TONGUE

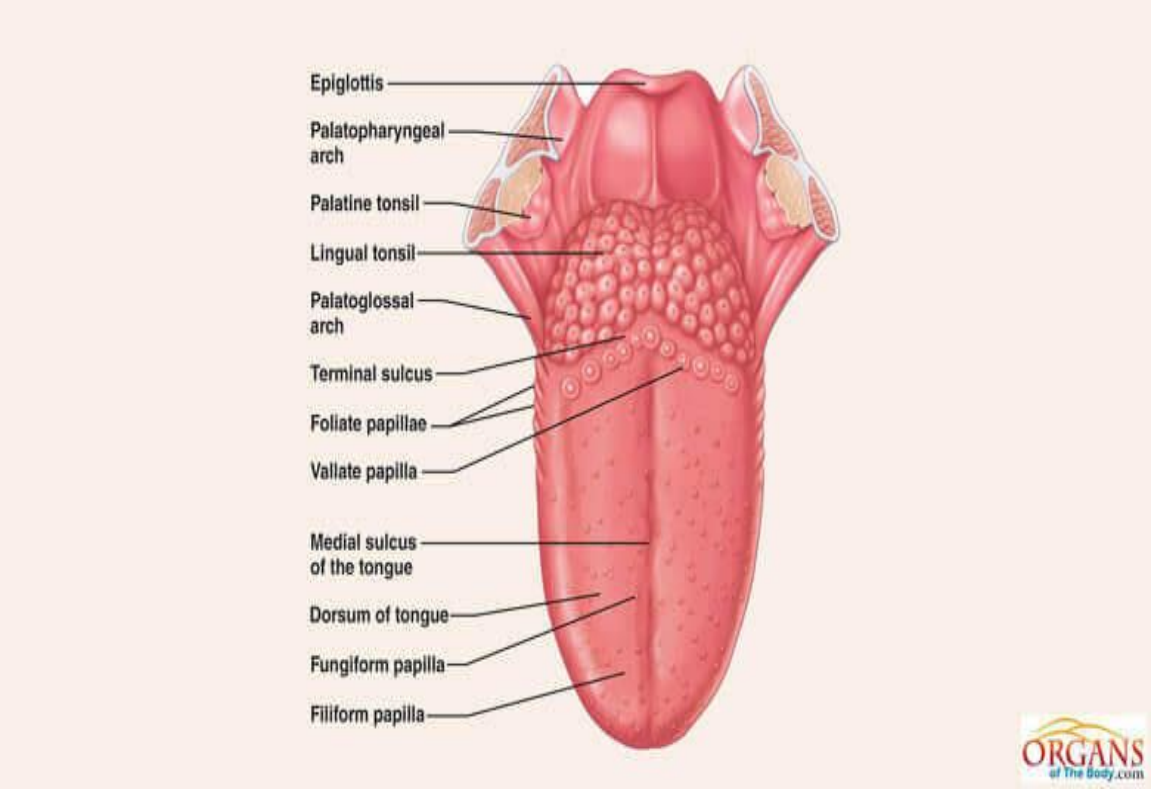


Fig. 2: Human Tongue and its Parts

The tongue is a muscular organ in the mouth covered with a moist, pink tissue called mucosa. It is involved in licking, tasting, breathing, swallowing, and speaking. The papillae present on the tongue give it a rough texture. It is covered by a number of taste buds. There are

several nerves in the tongue that help in transmitting taste signals to the brain, and thus help in taste sensation.

Structure of Tongue

The human tongue is about 3.3 inches in men and 3.1 inches in women. It is located in the oral cavity. The tongue is divided into three parts:

- Tip
- Body
- Base

The tongue is embryologically divided into the anterior and posterior part. The anterior part is known as the oral or presulcal part that includes the root attached to the floor of the oral cavity. While the posterior part is known as pharyngeal or postsulcal part that includes the base forming the ventral wall of oropharynx.

The tongue is made up of three elements:

- Epithelium
- Muscles
- Glands

Epithelium

The epithelium comprises papillae and taste buds. The taste buds help to sense taste. They are lined by squamous epithelial tissue and have a broad bottom.

The taste cells are slender, rod-shaped with a nucleus in the centre. The free surface comprises short taste hair. The taste cells help in detecting taste, which dissolves in saliva for proper sensation.

Muscles

The tongue muscles are voluntary and contain cross-striated muscular fibres.

Glands

The tongue consists of small and scattered glands. These glands are of three types:

- Mucous Glands
- Serous Glands
- Lymph Nodes

The lymph nodes are very prominent at the posterior part of the tongue and are known as lingual tonsils.

Nerve Supply

The glossopharyngeal nerve and the chorda tympanic branch of the facial nerve are responsible for taste sensation. The sensations of pain, touch, temperature are carried by the trigeminal nerve.

Tongue Functions

Following are the important tongue functions:

Mastication

The tongue helps in chewing.

Deglutition

It helps in swallowing food.

Taste

The tongue transmits taste signals to the brain and helps in sensing taste.

Speech

It is an important organ that facilitates speech.

Secretion

It secretes mucous and serous fluid which keeps the mouth moist.

Salivary Glands

Salivary glands comprise three pairs:

- Parotid
- Submaxillary
- Sublingual

Parotid

It opens on the inner surface of the cheek by the duct of Stensen. It is located opposite the second upper molar tooth.

Submaxillary

It opens by Wharton's duct on the floor of the mouth by the sides of the frenulum of the tongue.

Sublingual

It opens by the ducts of Rivinus on the floor of the mouth by the sides of the frenulum of the tongue.

DISORDERS OF SPECIAL SENSE ORGANS

Eye Diseases

The diseases or a disorder that destroy eye tissue and other parts of eyes can be referred to as the eye diseases. There are different types of eye diseases, which can either be minor, which doesn't last for a longer time or some can also lead to a permanent loss of vision.

There are different factors behind the causes of eye diseases. These factors include age, stress, infections, **heredity**, nutritional deficiencies, injuries or accidents, etc.

Types of Eye Diseases

There are different types of eye diseases that exist, all of these being common eye diseases.

The following is a list of human eye disease:

Age-Related Macular Degeneration

Macular degeneration is also known as an irregularity that affects the centre of the retina, which is called the Macula. The Macula is responsible for everyday acute vision.

There are two types of Macular degeneration-

1. Dry Macular degeneration.
2. Wet Macular degeneration.

Causes of Macular degeneration

Age, Smoking, Obesity, High blood pressure, Exposure to sunlight.

Symptoms of Macular degeneration

Blurred vision, A dark or empty area in the central area of vision, Distortion of straight lines.

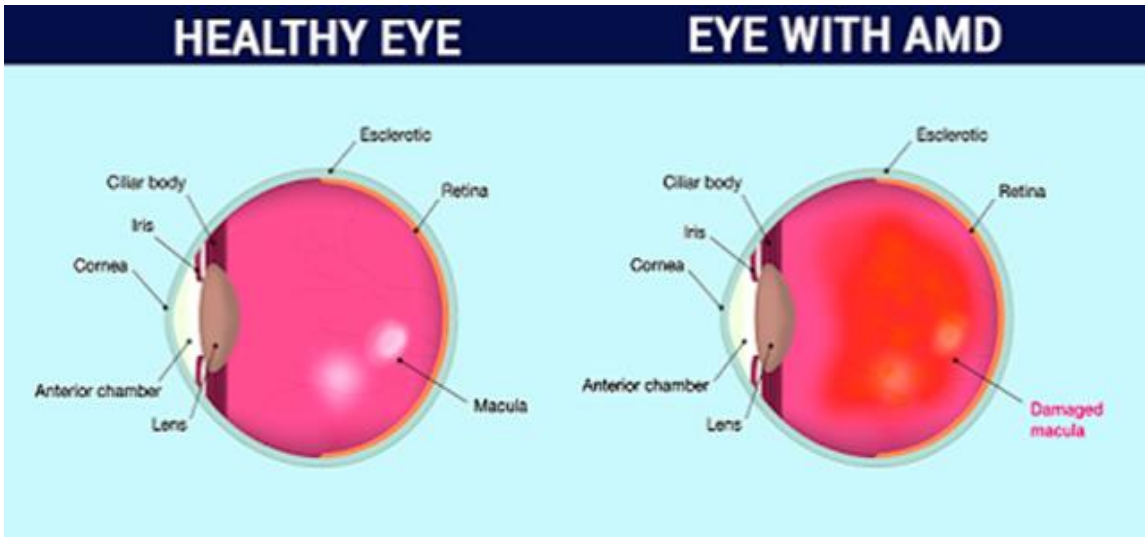


Figure 1: Age-Related Macular Degeneration

Treatments for Macular degeneration

People suffering from Dry AMD continue with the aid of low vision optical devices. But Wet AMD is treated with injected medications or laser surgery by sealing off the leaking blood vessels.

Bulging Eyes

Proptosis as it is also known as occurs due to the swelling of muscle fats and tissue behind the eye causing both eyes to protrude from the eye sockets leaving the cornea exposed to air, making it difficult to keep the eyes moist and lubricated.

Causes of Bulging Eyes

It has been linked to Glaucoma, Hyperthyroidism, and Leukemia the most common being Graves disease a condition where thyroid glands mistakenly sense harmful cells and release **antibodies** which fuse to eye muscles causing inflammation.

Symptoms of Bulging Eyes

Common symptoms include Appearance of protruding eyes, Excessive dryness in eyes, Visible whiteness between the top of iris and the eyelid, Eye pain, Eye redness.

Figure 2: Bulging Eyes

Treatments for of Bulging Eyes

Lack of lubrication is the main problem hence artificial tears and eye drops are used for moisture and lubrication.

Glaucoma

It is a situation which is caused by the damage to the eye's optic nerve which gets severer over time. It is often associated with an increase in the pressure inside the eye. Glaucoma tends to be inherited and turns up late in life. There are four different types of Glaucoma which include Chronic open-angle glaucoma, Acute closed-angle glaucoma, Secondary glaucoma, Normal-tension glaucoma.

Causes of Glaucoma

All four types of glaucoma are formed by different causes :

1. Chronic open-angle glaucoma results from a pressure build-up in the eye and causes severe vision loss without any symptoms.
2. Acute closed glaucoma appears all of sudden which is very painful and is extremely serious.

3. Secondary glaucoma arrives as a result of something else like medical conditions and injuries, irregularities.
4. Normal-tension glaucoma is a unique condition of the eye in which is caused by the damage to an optic nerve. This may result in the loss of vision, caused by the intraocular pressure in the eye.

Symptoms of Glaucoma

Blurred vision, severe eye pain, headache, rainbow halos, nausea, and vomiting.

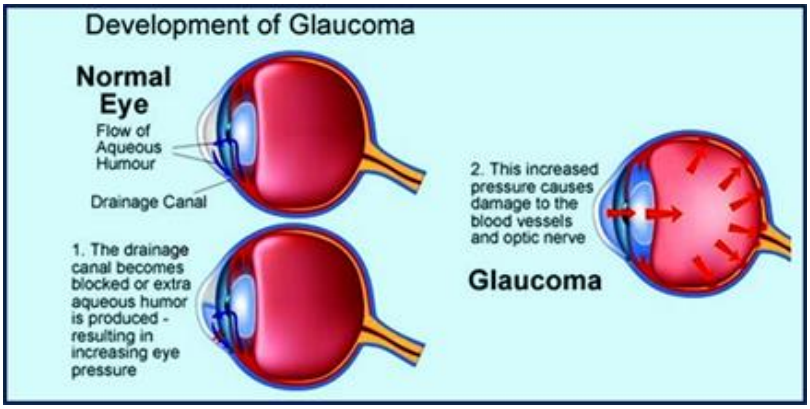


Figure 3: Glaucoma

Treatments for Glaucoma

Glaucoma could be treated with prescription eye drops which reduces eye pressure by slowing the production of fluids within the eye. Doctors also recommend highly focused laser beams to create an alternate hole in the iris. Surgery could treat glaucoma but could not reverse the existing damage.

Lazy Eye

This is a condition where there is a lack of vision in one eye because the eye and the brain stop working together, the brain ignores the image from the amblyopic eye this only affects one eye resulting in the amblyopic eye pointing away from the other thereby appearing “Lazy”.

Figure 3: Lazy eye

Causes of Lazy Eye

There are various causes behind this condition like Strabismus (Crossed Eyes) and cataracts, ptosis and refractive problems.

Symptoms of Lazy Eye

Symptoms include eyes that point in different directions, significant favouring of one eye, poor depth perception, poor vision in one eye.

Treatments for Lazy Eye

Improved sight in a lazy eye could be accomplished however in certain cases an untreated eye might become dysfunctional, Best possible methods are by Patching or covering the strong eye: This method forces the weaker eye to work harder hence strengthening its ability to move and focus. Contact lenses and eyeglasses in some cases surgery to realign the muscles in the eye.These were the most common eye diseases types that are caused by several factors.

Listed below are the few eye diseases names which are caused by immune system disorders, age-related and some may even result in permanent loss of vision.

1. Floaters.

2. Cataracts.
3. Presbyopia.
4. Conjunctivitis.
5. Vision Changes.
6. Colour blindness.
7. Retinal disorders.
8. Dry and Itchy Eyes.
9. Optic nerve disorders.
10. Macular degeneration.

Ear

Acoustic neuroma – A non-cancerous growth that begins in the nerve that carries hearing and balance sensation from the ear to the brain. This slow-growing tumor eventually fills the ear canal and, if untreated, can cause life-threatening damage to the brainstem. The optimal treatment is surgical removal of the tumor.

Cholesteatoma – A cholesteatoma is an abnormal cyst or pouch in the middle ear, usually caused by repeated infections. Over time, a cholesteatoma can cause deafness and even life-threatening complications. Treatment involves surgery to remove the cyst and infection, followed six to 12 months later by another operation to check for any residual cholesteatoma, to reconstruct the middle ear, and to restore hearing, if possible.

Mastoiditis – Infection of the mastoid bone, a honeycomb-type structure that is part of the skull behind the ear. Unchecked, mastoiditis can lead to deafness and life-threatening complications. The first line of defense is antibiotics, but mastoidectomy may be required to clean out the infection and, if necessary, tympanoplasty to repair a damaged eardrum.

Meniere's disease – A disorder of the inner ear characterized by dizziness, hearing loss, and ringing or noises in the ear. It is caused by an imbalance of fluid in the inner ear and is thought to be an immune or inflammatory response. The condition is usually treated with medication, but when medicine doesn't work, an option can be surgery to relieve pressure in the ear, remove a faulty balance organ (the labyrinth), or partially or completely remove a balance and/or hearing nerve.

Chronic otitis media – An ongoing infection or inflammation of the middle ear, usually affecting children. A persistent condition can lead to hearing loss and other serious complications. Treatment includes surgery, called a typanoplasty, to repair the eardrum and hearing bones. This procedure is sometimes combined with mastoidectomy to remove the diseased tissue. Another procedure, a tympanostomy or myringotomy, involves inserting a small metal or plastic tube in the affected ear to ventilate it and prevent buildup of pressure and fluid.

Otosclerosis – A condition characterized by abnormal bone growth in the middle ear, which limits the transmission of sound vibrations through the ear. Left untreated, this condition can lead to total deafness. The surgical option is a stapedectomy, in which the stapes, a spongy bone in the middle ear, is replaced with a prosthesis that transmits sound waves to the inner ear.

Nose

Sinusitis

Sinusitis is **one of the most common chronic (ongoing) conditions** in the United States effecting fifty million Americans, 20% of the nation's population.

Sinusitis is often a chronic (ongoing) disease that includes the symptoms of nasal obstruction (difficulty breathing through the nose), nasal drainage, decreased sense of smell, facial

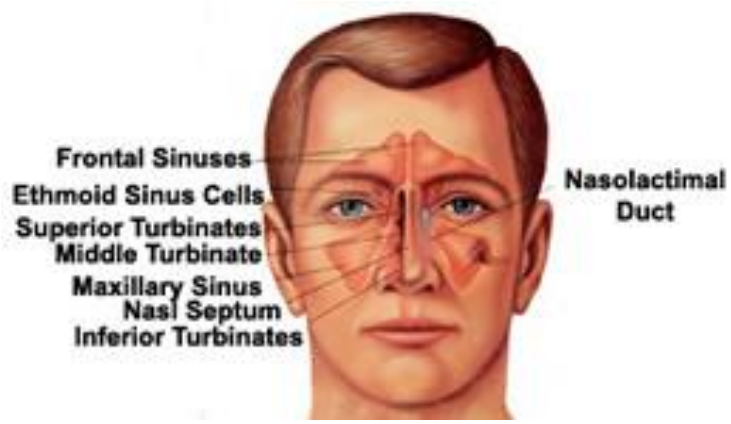
pressure, and frequent sinus infections. Allergies and related respiratory problems such as asthma can also be associated with chronic sinusitis.

It can sometimes be difficult for patients to decipher if they are suffering from allergies, an upper respiratory tract infection, or a sinus condition. Symptoms and signs for each condition differ, and each diagnosis requires a unique treatment regimen. The Oregon Sinus Center team can help make an informed choice as to the best management strategy for a patient with any of these conditions.

After getting the correct diagnosis, a number of medical treatments can be started. These medications may include anti-inflammatory nasal sprays, decongestants, oral inflammatory inhibitors, and systemic steroid medications. It is important that the physician and patient recognize that medications are often required on a long-term basis.

In some cases, surgery is required using a telescope (endoscope) which is placed through the nostril. This type of surgery is often referred to as Endoscopic Sinus Surgery, which is minimally invasive and does not require any external incisions. It is our goal that after surgery, patients will not require any further surgery on the nose and sinuses.

In some cases, however, sinusitis can return. Our surgeons have a particular interest in patients whose sinusitis has failed traditional surgery and require advanced techniques to control the underlying inflammation. The Oregon Sinus Center actively conducts ongoing research into better treatments for sinusitis.



Nasal & Sinus Polyps

Nasal polyps are associated with sinusitis and occur when the lining of the sinuses swell. Polyps may block the nasal airway, creating difficulty in breathing. Polyps may also block the natural drainage of the sinus cavities leading to infections. Polyps are generally thought to occur as a result of an ongoing inflammatory process within the nose and sinuses.

After getting the correct diagnosis, our team of can help patients decide on the most appropriate treatment plan. Most commonly, medications are tried as first line therapy. Different combinations can be tailored for individual patients. In some cases, a patient's disease cannot be fully controlled with medication and surgery may be recommended. This surgery is done with telescopes (endoscopes) through the nose in a minimally invasive fashion.

Following this type of surgery, it is very important to maintain medical treatment. Additionally, the nose and sinus cavities must be watched carefully to prevent the return of the polyps. It is our goal that after surgery, patients will not require any further surgery on the nose and sinuses to remove polyps.

In some cases, however, polyps may return. Our surgeons have a particular interest in patients who have experienced the return of polyps following previous nasal and sinus surgeries. We are experts in the more advanced techniques that may be required to control polyp formation. The Oregon Sinus Center actively conducts ongoing research into better treatments for sinus polyps.

Smell and Taste Disorders

Disorders of smell and taste can have a large impact on quality of life. Currently about 2 million adults in the United States are evaluated for smell and taste disorders every year, but it is believed many more cases go unreported. It is estimated that up to 80% of taste is a result of olfactory (or smell) input. As a result, loss of smell is frequently interpreted as a loss of taste.Problems with smell and taste can be due to a variety of causes. Examples of these include chronic rhinosinusitis, polyps, allergic rhinitis, upper respiratory infection, trauma, tumors or other neurological disorders.

Evaluations of these disorders include a thorough history and physical exam with an endoscope, objective smell testing, and may also include imaging. Treatment of these problems depends on the problem and the severity of the loss. Our team works with each patient to best understand the cause of their smell and taste problems. From there, a therapeutic plan can be initiated.

TONGUE

Loss of taste

Taste is a chemical sense that is activated during eating and drinking. Reasons for a loss of taste include:

- A person may lose their sense of taste if the facial nerve is damaged in some way. For example, Bell's palsy may stop the facial nerve working properly and prevent or reduce chewing function (and, therefore, alter taste). It is uncommon for every taste nerve (bitter, salty, sweet and sour) to be affected.
- The autoimmune disorder known as Sjogren's syndrome causes reduced saliva production, which in turn reduces the sense of taste. This is because the taste buds can only detect flavour when food is properly mixed with saliva.
- Glossodynia, a condition characterised by a burning sensation on the tongue, is also linked to loss of taste in some cases.
- Some medications can result in an unpleasant metallic taste in the mouth, such as tetracycline (an antibiotic), lithium carbonate (an antipsychotic) and captopril (an antihypertensive).

Sore tongue

A sore tongue is usually caused by some form of trauma, such as biting your tongue, or eating piping-hot or highly acidic food or drink. Other causes of a sore tongue include:

- If your top and bottom teeth don't fit neatly together, tongue trauma is more likely.
- Some people may experience a sore tongue from grinding their teeth (bruxism).
- Disorders such as diabetes, anaemia, some types of vitamin deficiency and certain skin diseases can include a sore tongue among the range of symptoms.
- A sore tongue can be caused by disorders including black hairy tongue.

Black hairy tongue

While the term 'black hairy tongue' suggests the tongue surface looks black, it may also be dark yellow, brown, green or white. The tongue papillae are constantly renewing themselves and, usually, the old cells are shed as the new cells emerge. Black hairy tongue, a comparatively rare condition, is caused by the failure of the old cells to shed. The overgrowth of papillae trap food and bacteria, which create the characteristic dark 'coat' on the tongue's surface, while the tongue looks furred because of the layering of unshed papillae. The cause isn't known, but risk factors include:

- Poor oral hygiene
- Cigarette smoking
- Particular antibiotics
- Chemotherapy and radiation treatment for cancers of the head and neck
- Poorly managed diabetes.

Glossodynia

The main symptom of glossodynia is a burning sensation on the tongue surface. The various causes of glossodynia can include:

- Local infections, such as oral thrush (candidiasis)
- Damage to the lingual nerve
- Damage to nerves of the mouth during dental extractions
- Cigarette smoking
- Vitamin deficiencies
- Particular medications, such as diuretics and some blood pressure drugs.

Benign migratory glossitis

This condition is characterised by irregular and inflamed patches on the tongue surface that often have white borders. The tongue may be generally swollen, red and sore. Another name for this condition is geographic tongue. The cause of benign migratory glossitis is unknown, but risk factors are thought to include:

- Mineral or vitamin deficiencies
- Local irritants, such as strong mouthwashes, cigarettes or alcohol
- Certain forms of anaemia
- Infection
- Certain medications
- Stress.

Tongue-tie

The medical name for tongue-tie is ankyloglossia. Frenula are little strings of tissue found underneath the tongue, inside the cheeks near the back molars, and under the top lip. The frenum (or frenulum) under the tongue is called the lingual frenum. Tongue-tie is a condition characterised by a short frenum that stops the tongue from poking out past the lips. Other symptoms can include:

- Tongue tip can't touch the roof of the mouth
- Tongue can't be moved sideways
- Tongue tip may look flat or square instead of pointy when the tongue is extended
- Tongue tip may be notched or heart-shaped
- The front teeth in the lower jaw are gapped
- History of feeding or sucking problems.

Diagnosis methods

Depending on the disorder under investigation, diagnosis methods can include:

- Physical examination
- Medical history
- Salivary gland tests
- Biopsy.

Treatment options

Depending on the disorder and cause, treatment options can include:

- **Loss of taste** - treatment for the underlying disorder, such as an artificial saliva spray or gel for Sjogren's syndrome.

- **Sore tongue** - avoid hot, spicy or acidic food and drinks until the injury heals; wear a mouth guard at night to prevent tongue trauma from bruxing (teeth grinding); dermatological treatment for the skin disorder; treatment for the underlying disorder such as iron supplements for iron-deficiency anaemia; better management of diabetes under medical supervision.
- **Black hairy tongue** - greater attention to oral hygiene; brushing the tongue every time the teeth are brushed; regular scraping of the tongue with a special tongue-scraper, often in conjunction with a mild bleaching solution; stopping smoking.
- **Glossodynia** - treatment of underlying disorders such as improved diet; topical anaesthetic creams; avoidance of irritants; surgery on the lingual nerve if damage is the cause.
- **Benign migratory glossitis** - topical anaesthetic creams and prescription drugs including steroids.
- **Tongue-tie** - this condition usually resolves by the age of two or three years, which means the frenum 'loosens' or recedes by itself, given time. In persistent cases, the child may need to have an operation (frenectomy) to release the tongue.

CLASSIFICATION OF HORMONES

Hormones are classified in to 5 categories. The categories are: 1. According to Chemical Nature 2.On the basis of Mechanism of Action 3. According to Nature of Action 4. According to Effect 5. On the basis of Stimulation of Endocrine Glands.

Category 1. According to Chemical Nature:

(a) Steroid Hormones:

These are made up of lipids, which basically derived from cholesterol, e.g. Testosterone, Estrogen, Progesterone etc.

(b) Amine Hormones:

These hormones are made up of amines. Amine hormone is derivative of the amino acid tyrosine. e.g. T_3, T_4, epinephrine, norepinephrine.

(c) Peptide Hormones:

These hormones are made up of few amino acid residues only and present as simple linear chain.

e.g. Oxytocin and vasopressin both consist of only 9-amino acid residues only.

(d) Protein Hormones:

These hormones are also made amino acid residues which are much more in numbers. They represent primary, secondary and tertiary configuration.

e.g. Insulin, glucagon, STH etc.

(e) Glycoprotein Hormones:

These hormones are glycoprotein in nature. They are conjugated protein where carbohydrate groups are mannose, galactose, fucose etc.

e.g. LH, FSH, TSH etc.

(f) Eicosanoids Hormones:

The eicosanoids are small fatty acid derivatives with a variety of arachidonic acid.

e.g. Prostaglandins.

Category 2. On the Basis of Mechanism of Action:

(a) Group I hormones:

These hormones bind to intracellular receptors to form hormone-receptor complexes (HRC), through which their biochemical functions are mediated. These hormones are lipophilic in nature and are derivatives of cholesterol (except T_3 and T_4). They are found in circulation in association with transport proteins and possess relatively longer half-lives (hours or day). e.g. Estrogen, Progesterone, Testosterone, T_3, T_4 etc.

(b) Group II hormones:

These hormones bind to cell surface (plasma membrane) receptors and stimulate the release of certain molecules, namely the second messengers which in turn, perform the biochemical functions. Thus, hormones themselves are lipophobic in nature, usually transported in the free form and possess short half-lives (in minutes).

Group II hormones are subdivided into three categories on the basis of chemical nature of second messengers:

(i) The second messenger is cAMP. e.g. ACTH, FSH, LH etc.

(ii) The second messenger is phospholipid/inositol/Ca^{++}.

e.g. TRH, GnRH, Gastrin etc.

(iii) The second messenger is unknown.

e.g. STH, LTH, Insulin, Oxytocin etc.

Category 3. According to Nature of Action:

(a) Local Hormones:

These hormones have got specific local effects by paracrine secretion.

e.g. Testosterone.

(b) General Hormones:

These hormones are transported by circulation to the distal target organ/tissue.

e.g. Insulin, Thyroid hormone etc.

Category # 4. According to Effect:

(a) Kinetic Hormones:

These hormones may cause pigment migration, muscle contraction, glandular secretion etc.

e.g. Pinealin, MSH, Epinephrine etc.

(b) Metabolic Hormones:

These hormones mainly changes the rate of metabolism and balance the reaction.

e.g. Insulin, Glucagon, PTH etc.

(c) Morphogenetic Hormones:

These hormones are involved in growth and differentiation.

e.g. STH, LTH, FSH, Thyroid hormones etc.

Category # 5. On the Basis of Stimulation of Endocrine Glands:

(a) Tropic Hormones:

These hormones stimulate other endocrine glands for secretion.

e.g. TSH of pituitary stimulates secretion of thyroid gland.

(b) Non-tropic Hormones:

These hormones exert their effect on non-endocrine target tissues.

e.g. Thyroid hormone increases the O_2 consumption rate and metabolic activity of almost every cell.

MECHANISM OF HORMONE ACTION

The mechanism of hormone action is grouped into two classes:

- Fixed membrane receptor mechanism
- Mobile receptor mechanism

Fixed Membrane Receptor Mechanism

This type of mechanism is shown by the water-soluble hormones that are amines or proteins in composition such as the growth hormone, oxytocin, ADH, etc.

These hormones can't pass through the lipid membrane. They have their target receptor on the cell membrane to which the hormone binds.

When the hormone binds on the specific target receptor, the enzyme adenyl cyclase in the cell membrane is activated. This helps in the production of cyclic AMP (cAMP).

cAMP acts as the secondary messenger. It diffuses through the cell membrane and activates several enzymatic reactions to cause biochemical changes.

The target cell responds to these changes and cAMP is deactivated by the enzyme phosphodiesterase.

Mobile Receptor Mechanism

This type of mechanism is shown by lipid soluble hormones such as fatty acids and steroids that can easily pass through the plasma membrane.

They possess intracellular receptors. The hormones bind to the target receptor that activates the enzymatic activity of the cell to bring about biochemical changes.

Transcription of DNA is initiated by the hormone-receptor complex.

The mRNA is translated into protein. This protein causes biochemical changes inside the cell.

Hormones as Regulators

Hormones help in maintaining the internal environment of the body. When the secretion of hormones is under the control of other hormones, it is known as feedback control. It can be of two types:

1. **Positive Feedback Control:** In this process, the end products of action cause more of the action to occur in a feedback loop. For eg., blood clotting, menstrual cycle.
2. **Negative Feedback Control:** In this type of regulation the end product of a process reduces the stimulus of that same process. For eg., temperature regulation, regulation of blood sugar.

Hormones as Messengers

The neurosecretory cells of the hypothalamus secrete hormones known as neurohormones into the blood. These neurohormones are carried to the pituitary gland and stimulate it to release various hormones. hence they are also known as “releasing factors”.

STRUCTURE AND FUNCTIONS OF PITUITARY GLAND AND THEIR DISORDERS

The Pituitary gland, also known as hypophysis, is a pea-sized endocrine gland situated at the base of our brain. It is often referred to as the ‘Master Gland’ because it produces some of the important hormones in the body. It is situated in a bony structure called the Pituitary fossa, just below the hypothalamus, close to the optic nerve.The pituitary gland is divided into three parts, also called lobes:

- Anterior pituitary
- Intermediate pituitary (Absent in adult human beings)
- Posterior pituitary

Function of Hormones Secreted By Pituitary Gland

A healthy adult human's pituitary gland consists of two parts – the Anterior and the Posterior parts. The Intermediate pituitary regresses during gestation and is absent in adult humans. Following are the major functions of hormones:

Anterior Pituitary Hormones

The anterior pituitary is responsible for the synthesis and secretion of several key hormones in the body. These hormones include:

Human Growth Hormone (HGH): Responsible for the growth and repair of all cells in the body.

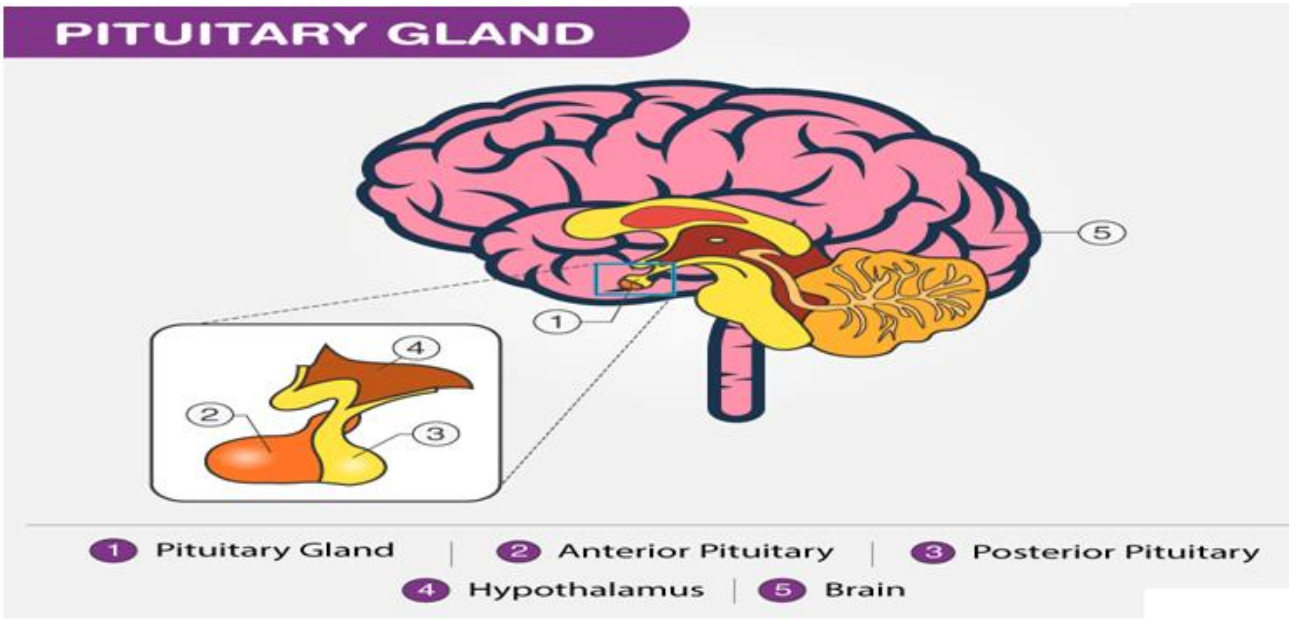
Thyroid Stimulating Hormone (TSH): Influences the thyroid gland for the release of thyroxine, its own hormone. TSH is also called Thyrotropin.

Adrenocorticotropic Hormone (ACTH): Influences the adrenal gland to release of Cortisol or the "stress hormone". ACTH is also known as corticotropin.

Luteinising Hormone (LH) and Follicle-Stimulating Hormone (FSH): Collectively known as Gonadotropins, LH and FSH control the sexual and reproductive characteristics in males and females.

Prolactin (PRL): Produces milk in the breast. Though it is present at all times, the secretion is increased during and just after pregnancy.

Melanocyte-Stimulating Hormone (MSH): Stimulates the production of melanin by skin and hair.



Posterior Pituitary Hormones

The posterior pituitary is responsible for the storage and secretion of two very important hormones:

Antidiuretic Hormone (ADH): Controls the water balance of the body by affecting reabsorption of water by the kidneys

Oxytocin: Controls certain aspects of pregnancy and childbirth such as uterine contraction and production of milk.

Pituitary disorders

Pituitary disorders affect the functioning of the pituitary gland, increasing or decreasing the level of certain hormone secretion. This generally happens because of a non-cancerous tumor called the pituitary adenoma.

A Pituitary macro adenoma (tumor larger than 10 mm) can also cause the impairment of blood supply into the gland. It can either cause overflow or stop the flow of blood completely into the gland. This is called pituitary apoplexy.

STRUCTURE AND FUNCTIONS OF THYROID GLAND AND PARATHYROID GLAND AND THEIR DISORDERS

The thyroid gland is an **endocrine** organ found in the neck, it is responsible for regulating the body's metabolic rate via hormones it produces. In this article, we will be looking at its anatomy, its cellular structure, its endocrine physiology and its clinical relevance.

Anatomy

The thyroid gland is a ductless **alveolar gland** found in the anterior neck, just below the laryngeal prominence (Adam's apple). It is roughly butterfly-shaped, with two lobes wrapping around the trachea and connected in the middle by an **isthmus**. The thyroid gland is not usually palpable.

It is supplied by superior and inferior **thyroid arteries,** drained via superior, middle and inferior **thyroid veins** and has a rich lymphatic system.

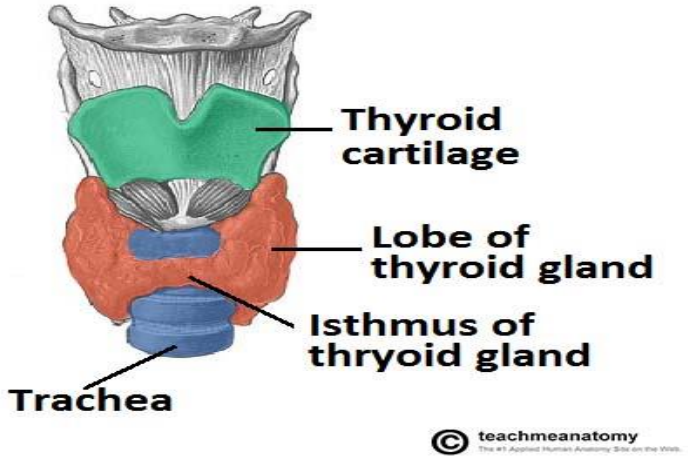


Fig 1 – Anterior view of the neck, showing the anatomical position of the thyroid gland

Fig 1 – Anterior view of the neck, showing the anatomical position of the thyroid gland

Cellular Structure

The function of the Thyroid gland is to produce and store thyroid hormones. Thyroid epithelia form follicles filled with **colloid** – a protein-rich reservoir of the materials needed for thyroid hormone production. These follicles range in size from 0.02-0.3mm and the epithelium may be simple cuboidal or simple columnar.

In the spaces between the follicles, **parafollicular cells** can be found. These cells secrete calcitonin, which is involved in the regulation of calcium metabolism in the body.

Function

The thyroid gland is one of the main regulators of **metabolism.** T3 and T4 typically act via nuclear receptors in target tissues and initiate a variety of metabolic pathways. High levels of them typically cause these processes to occur faster or more frequently. Metabolic processes increased by thyroid hormones include:

- Basal Metabolic Rate
- Gluconeogenesis
- Glycogenolysis
- Protein synthesis
- Lipogenesis
- Thermogenesis

This is achieved in a number of ways, such as increasing the size and number of **mitochondria** within cells, increasing Na-K pump activity and increasing the presence of β-adrenergic receptors in tissues such as cardiac muscle.

Thyroid Hormone Synthesis

There are six steps in the synthesis of thyroid hormone, and you can remember them using the mnemonic ATE ICE:

- **Active transport** of Iodide into the follicular cell via the Sodium-Iodide Symporter (NIS). This is actually secondary active transport, and the sodium gradient driving it is maintained by a Sodium-Potassium ATPase.
- **Thyroglobulin** (Tg), a large protein rich in Tyrosine, is formed in follicular ribosomes and placed into secretory vesicles.
- **Exocytosis** of Thyroglobulin into the follicle lumen, where it is stored as colloid. Thyroglobulin is the scaffold upon which thyroid hormone is synthesised.
- **Iodination** of the Thyroglobulin. Iodide is made reactive by the enzyme **thyroid peroxidase**. Iodide binds to the benzene ring on Tyrosine residues of Thyroglobulin, forming monoiodotyrosine (MIT) then diiodotyrosine (DIT).
- **Coupling** of MIT and DIT gives the Triiodothyronine (T3) hormone and coupling of DIT and DIT gives the Tetraiodothyronine (T4) hormone, also known as **Thyroxine**.
- **Endocytosis** of iodinated thyroglobulin back into the follicular cell. Thyroglobulin undergoes proteolysis in lysosomes to cleave the iodinated tyrosine residues from the larger protein. Free T3 or T4 is then released, and the Thyroglobulin scaffold is recycled.

T3 and T4 are the active thyroid hormones. They are **fat soluble** and mostly carried by plasma proteins – Thyronine Binding Globulin and Albumin. While T3 is the more potent form, it also has a shorter half-life due to its lower affinity for the binding proteins. Less than **1%** of T3 and T4 is unbound free hormone. At the peripheries, T4 is deiodinated to the more active T3.

T3 and T4 are deactivated by removing iodine. This happens in the liver and kidney. As T4 has a longer half-life, it is used in the treatment of hypothyroidism over T3 as its plasma concentrations are easier to manage.

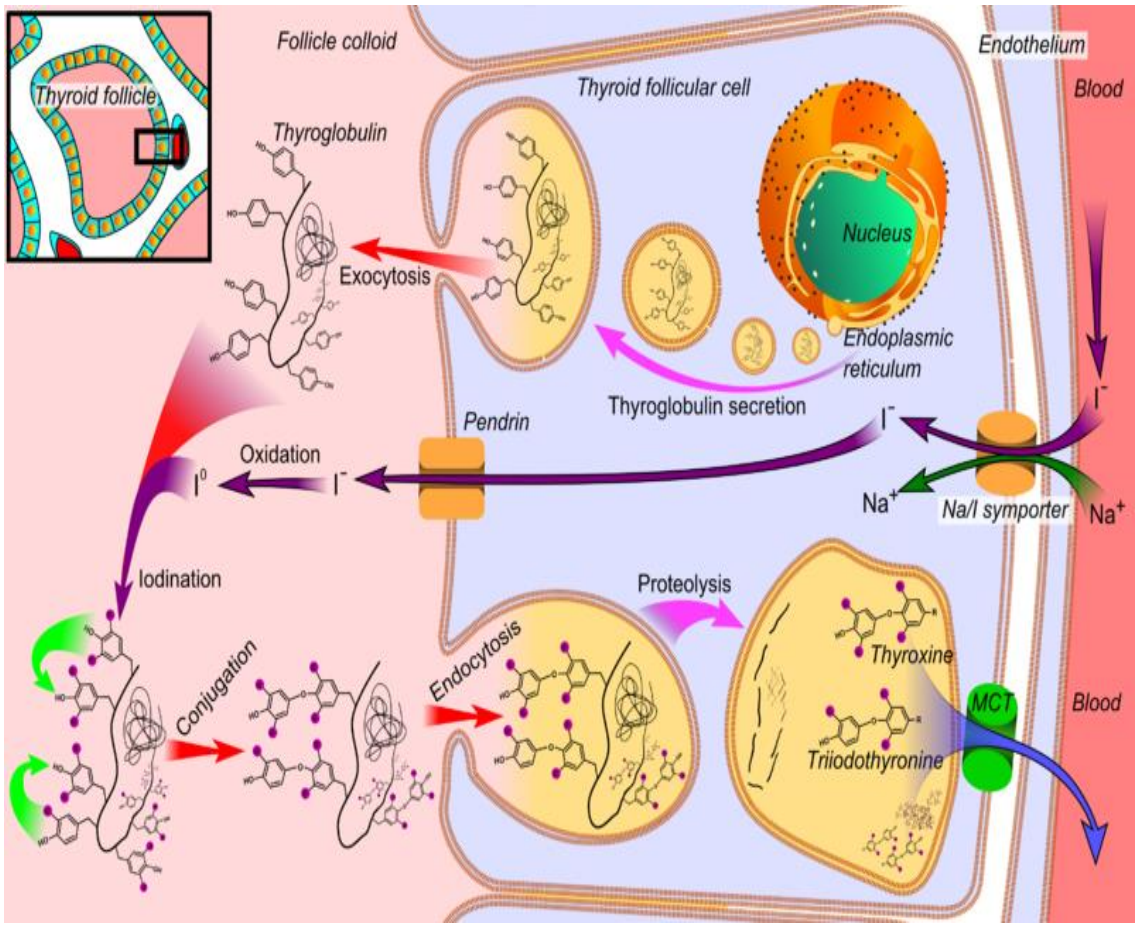


Fig 2 – Overview of the synthesis of thyroid hormones

Thyroid Hormone Release

Thyroid hormones are released as part of the hypothalamic-pituitary-thyroid axis. The Hypothalamus detects a low plasma concentration of thyroid hormone and releases **Thyrotropin-Releasing Hormone** (TRH) into the hypophyseal portal system.

TRH binds to receptors found on thyrotrophic cells of the anterior pituitary gland, causing them to release **Thyroid Stimulating Hormone** (TSH) into the systemic circulation. TSH binds to TSH receptors on the basolateral membrane of thyroid follicular cells and induces the synthesis and release of thyroid hormone

Endocrine System: Iodine Deficiency, Hypothyroidism, and Hyperthyroidism

As discussed above, dietary iodine is required for the synthesis of T_3 and T_4. But for much of the world's population, foods do not provide adequate levels of this mineral, because the amount varies according to the level in the soil in which the food was grown, as well as the irrigation and fertilizers used. Marine fish and shrimp tend to have high levels because they concentrate iodine from seawater, but many people in landlocked regions lack access to seafood. Thus, the primary source of dietary iodine in many countries is iodized salt. Fortification of salt with iodine began in the United States in 1924, and international efforts to iodize salt in the world's poorest nations continue today.

Dietary iodine deficiency can result in the impaired ability to synthesize T_3 and T_4, leading to a variety of severe disorders. When T_3 and T_4 cannot be produced, TSH is secreted in increasing amounts. As a result of this hyperstimulation, thyroglobulin accumulates in the thyroid gland follicles, increasing their deposits of colloid. The accumulation of colloid increases the overall size of the thyroid gland, a condition called a **goiter** (Figure 3). A goiter is only a visible indication of the deficiency. Other iodine deficiency disorders include impaired growth and development, decreased fertility, and prenatal and infant death. Moreover, iodine deficiency is the primary cause of preventable mental retardation worldwide. **Neonatal hypothyroidism** (cretinism) is characterized by cognitive deficits, short stature, and sometimes deafness and muteness in children and adults born to mothers who were iodine-deficient.

In areas of the world with access to iodized salt, dietary deficiency is rare. Instead, inflammation of the thyroid gland is the more common cause of low blood levels of thyroid hormones. Called **hypothyroidism**, the condition is characterized by a low metabolic rate, weight gain, cold extremities, constipation, reduced libido, menstrual irregularities, and reduced mental activity. In contrast, **hyperthyroidism**—an abnormally elevated blood level of thyroid hormones—is often caused by a pituitary or thyroid tumor. In Graves' disease, the hyperthyroid state results from an autoimmune reaction in which antibodies overstimulate the follicle cells of the thyroid gland. Hyperthyroidism can lead to an increased metabolic rate,

excessive body heat and sweating, diarrhea, weight loss, tremors, and increased heart rate. The person's eyes may bulge (called exophthalmos) as antibodies produce inflammation in the soft tissues of the orbits. The person may also develop a goiter.

PARATHYROID GLANDS

The parathyroid glands are small endocrine glands located in the anterior neck. They are responsible for the production of **parathyroid hormone (PTH)**.

This article will consider the anatomical location, the different cells of the parathyroid gland, the actions of parathyroid hormone and the regulation of its secretion. Finally, clinical diseases affecting the parathyroid glands will be discussed in detail.

Anatomical location

The parathyroid glands are located on the posterior, medial aspect of each lobe of the thyroid gland.

Anatomically, the glands can be divided into two pairs:

- **Superior parathyroid glands** – Derived embryologically from the fourth pharyngeal pouch. They are usually located at the level of the inferior border of the cricoid cartilage.
- **Inferior parathyroid glands** – Derived embryologically from the third pharyngeal pouch. They are usually located near the inferior poles of the thyroid gland. However in 1-5% of people they can be found deep in the superior mediastinum.

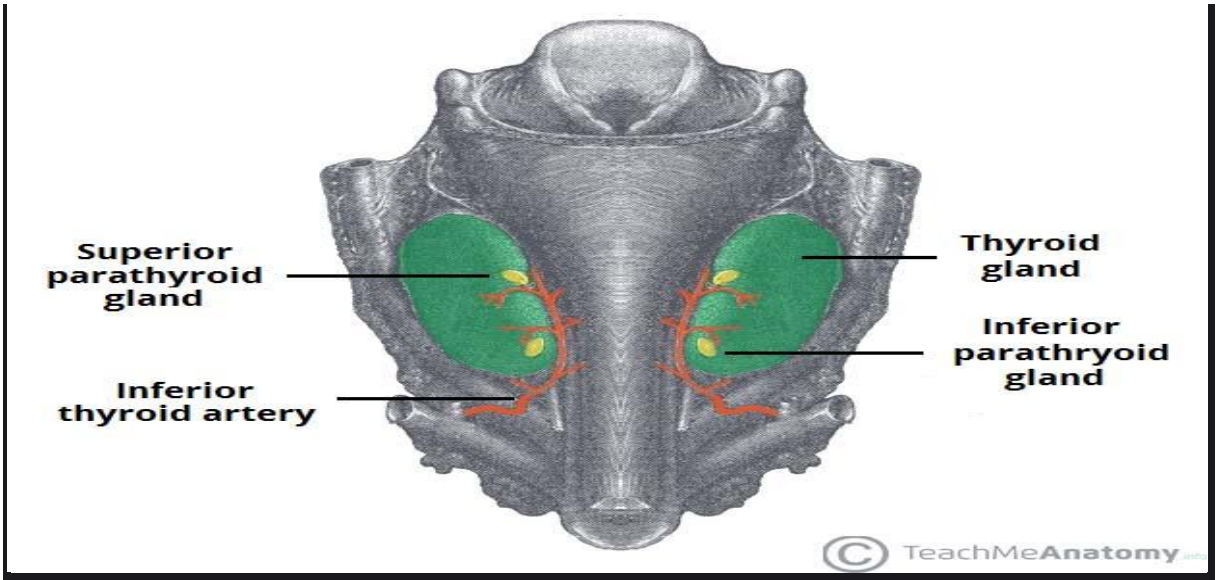


Fig 1 – Anatomical location of the parathyroid glands

Parathyroid Gland Histology

There are two types of cells within the parathyroid gland, the **chief cells** and the **oxyphil cells**.

- **Chief cells**– The role of this cell type is to secrete parathyroid hormone. They contain prominent Golgi apparatus and endoplasmic reticulum to allow for the synthesis and secretion of parathyroid hormone. The chief cells are the smaller of the two cell types, however they are more abundant.
- **Oxyphil cells**– These cells are much larger but less abundant than chief cells. Their purpose is unknown. It is interesting to note however that the number of oxyphil cells increases with age and few are seen before puberty.

Note that histologically fat cells (adipose cells) are also seen within the parathyroid gland.

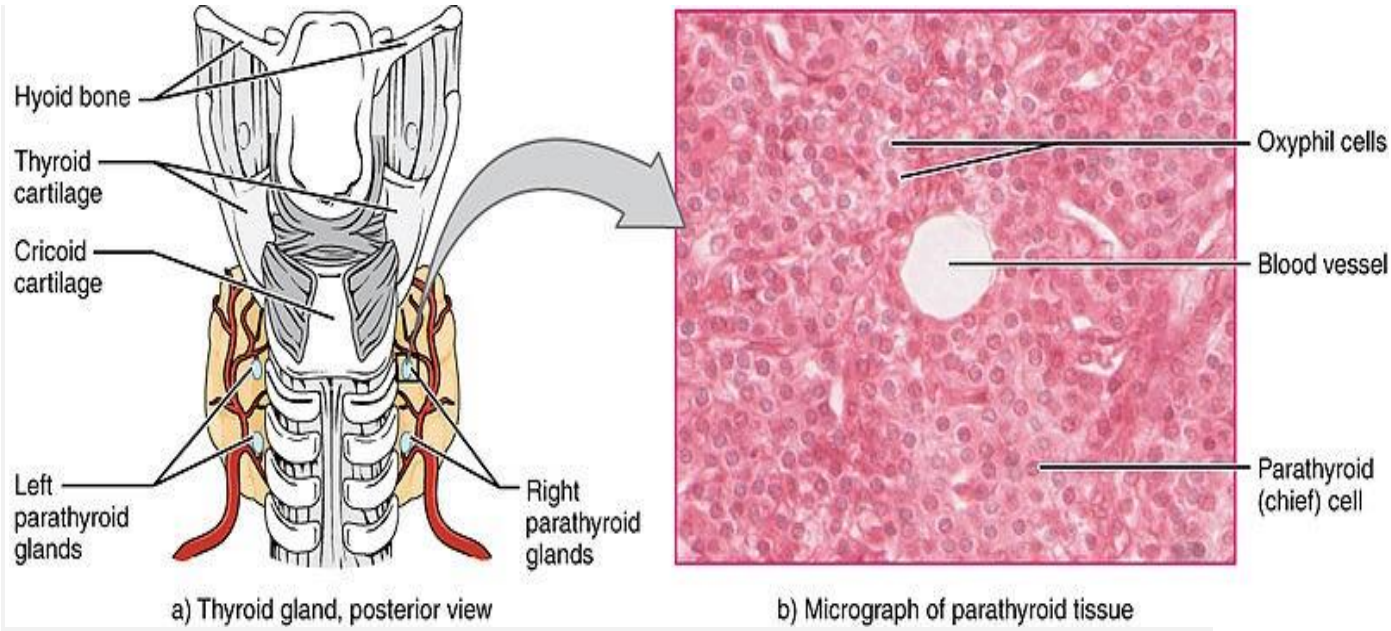


Fig 2 – Anatomical location of the Parathyroid glands and their histology.

Parathyroid Hormone Synthesis

The synthesis of PTH begins within the rough endoplasmic reticulum, where **pre-pro-PTH** is produced. Pre-pro-PTH is 115 amino acids long and consists of a biologically active sequence, a C terminal fragment sequence, a pro sequence and a signal sequence.

The signal sequence is cleaved within the lumen of the endoplasmic reticulum, leaving **pro-PTH.** After transfer to the Golgi apparatus the pro sequence is also cleaved, resulting in the production of mature **PTH**, which can then be stored in secretory granules for release.

Parathyroid Hormone Actions

Parathyroid hormone (PTH) has three main actions, all of which act to **increase calcium** levels in the body;

- **Increased bone resorption**– PTH acts directly on bone to increase bone resorption. It induces cytokine secretion from osteoblasts that act on osteoclast cells to increase their activity. Osteoclasts are responsible for the breakdown of bone and thus an increase in their activity leads to increased bone break down. This leads to an increase in calcium in the extracellular fluid.
- **Increased reabsorption in the kidney-** PTH increases the amount of calcium absorbed from the Loop of Henle and distal tubules, however the mechanism is not fully understood. Additionally, PTH increases the rate of phosphate excretion which is very important to prevent to formation of calcium phosphate kidney stones.
- **Vitamin D synthesis-** Although PTH does not actively increase the absorption of calcium from the gut it stimulates the formation of vitamin D, which subsequently increases absorption from the gut.

Parathyroid Hormone Regulation

Like most endocrine organs, the parathyroid gland is controlled by a negative feedback loop. Chief cells have a unique G-protein calcium receptor **(CaR)** on their surface, which regulates this.

When calcium levels in the blood are elevated, PTH production must be stopped in order to prevent further elevation of calcium which could lead to **hypercalcaemia**. Calcium binds to the G protein CaR which subsequently leads to the production of a molecule called **phosphoinositide**. The activation of this molecule prevents PTH secretion thus calcium is deposited back into the bones. Furthermore, as mentioned above, PTH stimulates vitamin D synthesis. Vitamin D also acts directly on the parathyroid gland to decrease the transcription of the PTH gene hence less PTH is synthesised.

When Calcium is reduced, the reverse occurs. Lowered calcium means reduced stimulation of CaR and decreased phosphoinositide. Subsequently, PTH secretion is not inhibited. Decreased Vitamin D results in upregulation of PTH gene transcription thus more **PTH** is synthesised.

Note: Elevated phosphate lowers free Calcium in the blood and inhibits the formation of Vitamin D**.**

About Parathyroid Disorders

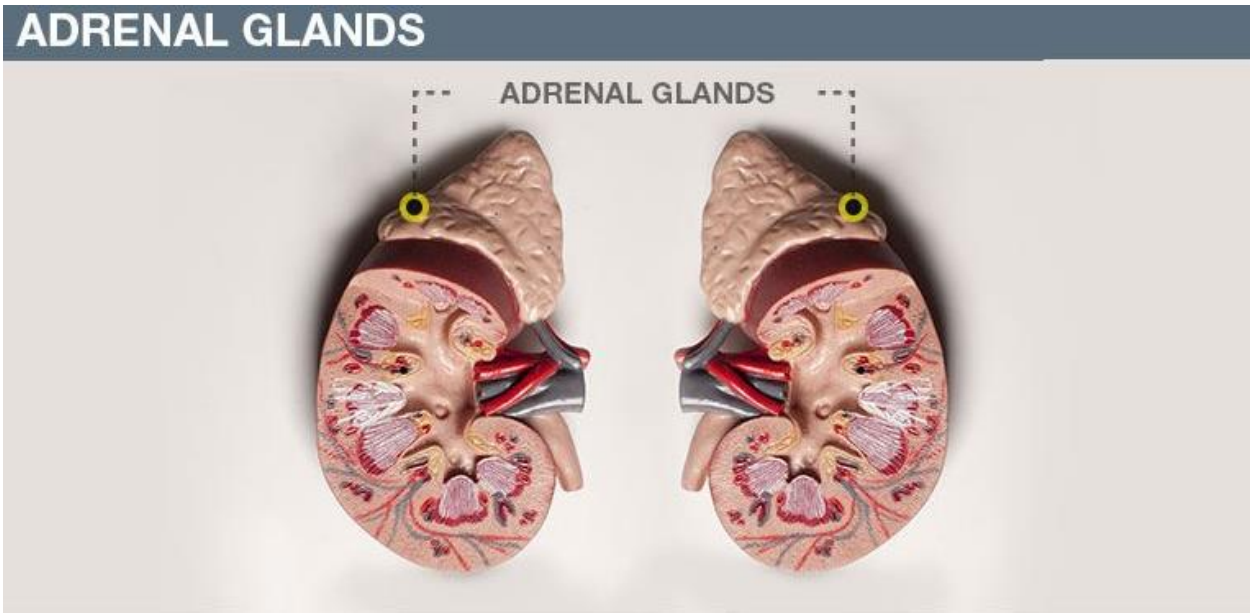
As a rule, if the calcium level in the blood is low, the parathyroid glands sense this and release PTH. PTH then causes release of calcium from the bones into the bloodstream, increases vitamin D production from the kidney which ultimately increases absorption of calcium from the intestines. If the calcium level is too high, then PTH secretion should decrease to a very low level.

Hyperparathyroidism exists when the parathyroid glands produce too much parathyroid hormone (PTH). This may be due to multiple reasons, and the reason helps determine the appropriate type of treatment. Sometimes treatment is as simple as replacing vitamin D when the parathyroid gland is responding appropriately to a problem elsewhere in the body. In other cases, there is an issue with the gland itself and surgery is required. Excess parathyroid hormone can lead to negative effects on the body such as osteoporosis which can lead to fractures, kidney stones, decreased kidney function, heart disease, pancreatitis, increased acid secretion in the stomach and ulcers. Many patients experience symptoms of fatigue, depression, anxiety, difficulty concentrating, difficulty with their memory, insomnia, generalized muscle aches and pains, frequent urination (especially at night), and constipation. Because these symptoms may be related to many other disorders, it is never known until after treatment whether or not these will improve.

The opposite problem, **hypoparathyroidism**, occurs when the parathyroid glands do not produce enough PTH. This leads to a low blood calcium level and can adversely affect muscle, nerve and other functions.

Structure and functions of Adrenal gland and their disorders

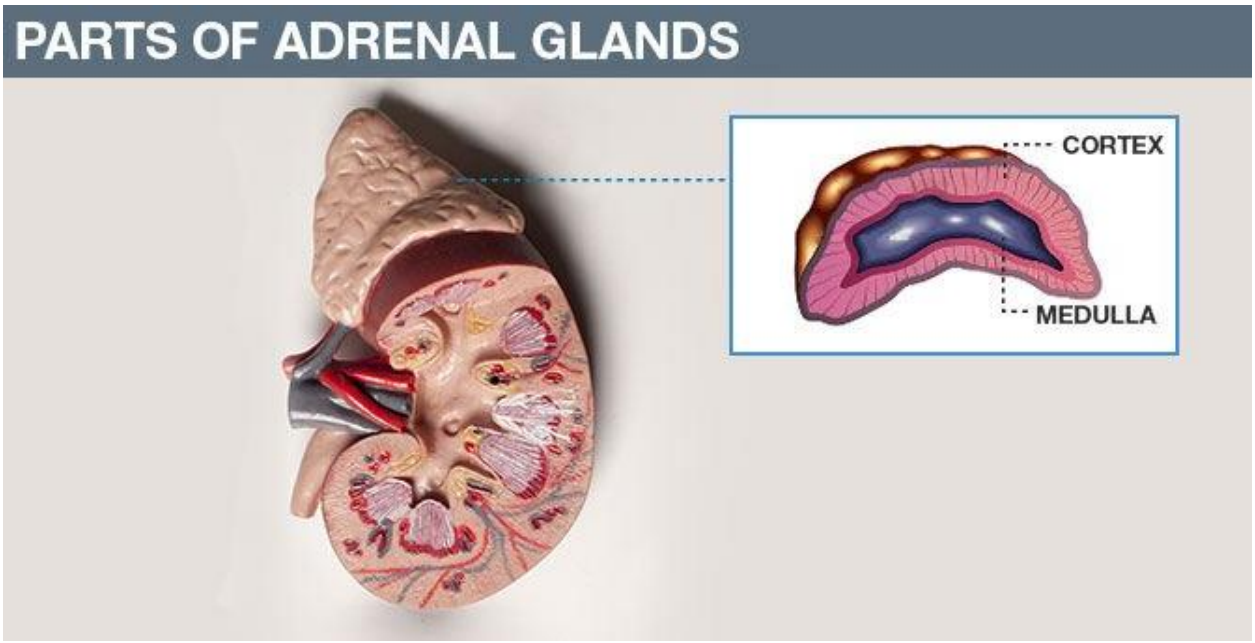
The Adrenal Glands are found on top of each kidney. Even the name "**Adrenal**" directly translates to their location: (Latin: ***ad***– "near" and ***renes*** – "kidneys.") These glands are also known as **suprarenal glands**. (Latin: ***supra*** – "above" and ***renes*** – "kidneys.")



On the anterior side of the right adrenal gland sits the Inferior vena cava and the right lobe of the liver. The posterior side is flanked by the right crus of the diaphragm. The stomach, pancreas and spleen sit on the anterior side of the left adrenal gland. The posterior side is flanked by the left crus of the diaphragm.

Adrenal Gland Anatomy

- As stated in the introduction, the human body has two adrenal glands, the right gland is pyramidal in shape and the left gland is semilunar in shape.
- The left adrenal gland is also comparatively larger than the right.
- The glands are usually about 5×3 cm in size and their combined weight ranges from 7 to 10 grams. Healthy glands are yellowish in colour.



There are three distinct layers of the adrenal glands.

Adrenal Capsule

The capsule is a protective layer of fat that surrounds each adrenal glands. They are not strictly a part of the adrenal glands, but the primary function of this capsule layer is to enclose and protect each of the adrenal glands.

Adrenal Cortex

The adrenal cortex is the outermost layer of the adrenal gland which is devoted to the production of aldosterone, cortisol, and androgens hormones. There are three layers of cortex called zones which can be examined and easily differentiated under a microscope:

- **Zona glomerulosa** – It secretes mineralocorticoids like aldosterone
- **Zona fasciculata –** It is responsible for producing corticosteroids like cortisol. Also secrets small quantities of androgens (such as testosterone and androstenedione)
- **Zona reticularis** – It produces DHES or dehydroepiandrosterone (also called androstenolone)

Adrenal Medulla

The last and innermost part of the adrenal gland is the medulla. It contains the Chromaffin cells, which produce the body's main source of catecholamines (such as adrenaline and noradrenaline) and endorphins. These are stored and released in response to stress.

Adrenal Gland Function

- One of the most well-known responses – the Fight or Flight Response is triggered by the release of stress hormones from the adrenal glands.
- The adrenal glands produce a variety of hormones. These hormones are very crucial for the normal functioning of the body. For instance, the glands secrete cortisol, which has anti-inflammatory properties and aids the immune system.
- The adrenal gland also helps to regulate metabolism and blood pressure through various other hormones.

Adrenal Gland Hormones

- **Epinephrine**: Also called adrenaline, this hormone rapidly responds to stress by increasing the heart rate and raising blood glucose levels in the blood.
- **Norepinephrine**: Also called noradrenaline, this hormone works with epinephrine in reacting to stress. Its primary function is to mobilize the body and brain for action.

- **Hydrocortisone:** It is commonly known as cortisol or a steroid hormone. It is involved in regulating body functions like the conversion of fats, and carbohydrates to energy and also plays a vital role in other metabolic processes.
- **Corticosterone:** This hormone works with hydrocortisone to control the immune response and prevents inflammatory reactions.

Adrenal Gland Disorders

Adrenal Gland disorders appear when not enough hormones or inadequate hormones are produced by the adrenal glands. Even abnormal growths or tumours can cause certain illness.

- **Cushing's Syndrome** is a condition where the cortisol levels in the body are very high. The cause can be a tumour in the adrenal gland or the pituitary gland.
- **Adrenocortical carcinoma** is a cancerous tumour that usually develops in the outer layer of the adrenal gland. This type of tumour is typically found years after they have spread to other organs in the body.
- **Congenital Adrenal Hyperplasia (CAH)** is a genetic disorder characterized by very low levels of cortisol production. The people inflicted with this condition may also have other hormonal imbalances where their bodies may make very little aldosterone, but too much androgen.
- **Addison's Disease** is an autoimmune disease where the body mistakenly attacks the adrenal glands. As a result, the adrenal gland does not produce the hormone aldosterone in sufficient quantities.

STRUCTURE AND FUNCTIONS OF PANCREAS AND THEIR DISORDERS

The pancreas lies inferior to the stomach in a bend of the duodenum. It is both an exocrine and an endocrine gland. A large pancreatic duct runs through the gland, carrying enzymes and other exocrine digestive secretions from the pancreatic acinar cells to the small intestine.

The tissue of the pancreas has in addition to the acinar cells, groups of cells called islets of Langerhans, after the name of their discoverer (1869). These produce endocrine secretions.

Four kinds of cells have been identified in the islets:

(i) Alpha cells (about 15%) produce glucagon. Alpha cells are also called A-cells.

(ii) Beta cells (about 65%) produce insulin. Beta cells are also called B-cells.

(iii) Delta cells or D-cells (about 5%) produce somatostatin (SS), and

(iv) Pancreatic Polypeptide cells or PP cells or F-cells (15%), produce pancreatic polypeptide (PP). Beta cells are usually found towards the middle of the islet, the alpha cells towards the periphery of the islet and Delta (D) and F-cells are found scattered.

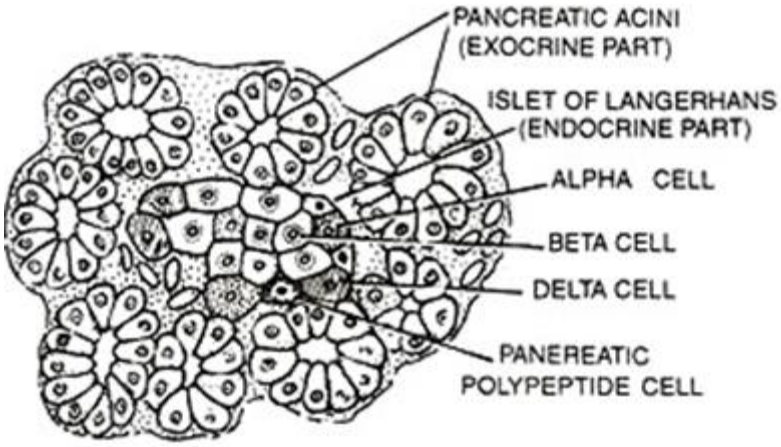


Fig. 1 Physiological anatomy of the pancreas.

Hormones of Pancreas and Their Role:

(i) Glucagon:

It stimulates the liver to convert stored glycogen into glucose. Glucagon is also called an "anti-insulin" hormone.

Target Cells:

Glucagon acts on the cells of the liver and adipose tissue.

(ii) Insulin:

(a) It is antagonistic to glucagon. Insulin converts glucose into glycogen in the liver and muscles.

b) It promotes protein synthesis in tissue from amino acids.

(c) Insulin reduces catabolism of proteins. It is an anabolic hormone.

(d) It increases the synthesis of fat in the adipose tissue from fatty acids.

(e) Insulin reduces the breakdown and oxidation of fat.

Target Cells:

Insulin acts on the cells of the liver muscles and adipose tissue. Alloxan and Cobalt chloride are compounds widely used by scientists to study cell physiology of islets of Langerhans. Alloxan is used to destroy the beta cells while cobalt chloride to destroy alpha cells of the islets of Langerhans.

(iii) Somatostatin (SS):

The same substance as growth inhibiting hormone from the hypothalamus, is produced not only by the pancreas and hypothalamus but also by some cells of the digestive tract. One of the actions of somatostatin seems to suppress the release of other hormones from the pancreas. It also appears to suppress the release of hormones from the digestive tract.

Target Cells:

Both somatostatin and pancreatic polypeptide act on the cells of the pancreas.

(iv) Pancreatic Polypeptide (PP):

It appears that pancreatic polypeptide inhibits the release of digestive secretion of the pancreas. Both somatostatin and pancreatic polypeptide are relatively newly discovered hormones of the pancreas, and both are still being studied.

Disorders of Pancreas:

(i) Diabetes mellitus (Hyperglycemia):

The most common endocrine disorder of the pancreas is the diabetes mellitus, now recognized to exist in two forms — insulin-dependent and non-insulin-dependent.

The insulin-dependent diabetes mellitus (IDDM) is caused by a failure of the Beta-cells to produce adequate amount of insulin while the non-insulin-dependent diabetes mellitus (NIDDM) appears to involve failure of insulin to facilitate the movement of glucose into cells.

In both disorders the blood glucose concentration is elevated above the normal range. Some of the glucose is excreted in the urine, and water follows the glucose, causing excessive urination and dehydration of body tissues. This causes excessive thirst (polydipsia). The cells are unable to utilize glucose and other carbohydrates for energy production.

They utilize their proteins for it. The person becomes very weak. Degradation of fats increases, producing ketone bodies (ketosis). The latter are acidic and poisonous. Blood cholesterol level rises. Healing power is impaired.

Administration of insulin lowers the blood-glucose level. It gives relief to the patient. A tendency towards non-insulin-dependent diabetes appears to be inherited as an autosomal recessive characteristic.

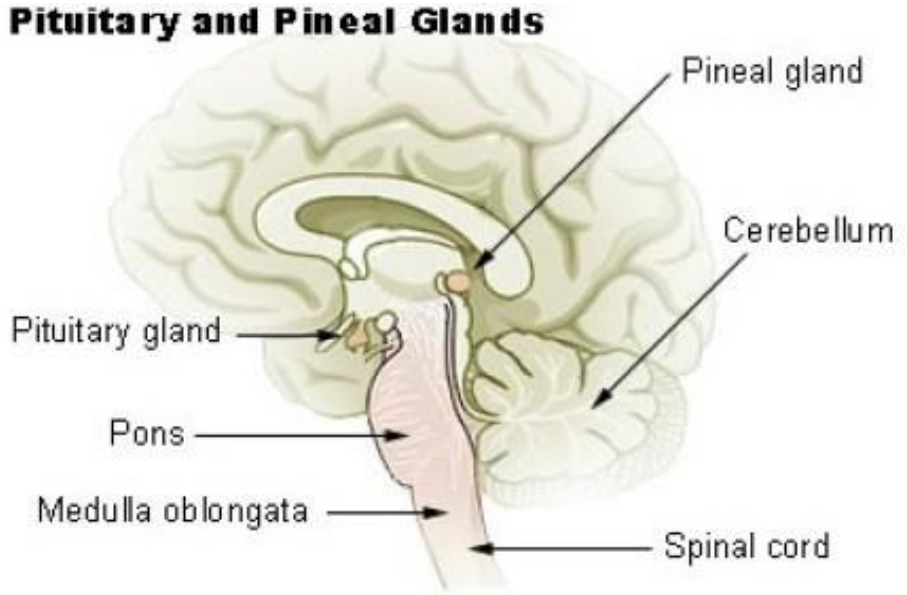
(ii) Hypoglycemia:

It occurs when the blood glucose level falls below normal. Theoretically, it may be caused by an excess of insulin, a deficiency of glucagon, or a failure of the secretion of the two hormones to completely regulate the blood sugar.

Some individuals have been found to have few or no Alpha cells and thus are deficient in glucagon, whereas others produce excess quantities of insulin usually because of a tumour of the beta cells.

The presence of excess insulin is more correctly referred to as hyperinsulinism. Symptoms of hypoglycemia include weakness, profuse sweating, irritability, confusion, unconsciousness and convulsions. It needs urgent intake of sugar or glucose.

STRUCTURE AND FUNCTIONS OF PINEAL GLAND AND THYMUS AND THEIR DISORDERS



Pineal gland is a pinecone-shaped small gland located in the middle of the human brain in between the two hemispheres in an area called epithalamus. It was once known as “the third eye”. It is the major site for melatonin secretion, which regulates the body’s internal clock (Circadian rhythm).

This gland is rich in calcium levels. The calcium acts as a radiographer to locate the middle of the brain in X-ray images. It was also one of the last glands to discovered.

Anatomy of Pineal Gland

The pineal gland is about 0.3 inches long and weighs 0.1 grams. The adrenergic nerves entering the pineal gland regulate its functions.

The pineal gland is composed of pinealocytes and supporting cells that resemble the astrocytes present in the brain.

Some lower vertebrates have a well-developed eye-like structure that acts as a light receptor.

Hormones Secreted by Pineal Gland– Melatonin

The pineal gland synthesises melatonin and serotonin, hence they are also called as the Pineal Gland Hormone. The pineal gland also produces neurosteroids.

Serotonin is the precursor of melatonin. Serotonin is acetylated and methylated to yield melatonin within the pineal gland. The light exposure to the eyes affects the synthesis and secretion of melatonin.

Two melatonin receptors have been found in mammals- Mel1A and Mel1B. These are G-protein coupled cell surface receptors.

Melatonin affects circadian rhythm.

Our circadian rhythm is a 24-hour biological cycle, characterised by the sleep-wake patterns. The daylight and darkness regulate our circadian rhythms. The secretion of melatonin is stopped on exposure to light which in turn controls the circadian rhythm. The secretion of melatonin is high during dark and low during daylight. This influences our reaction to photoperiod.

The secretion of gonadotropins from the anterior **Pituitary gland** is blocked by melatonin thereby affecting reproduction. These hormones aid in the development of ovaries and testes.

Functions Of Pineal Gland

Secretion Of Melatonin

This gland secretes the hormone melatonin which regulates the circadian rhythm of the body and also certain reproductive hormones. The secretion of this hormone depends upon the amount of light a person is exposed to. This hormone is produced in large amounts when it is

dark. The presence of light inhibits the secretion of melatonin which controls our circadian rhythms.

Cardiovascular Health

The melatonin secretion has a positive impact on the heart and blood pressure. It may also be used for the treatment of cardiovascular diseases.

Reproduction

Melatonin inhibits the secretion of reproductive hormones from the anterior pituitary, which are responsible for the development and functioning of reproductive organs.

Disorders Of Pineal Gland

Listed below are few disorders caused by the malfunctioning of the pineal gland.

1. Depression.
2. Mood swings.
3. Peptic or stomach ulcers.
4. Disruption in sleep patterns.
5. An impaired pineal gland leads to hormonal imbalance.
6. Sexual disorders are caused by the dysfunctioning of the pineal gland.

Other disorders include:

Low melatonin secretion also leads to anxiety, low thyroid hormone production, menopause symptoms, etc.

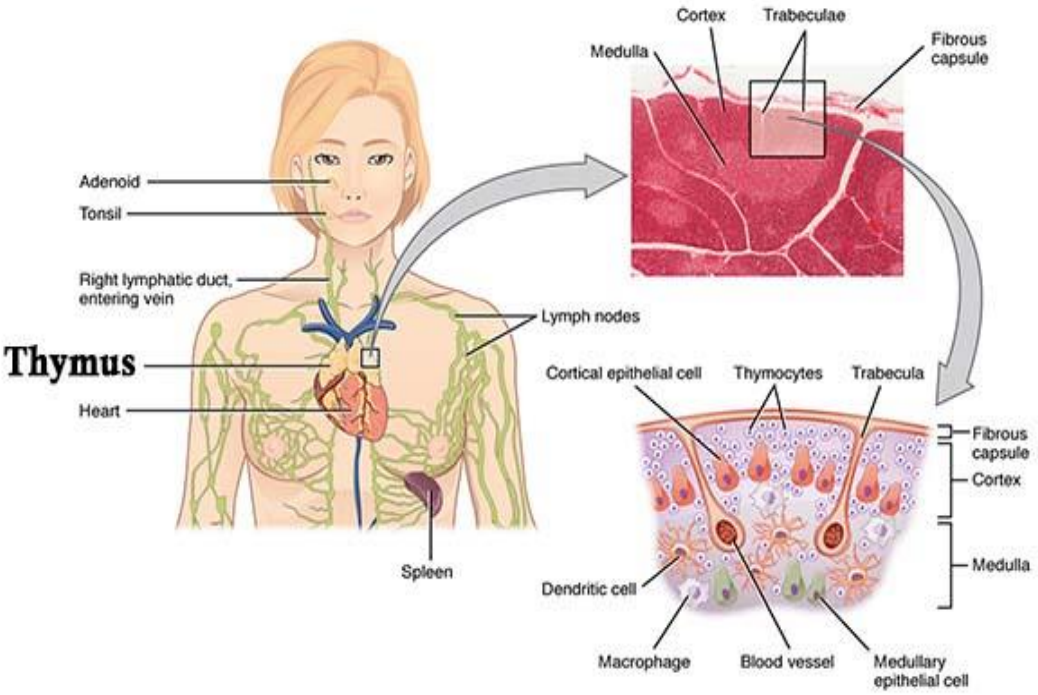
Over secretion of melatonin can lead to low blood pressure and improper functioning of the thyroid glands and adrenal glands.

Seasonal affective disorders of pineal gland include a depressive disorder. This disorder is mainly caused in the winter season when melatonin secretion is high due to the presence of low sunlight.

If a tumour develops in the pineal gland, it affects several other factors in the body:

- Nausea.
- Seizures.
- Headache.
- Memory disruption.
- Impaired vision and other senses

THYMUS



The Thymus is an obscure organ located deep within the chest. It may not function throughout human life but is a very important organ while active. Read on to explore more about thymus.

What is Thymus?

The thymus gland is a very unique organ that is at its largest in children and shrinks away as the body grows older. It is about 2.5 to 5 cms wide, 4 to 6 cms long and 1 cm thick at

birth. At its largest instance, (viz. during puberty) the thymus weighs just under 30 grams. After puberty, the thymus slowly starts to shrink and by the age of 75, it is nothing more than fatty tissue.

Thymus Location

The thymus gland is located in the anterior part of the chest, right behind the breastbone (or the sternum) and between the lungs. It has a pinkish-grey complexion and is lobed, with primary two lobes and smaller lobes radiating from within. The two lobes may be separated or united and generally vary in size.

Histology of Thymus

There are two general cell lines of interest in the thymus. These are thymic epithelial cells and lymphoid cells. The lymphoid cells migrate into the thymus during the intrauterine angiogenesis. The thymic epithelium is important for the maturation and development of these lymphoid cells.

The lymphoid progenitor cells can access the thymus in the 10th week of gestation. A well-differentiated thymus is observed in the 12th week of gestation.

Thymus Function

One of the most important functions of the thymus is to stimulate the production of very specialized cells called T-cells (also called T-lymphocytes). These cells are responsible for directly fending off foreign pathogens such as viruses and bacteria. They also regulate the immune system, helping to prevent autoimmunity, wherein, the body's immune system elicits immune responses on its own healthy cells.

Thymus also secretes thymosin to stimulate the development of T-cells.

Thymus Gland Disorders

The most common disorders caused by the dysfunctioning of thymus gland are- Myasthenia gravis, pure red cell aplasia, and hypogammaglobulinemia. Myasthenia gravis is caused due to abnormal enlargement of the thymus. The enlarged thymus produces antibodies that destroy the muscle receptor sites. Thus the muscles become very weak. Pure red aplasia is caused when the patient's own immune cells attack the blood-forming stem cells. This happens when there is a tumour in the thymus. Hypogammaglobulinemia occurs when the body does not produce enough antibodies.

Thymosin- The Thymus Hormone

To stimulate the production of T-Cells, the thymus secretes a hormone called Thymosin. Then, a type of white blood cell called lymphocytes pass through the thymus and gets transformed into T-Cells. Once these T-cells have matured, they migrate to the lymph nodes in the body and consequently aid the immune system. The thymus gland is only active until puberty, however, they produce all the T-cells required by the body well before this period.