Level 3 Anatomy and Physiology Diploma

ACCREDITED BY THE CMA and IPHM A & P Diploma

Introduction

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This course is amazing, in that you get to work ……..so enjoy the journey and let's get started.

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Module 1: Structural organisation of the body

Part 1: From the Smallest to the Largest

Module objectives

By the end of this module, you will learn:

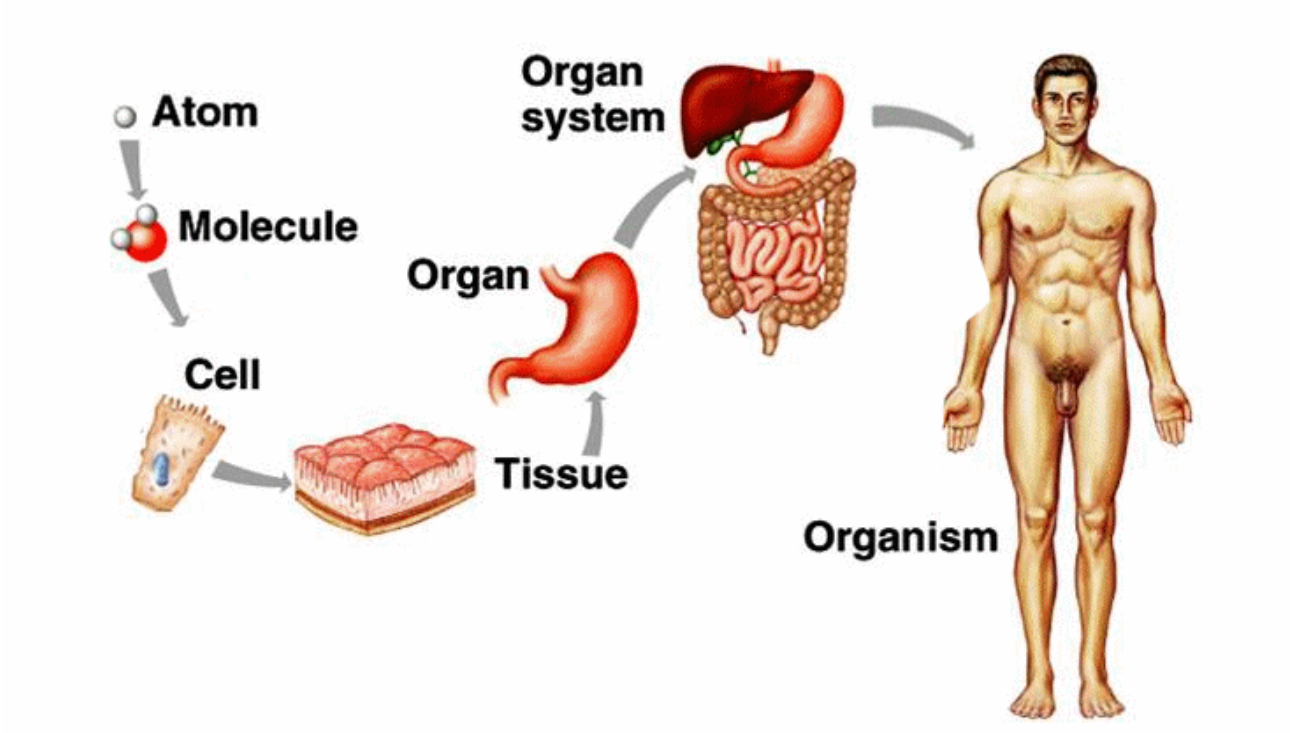
- The different levels of structural organisation in the body.
- The importance of homeostasis and metabolism for correct body function.
- Cell structure and function.
- Structure and function of the main tissue types.

Welcome to the Anatomy and Physiology course. Anatomy refers to the structure of the body. Physiology refers to the function of the body. We hope this course will awaken your passion and wonder for the human body in all its amazing intricacies!

Here are some amazing facts:

- Your body has approx. 10 trillion cells.
- Every second your body produces 15 million red blood cells.
- Your nervous system can transmit impulses at a speed of 450 miles per hour.
- During an average lifetime, the heart beats around 2.5 billion times.
- In one day your blood journeys in the region of 1000 miles.

From the smallest to the largest



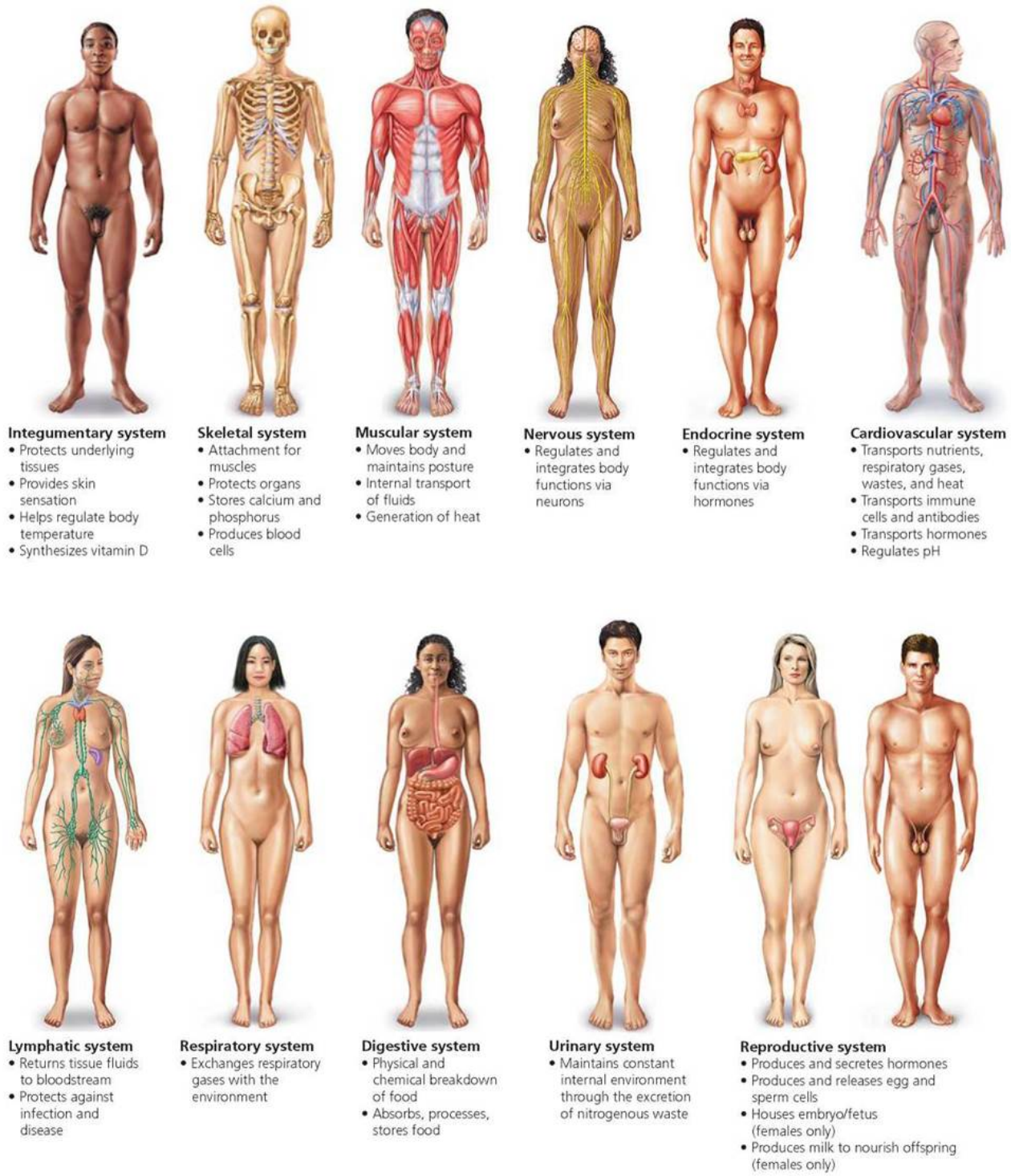
To study the chemical level of organisation, we have to start with the simplest building blocks: subatomic particles, atoms and molecules.

- All matter is made of one or more unique substances known as elements, for example, hydrogen, oxygen, carbon, nitrogen, calcium, and iron.
- The smallest element is an atom. Atoms are made up of subatomic particles: protons, neutrons and electrons.

- Two or more atoms together form a molecule, such as water molecules, made up of one oxygen and two hydrogen atoms. Molecules are the building blocks of all body structures. Molecules combine to form cells.
- A cell is the smallest unit that functions individually within a living organism. All living structures of the human anatomy contain cells, and almost all functions of human physiology are performed within cells or are initiated by the cells. There are different types of cells which vary in size and shape according to the function it carries out.
- Every human cell consists of flexible membranes that enclose cytoplasm, a water-based cellular fluid, together with a variety of tiny functioning units called organelles.
- In humans, as in all organisms, cells carry out all functions of life.
- A tissue is a group of similar cells that work together to perform functions specific to that group.
- An organ is composed of two or more tissue types, forming an anatomically distinct structure. Each organ carries out one or several specific physiological functions.
- An organ system is a group of organs working together to conduct major functions or satisfy physiological needs of the body.
- At the top, the highest level of organisation is the *organism*. An organism is defined as having a cellular structure that can independently carry out all physiological functions necessary for life. In humans, all cells, tissues, organs and organ systems work together to maintain life and health of you – the human organism.

Organ Systems

You will learn about the 11 distinct organ systems within the body. Some organs overlap and perform tasks in more than one system, like reproductive and endocrine systems.

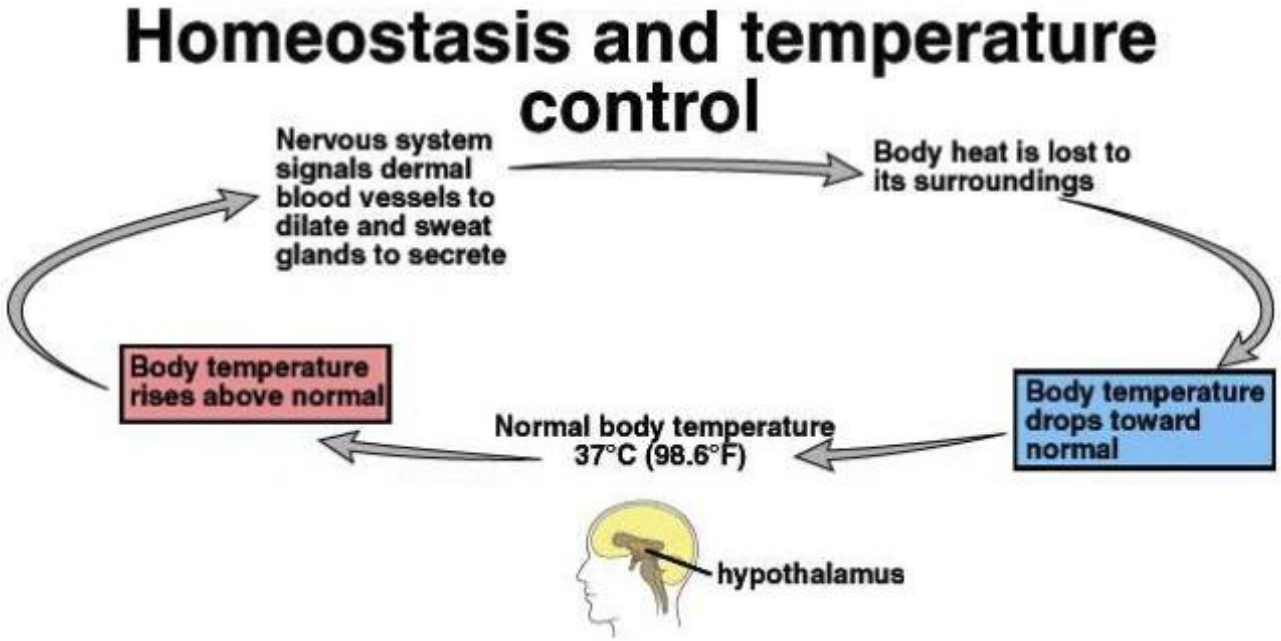


Homeostasis

As you can see, the body is divided into the different systems according to the specific functions they perform. But each system has an ultimate function to perform – no matter what – and that is to maintain a constant internal environment to ensure the survival of the cell.

Your body is constantly exposed to a changing external environment and these changes are corrected by the internal environment of blood, lymph and tissue fluids that, by bathing them, protects the cells.

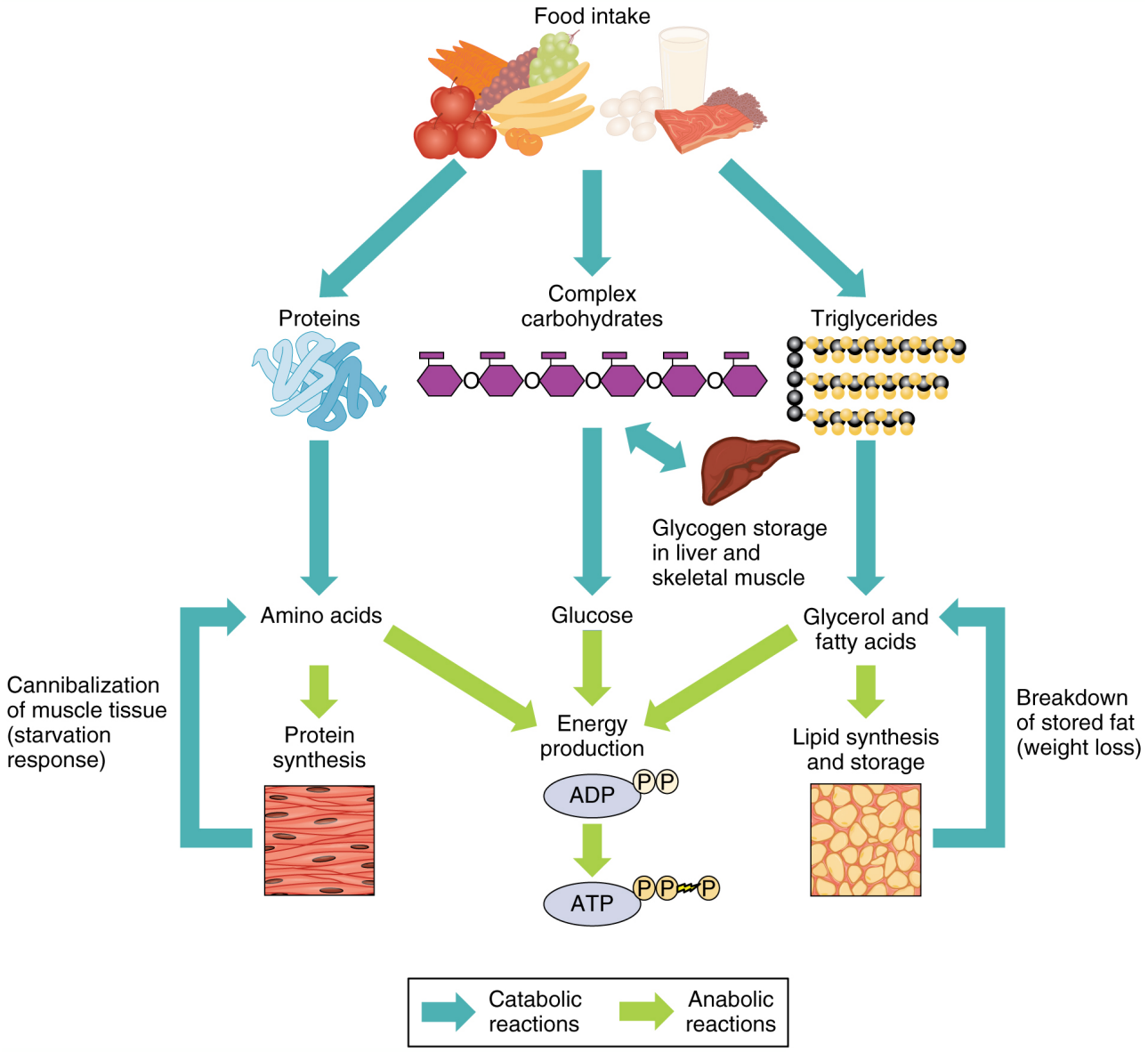
Any body part can only function efficiently when the correct levels of water, food, oxygen, heat and pressure are maintained within specific narrow limits. This balancing process performed to maintain a stable internal environment is called ***homeostasis***.



Your body maintains certain levels of substances in your blood, for example, your blood contains glucose. The level of glucose is maintained and monitored by your body. If the level goes above or below a certain level, hormones are released to bring it to within the acceptable limits.
Homeostasis relies on *feedback mechanisms*. Your body has thousands of different systems like these, all working to regulate a variety of different substances.
There are two types of feedback:
Negative Feedback is when the response is opposite to the catalyst.
Positive Feedback is where the response is the same as the catalyst.
So, the body automatically monitors and maintains this finely tuned mechanism, but when the systems become imbalanced, through stress, infection, pain or low oxygen levels, you'll see signs of disorder and disease. The systems work together to maintain:

- Body temperature
- Blood pressure
- Blood sugar levels
- pH levels

Regulating the pH balance
The pH scale is used to measure how acid or alkaline a substance is. 0-7 is acid and 7-14 is alkaline. Human blood needs to be around 7.4. If it goes below 7, it's a condition known as acidosis and if it goes above 8, the condition is known as alkalosis. Both conditions can be life-threatening. Because blood comes into contact with just about every cell in the body, it is especially critical to maintain the blood pH level.
In order to maintain a healthy level, the body produces substances known as buffers to regulate acidity or alkalinity.
The lungs also help to maintain the pH and the kidneys play a significant role, detecting acidity in urine, signalling that the pH levels of body fluids are too acidic.



To maintain homeostasis, the body regulates the metabolism.
The hypothalamus is key to maintaining homeostasis. Blood vessels throughout the body have receptors monitoring pressure, temperature, glucose and pH levels and send signals to the hypothalamus via the nervous system when it needs to instigate change to bring about homeostasis.

Metabolism
Metabolism is the term used for the process that happens to the food we eat and the air we breathe which then converts it to the energy we need to function or to materials for use or storage. The metabolism is made up of two processes:

Catabolism– this is the chemical breakdown of complex substances (food) into simpler ones (nutrients) while releasing energy.

Anabolism – this is the construction of complex molecules (e.g. proteins or lipids) from simpler ones.
The rate at which you use energy through activities and body functions is your **metabolic rate**.

The minimum amount of energy needed to keep your body alive is known as your **basal metabolic rate**.

The significance of elements in the chemical make-up of the body
You need to consider not only the major, common compounds and elements that make up the body, but also their role in the physical processes of the body.
Elements and compounds come in three different states:

- liquid
- solid
- gas

As an example, water usually comes as a liquid, salt is a solid and carbon dioxide is a gas.
Energy is used to change the state of a compound or element. When this energy is released, it's used in different ways: to start chemical processes, to help with movement or for growth, maintenance and repair.

What cells are made of
A cell contains the major elements carbon, hydrogen, oxygen and nitrogen and a whole host of trace elements, among them potassium, iodine, calcium and iron. A cell is made of:

- 80% water
- 15% protein
- 3% fat
- 1% carbohydrate
- 1% nucleic acid

Part 2: The Cell
The cell is the simplest form of life that can survive by itself and is the building block that makes up the human body. Cells come in many different shapes, forms and sizes, depending on the special function it performs. Some are disease fighting, others transport oxygen and some store nutrients.
Cell shapes are different according to the functions it has to perform, so e.g. muscle cells are long and thin to be able to stretch and contract and skin cells are flat to provide waterproof coverage – like tiles on a roof.

Cell structure

Organelles
Literally, little organs, organelles are molecules combined in specific ways to form the basic component of a cell. Every organelle has a particular functional purpose within the cell.
Although there are a multitude of different cells, they all have the same basic structure. It's easier to think of a cell in three parts:

- The outer part is the cell membrane
- The inner part is where you find the nucleus
- The middle part is made of cytoplasm, housing all the organelles

The outer part – the cell membrane:
Also called the plasma membrane, this is a semi-permeable lipid bi-layer common to all living cells. It contains a variety of biological molecules, primarily proteins and lipids, and because it's semi-permeable, it can selectively move molecules in and out of the cell. Oxygen, protein, nutrients and hormones are taken in and cellular waste is removed.

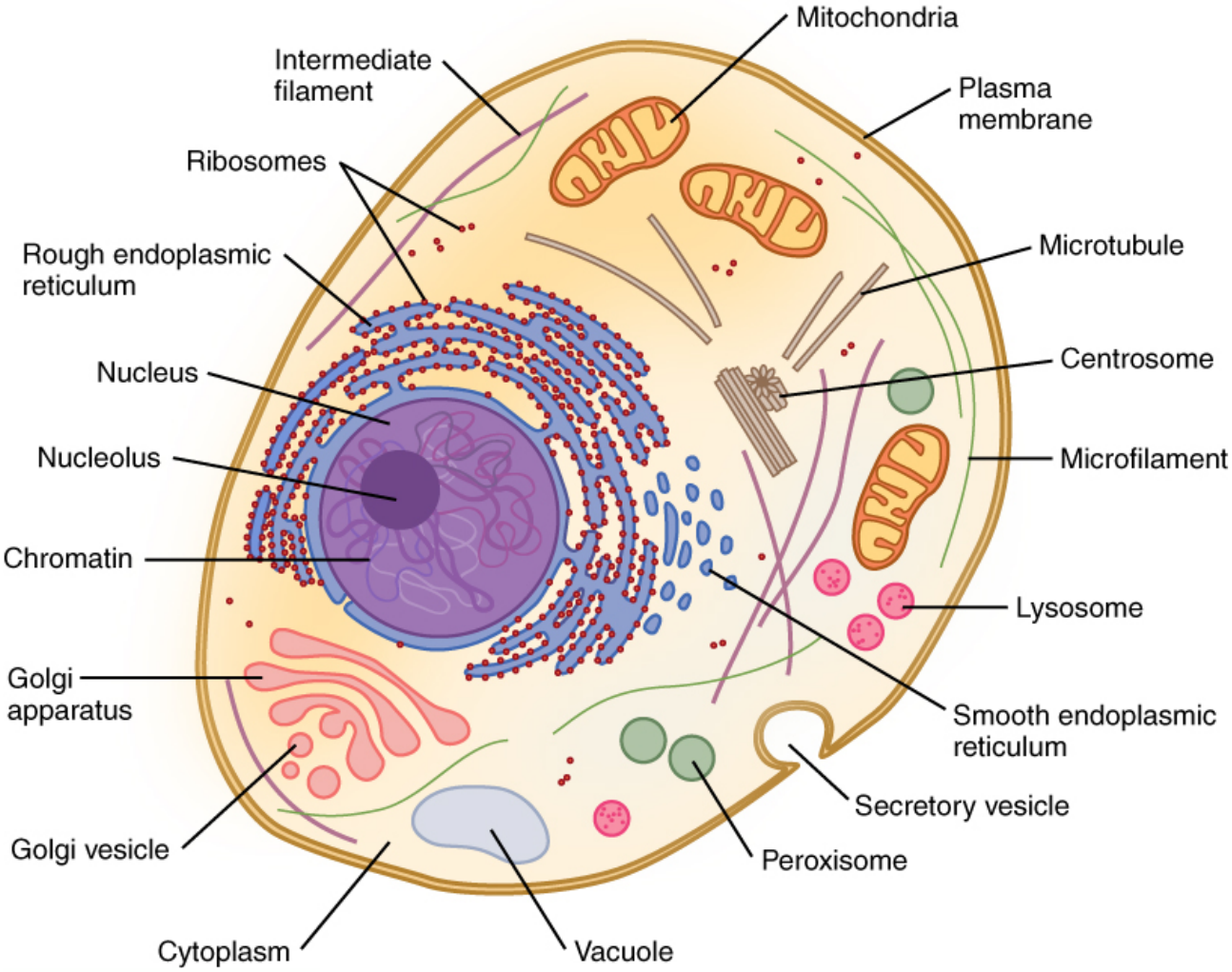
The inner part – the nucleus

The nucleus is a highly specialised organelle that serves as the information processing and administrative centre of the cell. This organelle has two major functions: it stores the cell's deoxyribonucleic acid or DNA, and it coordinates the cell's activities, which include growth, intermediary metabolism, protein synthesis, and reproduction (cell division). The DNA strands are known as chromosomes. Chromosomes contain genes, and a human cell contains 23 maternal chromosomes and 23 paternal chromosomes – 46 in total. Every cell has the capacity to duplicate itself, making sure the new copy has all 46 chromosomes.

Chromatin– a substance within the nucleus that contains the genetic material.

Nucleolus – a spherical structure within the nucleus containing ribonucleic acid structures, forming ribosomes.

Nuclear membrane – the nucleus is surrounded by a membrane similar to the outer membrane, allowing material to be moved in and out from the cytoplasm.



Middle part of the cell

Inside the cell membrane is a thick liquid called cytoplasm. The cytoplasm is composed mostly of water. The jelly-like liquid includes salts, nutrients and proteins. Some proteins are known as enzymes and are involved in various reactions that occur in the cell, such as breaking down or building up nutrients.

Other proteins form a network of filaments that serves as a body in the cell. The network is called the cytoskeleton and allows the cell to change shape and move. Substances that are not water-soluble form droplets in the cytoplasm. Fat cells, for example, are lots of fat droplets.

The cytoplasm also contains several small structures or parts that the cell needs to survive. Each part has its special task and can be likened to the body's organs. These miniature organs, as mentioned before, are called organelles.
The most important organelles are:

- Mitochondria – these are the cell's power plant
- Ribosomes – assemble proteins
- Endoplasmic reticulum and Golgi apparatus – the cell's transport system
- Lysosomes – the cell's cleaning system

You'll also find:

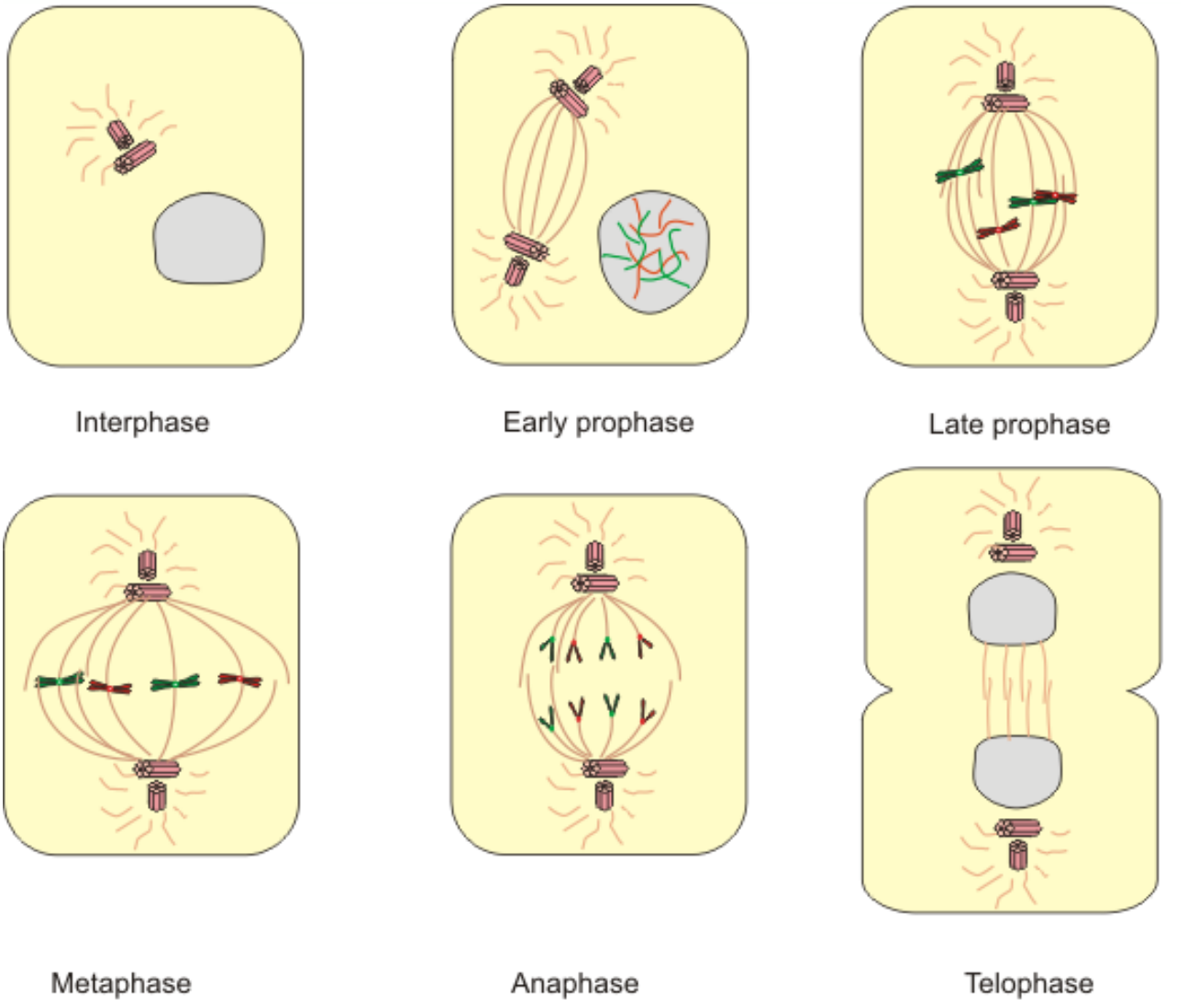
- Centrosome – an area of clear cytoplasm next to the nucleus, containing centrioles
- Centrioles – small spherical structures associated with cell division (mitosis)
- Chromatids – identical strands joined at the centromere and separated during mitosis
- Centromere – the part of a chromosome where two chromatids are joined
- Vacuole – empty spaces containing waste material, used as temporary storage, transportation or digestive purposes

Cell function
Cells have to be able to carry out a variety of functions in order to survive:

Cell respiration
To carry out the process of metabolism, every cell requires oxygen. The cell's semi-permeable membrane absorbs oxygen, which is used to oxidise nutrients to provide heat and energy. Cell respiration produces waste products, including carbon dioxide and water. This is passed out from the cell through the semi-permeable membrane.
Cell growth
Cells are able to grow until they are mature and ready to produce. A cell is able to both grow and repair itself because it can manufacture proteins.
Cell waste
Metabolism produces a variety of waste material, which is removed from the cell through the semi-permeable membrane.
Movement within the cell
Movement is possible within the whole, or part of the cell. White blood cells can move freely within the whole cell.
Cell stimulus and irritability
A cell can respond to a chemical, thermal or physical stimulus. As an example, when stimulated by a nerve cell, a muscle fibre contracts.
Cell reproduction
When growth is complete, cell division occurs through the process of mitosis.
Cell growth and reproduction need healthy and favourable conditions to function optimally, including food, water, oxygen, the right temperature and the ability to eliminate waste. Sun damage, pollution and smoking are less favourable and damage cells – leading to loss of elasticity, wrinkles, dehydration and lines.
A massage will help with getting nutrients to the cell and eliminating waste material. It also helps with cell regeneration, so regular treatments are beneficial for health in general.

Part 3: Life Cycle of the Cell
Cell division happens through *mitosis* and *meiosis*.
Mitosis
We all begin as one cell. This cell becomes many cells by dividing in a process known as mitosis.

In mitosis, the genetic material (DNA) is carried on to two daughter cells, identical to the original cell. This is the way the body carries out growth and repair. The nucleus divides in four phases: prophase, metaphase, anaphase and telophase. This is then followed by the division of the cytoplasm to form the daughter cells.
Some cells in the body live for a few days, others live many years; it all depends on its function.



Cell Mitosis

Prophase
During prophase, the genetic material forms chromosomes. Remember that there are 2 sets of identical chromosomes. During prophase, the nuclear membrane begins to break up and disappear. The nucleolus also disappears as the chromosomes form. A system of microtubules forms a mitotic spindle at opposite ends of the cell.
Metaphase
During the metaphase, the chromosomes all line up in the centre of the cell.
Anaphase
During anaphase, the spindle fibres shorten and the centromeres divide separating the pair of chromosomes. The chromosomes move to opposite sides of the cell.
Telophase

The final stage of mitosis is telophase. The nuclear membrane and nucleolus begin to reappear. The mitotic spindle breaks up and the chromosomes uncoil. Two daughter cells are now present.

Meiosis

Meiosis is the production of a new organism, formed from four identical daughter cells, each containing half the chromosomes of the original. This is the fusion of a male sperm and a female egg. The sperm and egg contain 23 chromosomes each, and after fertilisation, the sperm/egg fusion contains 46 chromosomes, forming a cell called a zygote. The zygote is capable of reproducing itself through mitosis, forming an embryo that grows into a foetus and later a fully formed human being (or other individual).

Cellular respiration

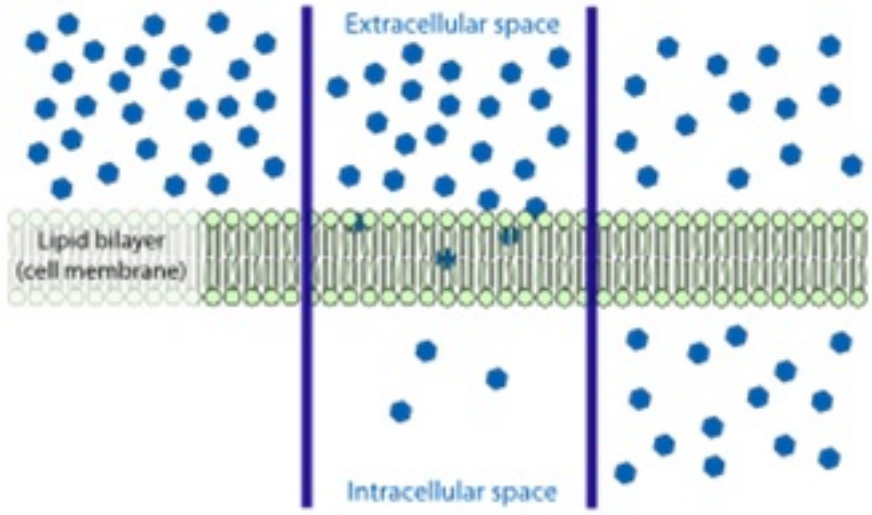
As we mentioned before, cell respiration is one function the cell has to be able to perform in order to survive. All cell functions are dependent on the generation of energy and the transportation of substances within and between cells. A healthy environment for the cell includes the maintenance of a stable internal environment which can be achieved if there is no excessive build-up of chemicals.

"Respiration" refers to the exchange of nutrients and waste: oxygen and glucose in – carbon dioxide out, for example. This produces the energy the cell needs to function. Fuel comes from glucose produced by metabolising carbohydrates. The glucose is released (oxidised) when oxygen is absorbed from the respiratory system into the bloodstream. Cells are surrounded by a fluid known as tissue fluid or interstitial fluid, allowing substances between the blood and cells to be interchanged – internal respiration.

The blood carries oxygen from the respiratory system and nutrients from the digestive system to the cells where they are absorbed through the cell membrane in a variety of ways:

Diffusion

When chemicals become too concentrated outside the cell, small molecules begin to flow through the cell membrane until a balance has been achieved. The action of molecules moving from an area of high concentration to an area of low concentration is known as diffusion. This is how the cells in the small intestine's lining absorb nutrients to be used by the body.



Osmosis

Osmosis is when water moves across the semi-permeable membrane from a higher area of concentration of solute to a lower concentration of solute. Or, in the other direction:

water moves across the semi-permeable membrane from an area of lower concentration of solute to an area of higher concentration of solute in order to maintain balance.

Active transport

In active transport, substances are moved against their concentration gradients by carrier proteins. Normally, there is more sodium outside of the cell than in, so sodium would move from outside to in.

Carrier molecules from within the cell attach themselves to molecules which would otherwise be too large to enter in enough quantities. Then, they rotate around them and release them into the cell. This is how a cell absorbs glucose.

Filtration

Sometimes cells arrange themselves in thin layers and substances can move between the cells. These layers or membranes work the same way as filters. Filters sort substances based on size. Smaller substances move through the spaces and larger substances do not. Think of a coffee filter. The filter has very small holes that only allow the water to move through. The grounds are too large to fit through the holes.

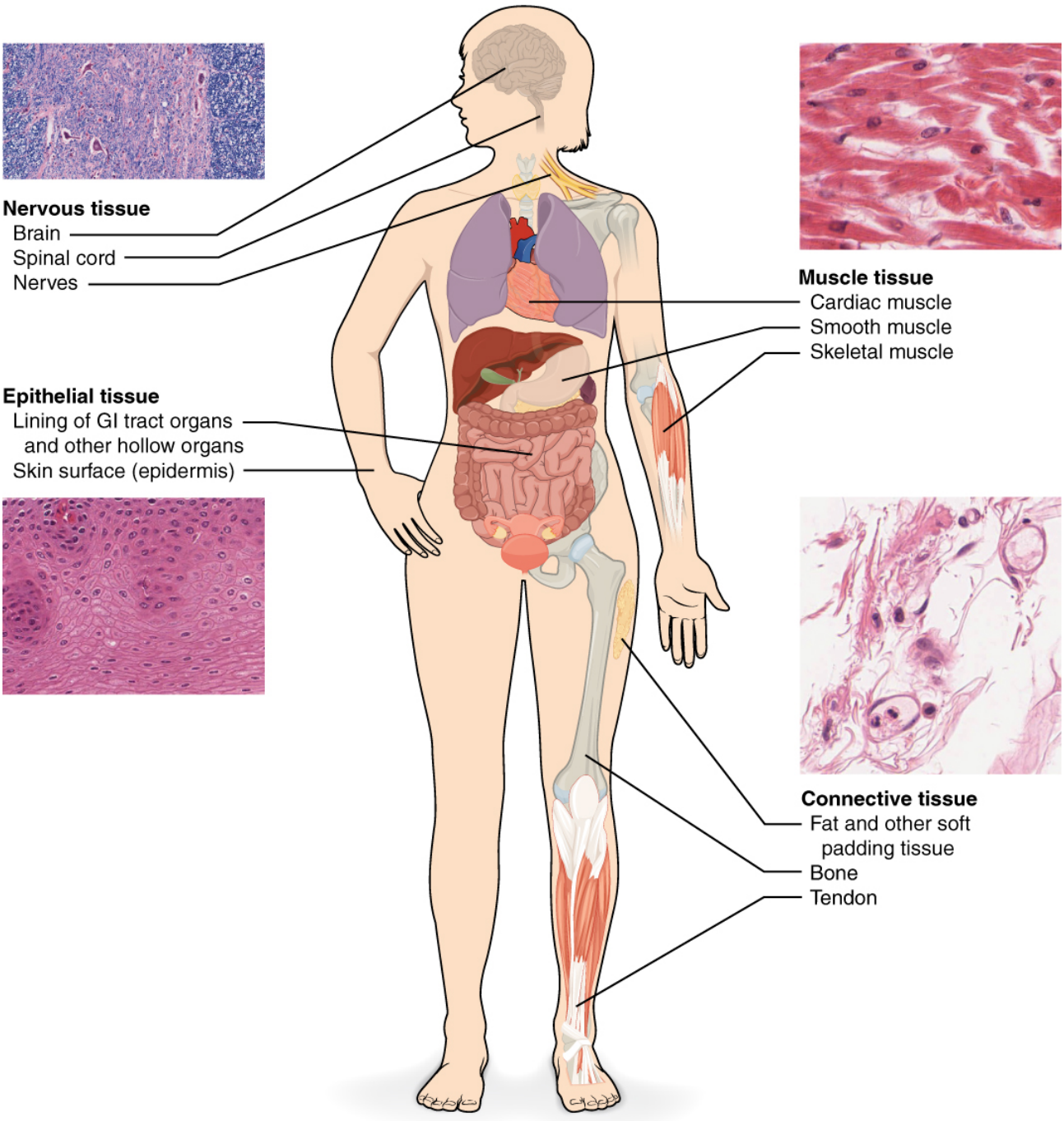
The force that drives filtration is fluid pressure. This pressure is also known as hydrostatic pressure. In order to move substances through a filter, they must move from an area of higher pressure to lower pressure.

There are many examples of filters in the body, including the capillaries and kidneys.

Part 4: Tissues

Tissues are a group of similar cells that work together to carry out a specific function. *Histology* is the study of tissues. The four major types of tissue in the human body are:

- Epithelial tissue – provide a protective layer for internal and external body surfaces
- Connective tissue – binds, supports and protects the body and the organs
- Muscle tissue – gives us movement
- Nervous tissue – instigates and transmits nerve impulses



Epithelium is a tissue that covers other structures. Therefore, one side is always exposed to the outside, which could still be inside the body. Epithelial tissue covers the inside of body cavities and organs. The outer or superficial portion of your skin is an epithelial tissue. Epithelial tissue does not have a blood supply. Therefore, nutrients must enter the tissue by diffusion. Epithelial tissue anchors to other structures via a basement membrane.

There are two categories of epithelial tissue:

- Simple – single layer
- Compound – multi-layered

A simple epithelial tissue is fragile and thin and consists of only one layer. You find it internally in the lining of the heart, blood vessels and body cavities. Because it's thin, it has advantages in speed of absorption across it, like in the digestive tract and exchange surfaces of the lungs. There are four different types of simple epithelia:

Type	Structure and Function	Location
Simple squamous epithelium	Single layer of flattened cells; diffusion and filtration	Forming capillary walls; lining air sacs (alveoli) of lungs; covering visceral organs; lining body cavities
Simple cuboidal epithelium	Single layer of cube-shaped cells; excretion, secretion, or absorption	Covering surface of ovaries; lining kidney tubules, salivary ducts, and pancreatic ducts
Simple columnar epithelium	Single layer of nonciliated column-shaped cells; protection, secretion and absorption	Lining digestive tract, gall bladder, and excretory ducts of some glands
Simple ciliated columnar epithelium	Single layer of ciliated column-shaped cells; transport role through ciliary motion	Lining uterine (fallopian) tubes and limited areas of respiratory tract
Pseudo-stratified ciliated columnar epithelium	Single layer of ciliated, irregularly shaped cells; protection, secretion, ciliary motion	Lining respiratory passageways and auditory tubes

Compound epithelium consists of two or more layers of cells which protect underlying formations. These cells are divided into two types of epithelia– stratified and transitional.

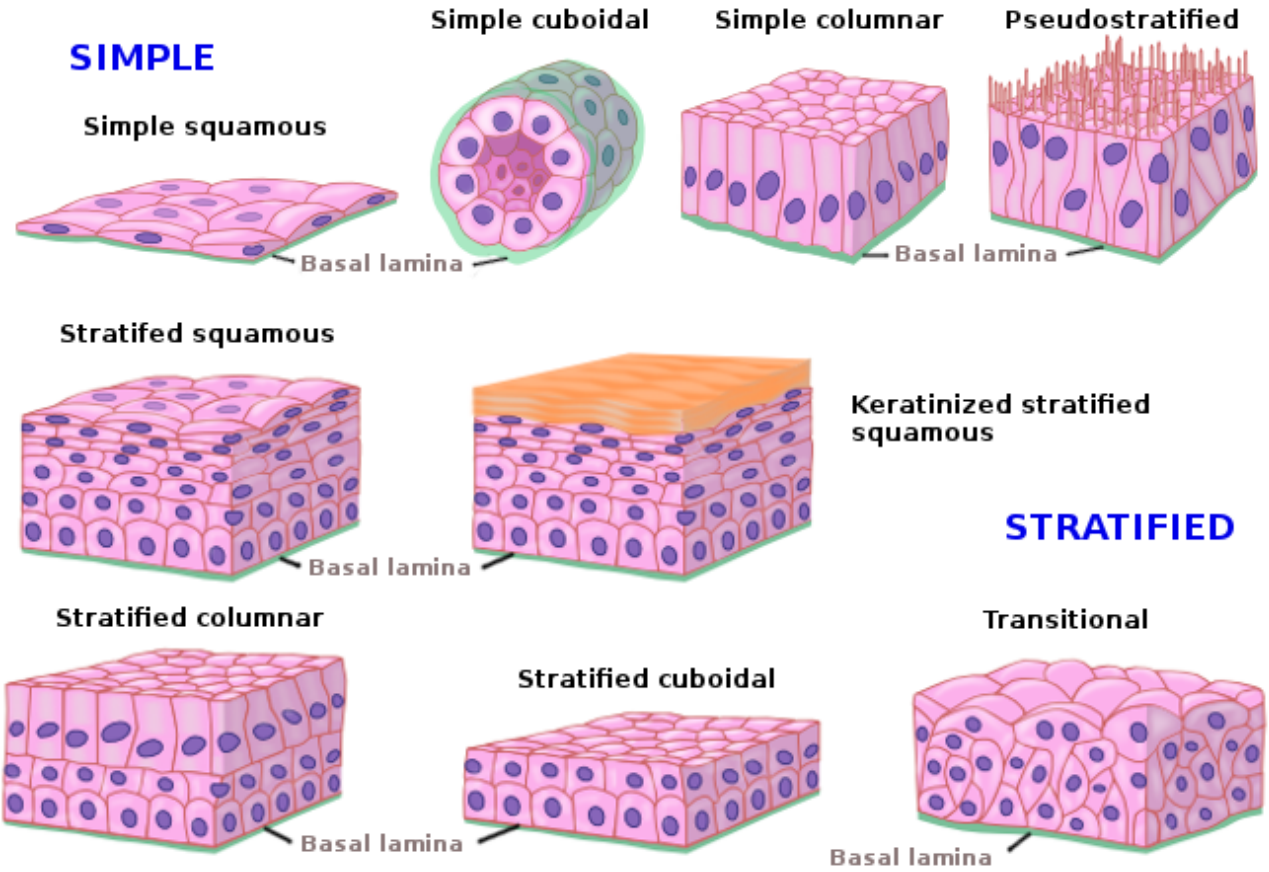
Stratified epithelium

A stratified epithelium consists of a number of cells, at the deeper levels these are mainly columnar, but the closer to the surface you get, the more flattened they become.

The stratified epithelium is divided further, into:

Non-keratinized stratified epithelium – found on wet surfaces that get a lot of use, like the conjunctiva of the eye, the lining of the mouth, pharynx and oesophagus.

Keratinized stratified epithelium – found on dry surfaces, like hair, skin and nails. The top layer consists of dead skin cells, protecting the cells at a deeper level and preventing them from drying out. These cells are continually replenished from below and the surface layer is rubbed off.

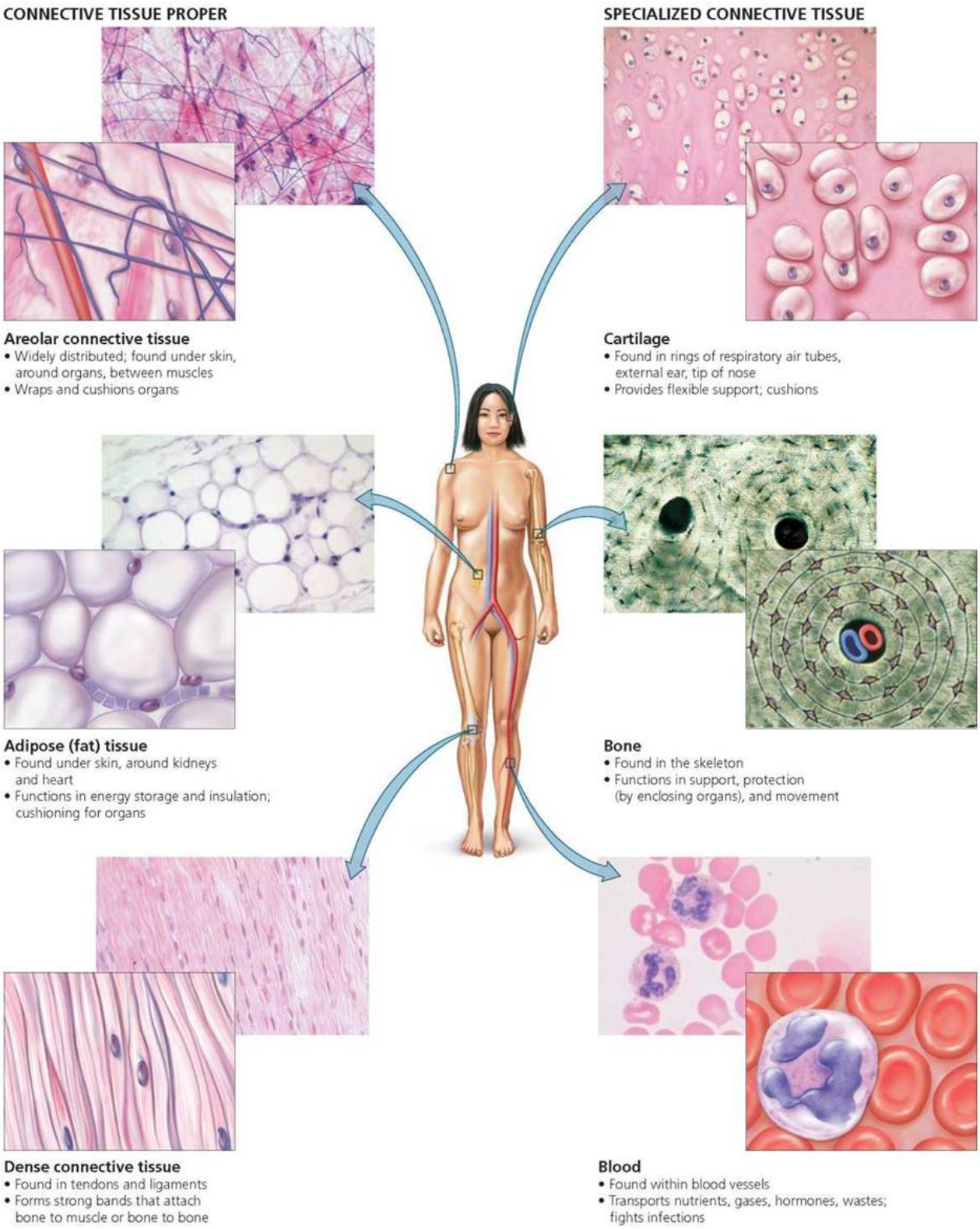


Transitional epithelium

Consists of several layers of pear-shaped cells which can change shape when they are stretched. You'll find this tissue in the uterus, bladder and pelvis of the kidneys.

Connective tissue

Connective tissue is the most abundant type in the body. It connects and joins tissues and organs parts of the body together and it protects and supports. Connective tissue contains fibroblasts and fibre made of protein.



Connective tissue cells are more often separated from each other and not close together like the epithelial cells, and the space between the cells is filled with a non-living matrix which may contain fibres that are either a viscous consistency or solid and inflexible, depending on the position and function of the tissue.

Cartilage

There are three types of cartilage:

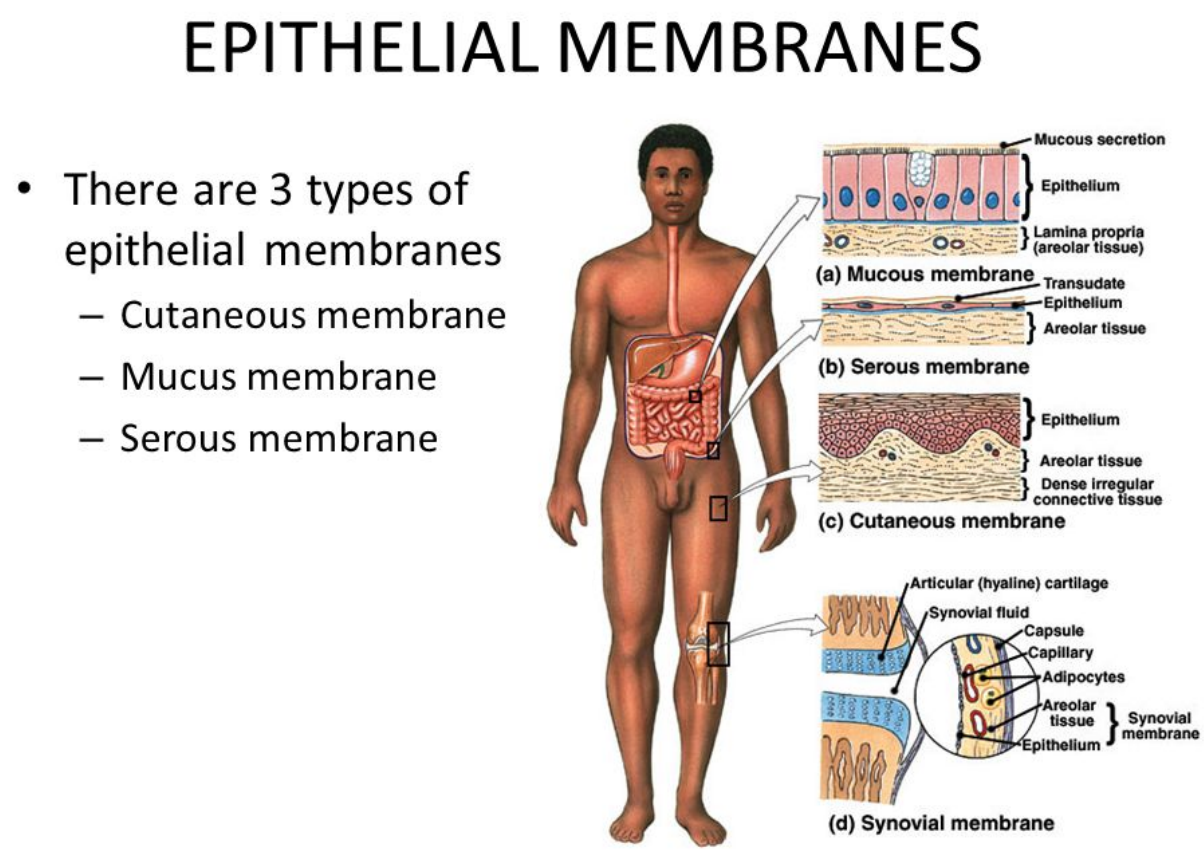
- Hyaline cartilage
- White fibrous cartilage
- Yellow elastic fibrocartilage

Muscle tissue
Muscle tissue is elastic and unique in that it can provide movement when it shortens through contraction. Muscle tissue is made up of bundles of contractile fibres surrounded by connective tissue. There are three types:

- Voluntary tissue (skeletal)
- Involuntary tissue (smooth tissue)
- Cardiac muscle tissue

Muscles are further discussed in the module for the muscular system.

Nervous tissue
Nervous tissue consists of neurone cells, which pick up and transmit electrical signals by converting stimuli into nerve impulses. Characteristics of nervous tissue are excitability and conductivity. Its function is to regulate and coordinate body activity.
Nervous tissue and neurones are discussed in the module for the nervous system.



Membranes
There are three types of membranes in the body as follows:

- Mucous membrane
- Synovial membrane
- Serous membrane

Common pathologies of cells and tissues
The most widely known, and the one we all worry about most, is no doubt cancer. When cells in any area begin to divide without control, it develops into a growth tumour or neoplasm. Tumours can be benign or malignant – harmless or fatal. Benign tumours don't spread, but sometimes they are removed if they impact on other body functions or if they are disfiguring.

The microscopic appearance of cancer and the body site they originate from gives them their classification.
Cancers are named according to the tissue type it develops in – most cancers are carcinomas, malignant tumours developing from epithelial cells. *Melanoma*, for example, is a cancerous growth of melanocytes; skin cells producing the pigment melanin. *Sarcoma* is the common name given to cancers developing from muscle cells or connective tissues. *Osteogenic sarcoma* (bone cancer) is the most common type of childhood cancer, destroying normal bone tissue and spreading to other parts of the body. *Leukaemia* is cancer of the blood-forming organs, characterised by its rapid growth. *Lymphoma* is the malignant disease of lymphatic tissue, such as Hodgkin's disease.
Now you have a clear picture of the origins of who you are and what you are made of.

Module Two: Skin, Hair and Nails

Part 1: Functions of the Skin

Learning objectives

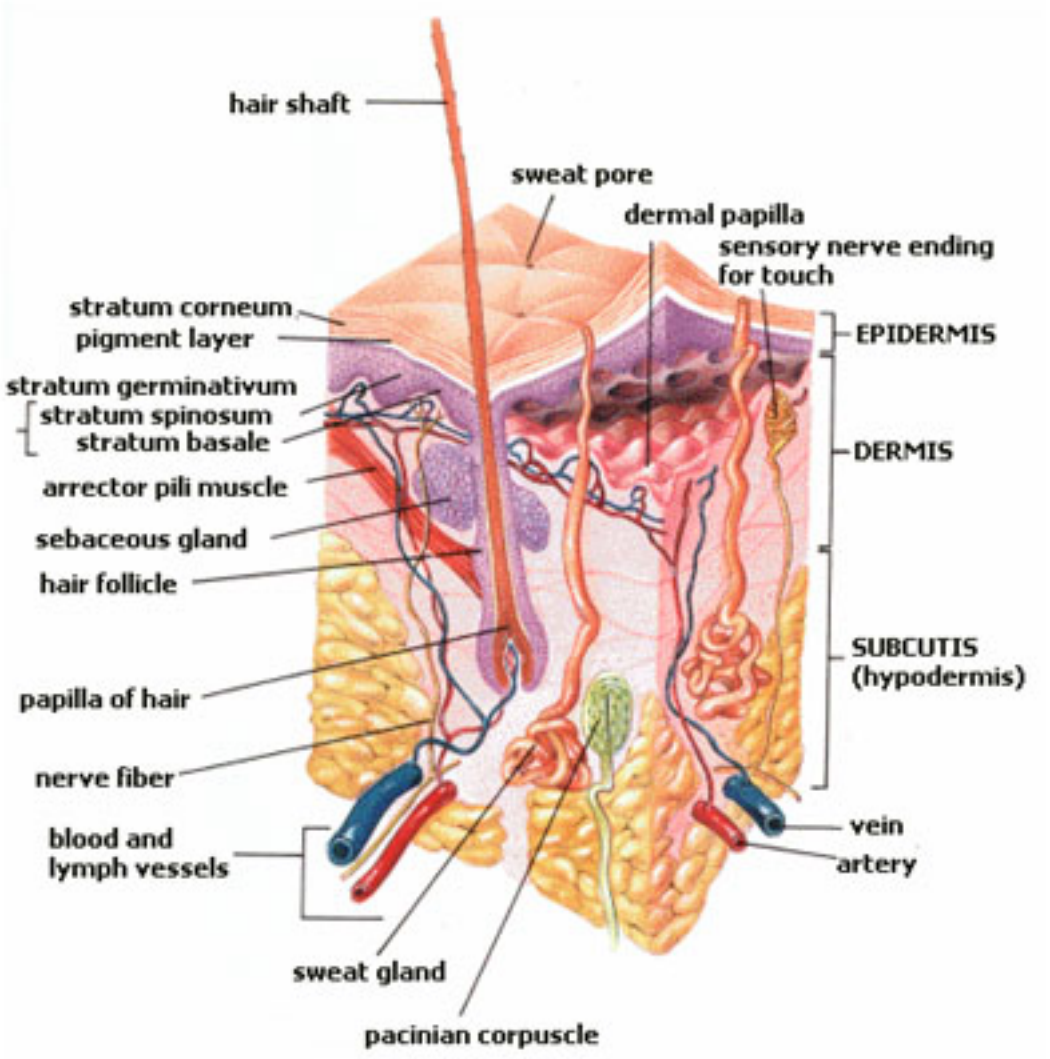
In this module, you will learn:

- Structure and function of the skin.
- Characteristics of different skin types.
- Structure and function of the nails and hair.
- Common pathologies of skin, hair and nails.

Functions of the skin

Apart from making sure that we don't float out over the edges, skin is an extraordinary organ, acting as a sensor between us and the environment.

The skin is the largest organ of the body and has a variety of functions. It provides a protective covering to the body that inhibits the loss of water, it helps to regulate temperature, has sensory receptors that send information to the nervous system and synthesises chemicals and excretes wastes. The skin also contains a good deal of immune system cells that help to protect the body against pathogens.



Sensitivity – the skin acts as an extension of the nervous system, detecting changes in temperature, pressure and can register pain, all thanks to the many sensory nerve endings it contains.

Heat regulation – the skin regulates body temperatures in the following ways:

- When the body loses heat, the blood capillaries close to the surface contract, keeping warm blood away from the skin surface and closer to internal major organs.
- Erector pili muscles raise the body hair to trap air next to the skin, where heat needs to be retained.
- Adipose tissue in the dermis and the subcutaneous layer insulates against heat loss.
- When the body gets too hot, the blood capillaries close to the surface dilate to divert more blood (and heat) away and cool the body.
- Sweat evaporating from the skin surface will also help to cool the body.

More about temperature regulation

The skin is very important in regulating body temperature. The skin helps keep in heat produced by skeletal muscles and liver cells. When the body gets too hot, the skin opens up the sweat pores so that the sweat can carry the heat away by evaporation.

Heat can be lost by the body in a number of ways. Heat always moves along a gradient from warmer to cooler temperatures. Heat can radiate from the body to the surrounding areas at lower temperatures. In conduction, heat moves via molecules from the warmer body to cooler objects. An example of conduction would be to lean against a cooler concrete wall. The heat flows from your body into the wall. In convection, heat moves via air molecules circulating around the body. In evaporation fluid on the surface of the body carries heat away.

Body temperature is primarily regulated by the hypothalamus. This sets the body's temperature and controls it by opening and closing sweat glands and contracting muscles.

Let's say that it is a hot summer day and you are working outside. As your body's temperature rises, the hypothalamus senses this and sends a message to your sweat glands to open. The sweat evaporates from your skin and you begin to cool down.

Now let's say that you've finished working and you go inside to your air-conditioned home. Your body's temperature will begin to drop. The hypothalamus senses this and sends a message to your muscles to contract or shiver. The muscles will generate heat to help maintain your core temperature. In more severe cases of cold, your blood vessels will constrict in your extremities in an attempt to conserve heat at the core of your body for survival.

If your core body temperature continues to drop, you may develop a condition called *hypothermia*. You will progress from feeling cold to shivering, experiencing mental confusion, lethargy, loss of reflexes and eventually loss of consciousness and shutting down of organs.

Conversely, if your core body temperature increases too much, you can develop *hyperthermia*. This can develop in humid conditions because of lack of evaporation. The signs of hyperthermia include light-headedness, dizziness, headaches, muscle cramps, fatigue and nausea.

Absorption The skin is limited in what substances can be absorbed by the epidermis: fat-soluble substances like oxygen, carbon dioxide, fat-soluble vitamins, steroids and a small amount of water are absorbable.

Protection

The skin protects you in the following ways:

The thin film of sebum and sweat on the surface, known as the acid mantle, is like an anti-bacterial agent, prohibiting the growth and multiplication of micro-organisms on the skin.

Deeper down, fat cells in the subcutaneous layer protect bones and major organs from being injured.

Melanin, produced in the basal layer of the skin, protects against harmful effects of UV radiation.
The horny layer of the skin contains overlapping, scale-like cells, preventing microorganisms from entering the body and too much water from escaping.

Excretion

Waste is eliminated through perspiration. Sweat is produced by the eccrine glands, removing some waste material from the skin, like urea, uric acid, lactic acid and ammonia.

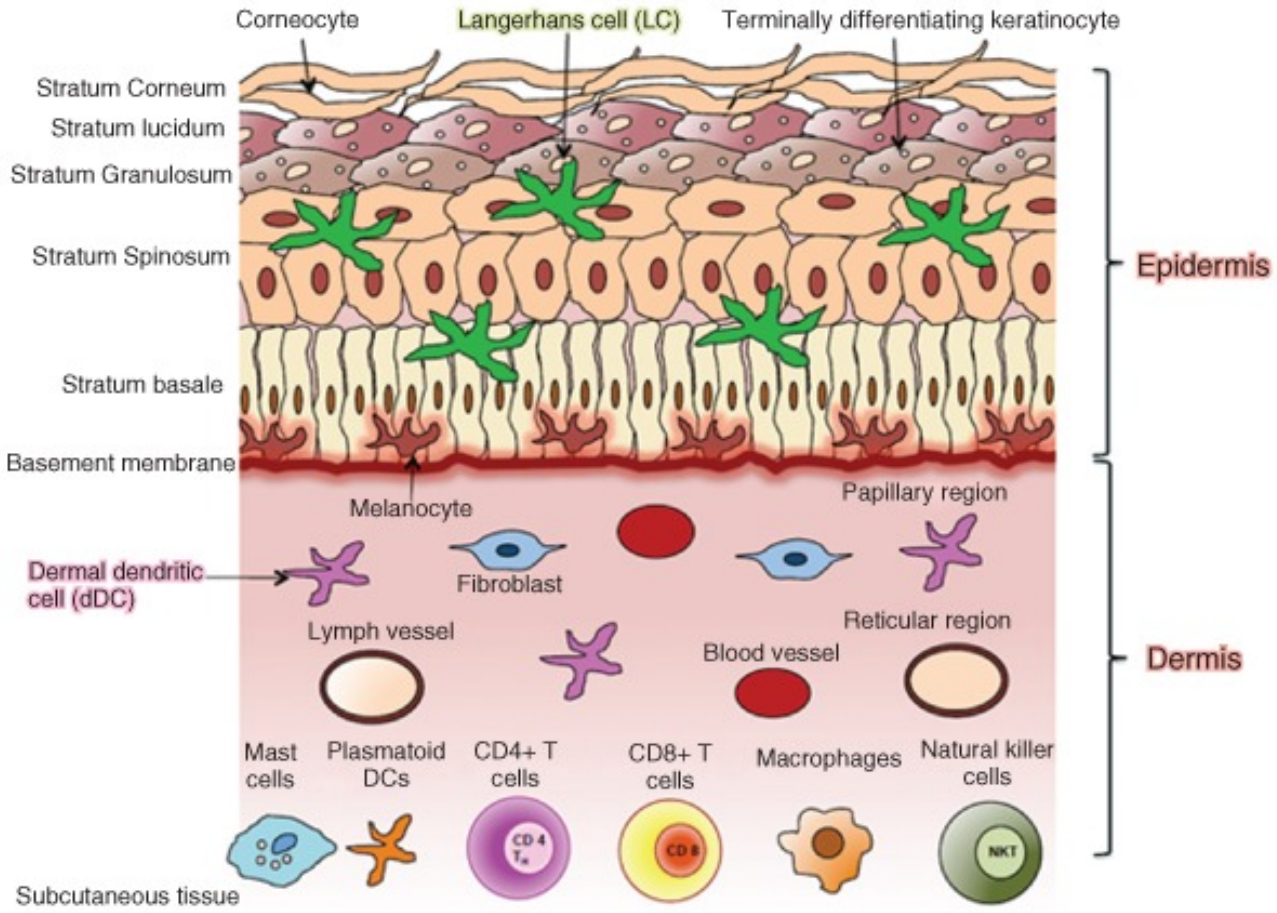
Storage

The skin is also like a storage facility for water and fat. 15% of the body's fluids is stored in the subcutaneous layer.

Vitamin D

The skin also helps to synthesise vitamin D. Vitamin D (cholecalciferol) is synthesised when a precursor molecule known as 7-dehydrocholesterol absorbs ultraviolet radiation. This molecule then travels to the liver and kidney where it is converted to the active form of vitamin D.
Vitamin D is an important substance in the body. It functions to help the body absorb calcium. It also works to help in calcium transport in the intestines.

Part 2: Layers of the Skin



The skin contains 2 layers and a subcutaneous layer. The superficial layer is called the epidermis. The epidermis consists of stratified epithelium tissue arranged in layers called strata. Deep to the epidermis is the dermis. The dermis consists of loose connective tissue and a number of other structures that we will investigate later. The deepest layer is the subcutaneous layer that consists of loose connective tissue and adipose tissue along with blood vessels and nerves.

The epidermis consists of stratified squamous epithelium arranged in layers or strata. The layers are:

- Stratum corneum
- Stratum lucidum
- Stratum granulosum
- Stratum spinosum
- Stratum basale (basal layer)

The epidermis is anchored to the dermis by means of a basement membrane. The epidermis does not contain any blood vessels. The cells of the stratum basale are nourished by the blood vessels in the dermis. These cells can divide and move toward the surface pushing the old cells off the superficial layers.

The stratum corneum is the most superficial layer of the epidermis. It consists of cells that have been hardened with keratin. Keratin is secreted by cells located in the deep layers of the epidermis called keratinocytes.

The stratum lucidum is an additional layer that is found only in the palms of the hands and soles of the feet. It provides an added thickness to these layers.

The stratum granulosum contains cells that have lost their nuclei. These cells remain active and secrete keratin. The cells contain granules in their cytoplasm that harbour keratin.

The stratum spinosum contains cells called prickle cells. These cells have small radiating processes that connect with other cells. Keratin is synthesised in this layer.

The stratum basale or basal cell layer contains epidermal stem cells. This is the deepest layer of the epidermis. It consists of one layer of cells that divide and begin their migration to the superficial layers. This is the layer where basal cell cancer develops.

As we have seen, there are a good number of keratinocytes located in the epidermis. Psoriasis is an abnormality of keratinocytes, where the cells abnormally divide rapidly and migrate from stratum basale to stratum corneum. Many immature cells reach the stratum corneum producing flaky, silvery scales (mostly on knees, elbows and scalp).

The epidermis also responds to the environment. Friction causes the formation of corns and calluses.

Another kind of cell found in the epidermis is the melanocyte. This cell produces the pigment melanin that gives skin its colour. Melanocytes are located in the deepest portion of the epidermis and superficial dermis.

The colour of the skin results from the activity of the melanocytes. Melanocytes are located in the deepest layer of the epidermis. They respond to ultraviolet radiation by producing more melanin pigment, which turns skin a darker colour. Melanocytes respond to UVB radiation. The hair and middle layer of the eye also contain melanocytes. A condition known as malignant melanoma can develop in melanocytes.

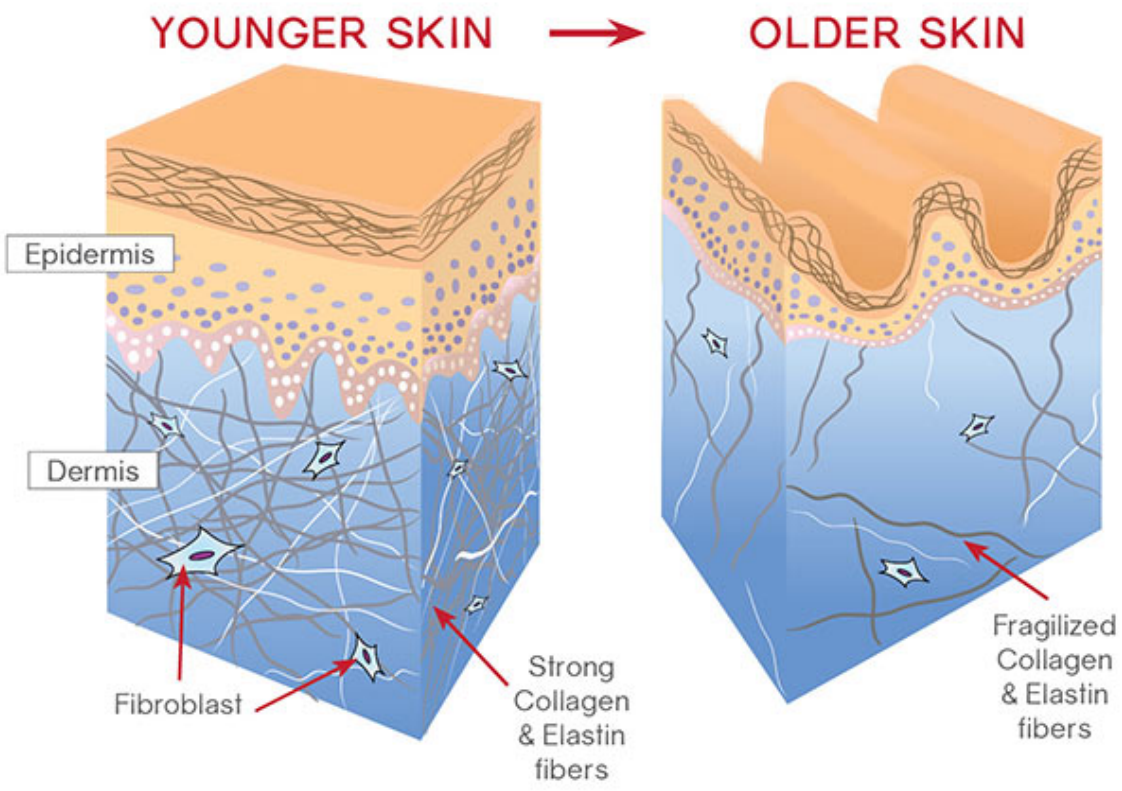
The dermis

The dermis is the middle layer of the integument. It consists of loose connective tissue and houses a number of accessory structures of the skin and connects to the epidermis by means of wavy structures called dermal papillae.

The dermis is a thicker layer than the epidermis and can be up to 3mm thick. It provides nourishment for the epidermis, removes waste products, provides a supportive framework and contributes to skin colour.

In the reticular layer of the dermis, you'll find the protein *collagen*, which accounts for approx. ¾ of the weight of the dermis. It's organised in horizontally running bundles all through the dermis and is covered in a jelly-like substance called ground substance.Collagen makes the skin resilient and gives it elasticity.

The collagen bundles are held together by protein fibres called elastin. Both collagen and elastin are made of fibres called fibroblasts which can be found all through the dermis.



Collagen damage and breakdown of elastin fibres are the main reason for skin ageing and wrinkles. As we age, the production of hyaluronic acid and glycoproteins in the skin slow down, contributing further to the ageing process.

We mentioned fibroblasts, a fibre in the dermis, and you'll also find:

- Mast cells – secreting histamine and dilating blood vessels and sending blood to the area
- Phagocytic cells (macrophages) – white blood cells with the ability to move around in the dermis, destroying bacteria and foreign matter.

Lymphatic vessels

The dermis contains numerous lymph nodes, a network of waste removal vessels which keep the skin tissue clear. As a rule, they follow the path of the veins and can be found around dermal papillae, dermal glands and hair follicles.

Structures of the dermis

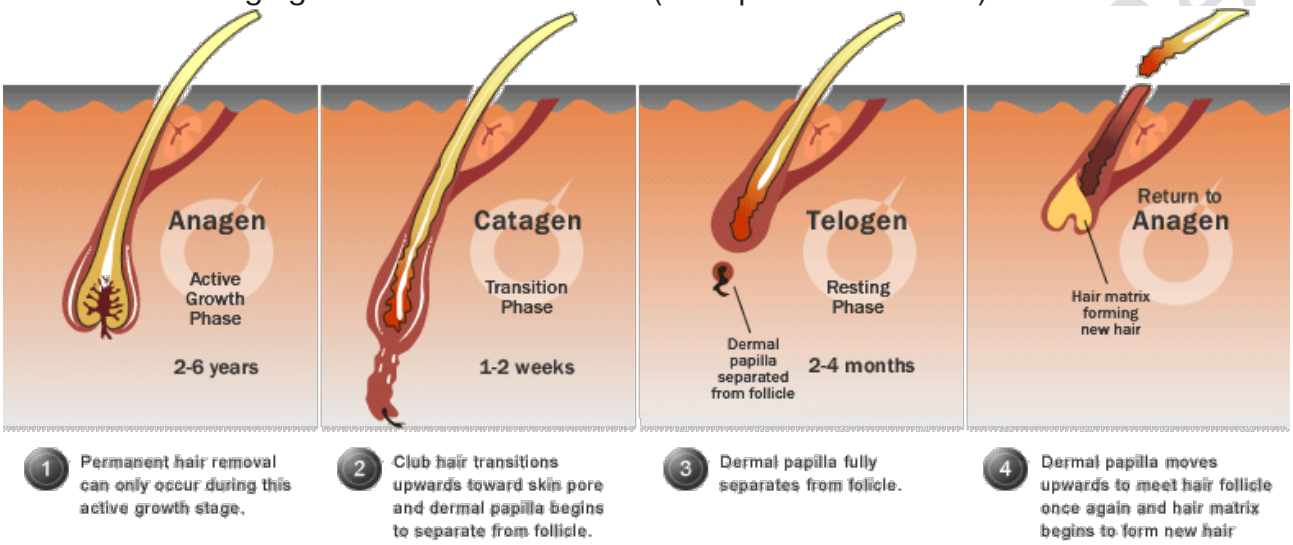
The dermis contains a variety of accessory structures of the integument. These include:

- Hair follicles
- Arrector pili muscles
- Sweat glands
- Sebaceous glands
- Sensory receptors
- Blood vessels

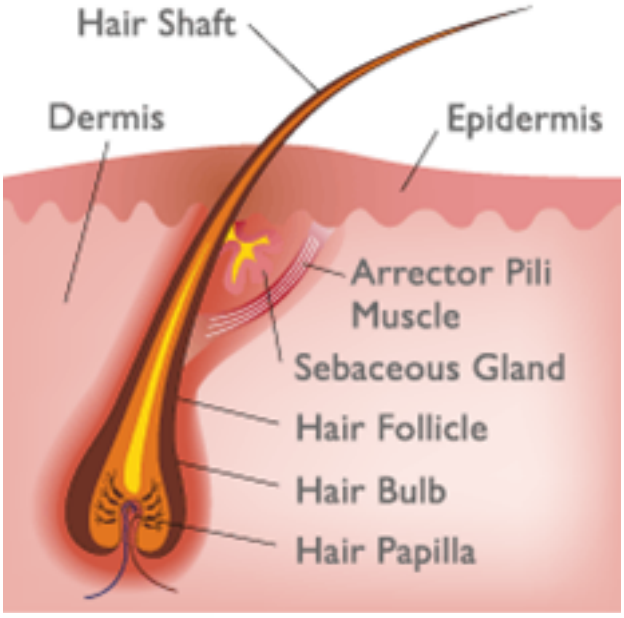
Part 3: Hair Follicles/Sebaceous Glands

The human body has approximately 2.5 million hairs on its surface. Hair is not found on the palms of the hands and soles of the feet as well as on the lips, parts of the external genitalia and sides of the feet and fingers. Hair is not alive and develops from old dead

cells pushed outward by new cells. The cells contain keratin for hardness and melanin for colour. Hairs can be very sensitive. This is due to a tiny plexus of nerves that surround each hair follicle. Hair is so sensitive that you can feel the movement of even a single hair. A band of smooth muscle connects to each hair follicle. This structure, called an arrector pili muscle, is capable of moving each follicle, causing it to stand up in times of sympathetic nervous system activity such as emotional stress.
Hair begins to grow at the base of the hair follicle in a structure called the hair bulb. The hair bulb is surrounded by a hair papilla that contains blood vessels and nerves. The cells of the hair bulb divide and push the cells toward the surface along the hair root and shaft. Hair grows at a rate of about 0.33 mm per day. Normal adults lose about 50 hairs per day. A loss of over 100 hairs per day will cause a net loss of hair. This happens especially in men due to changing levels of sex hormones (male pattern baldness).



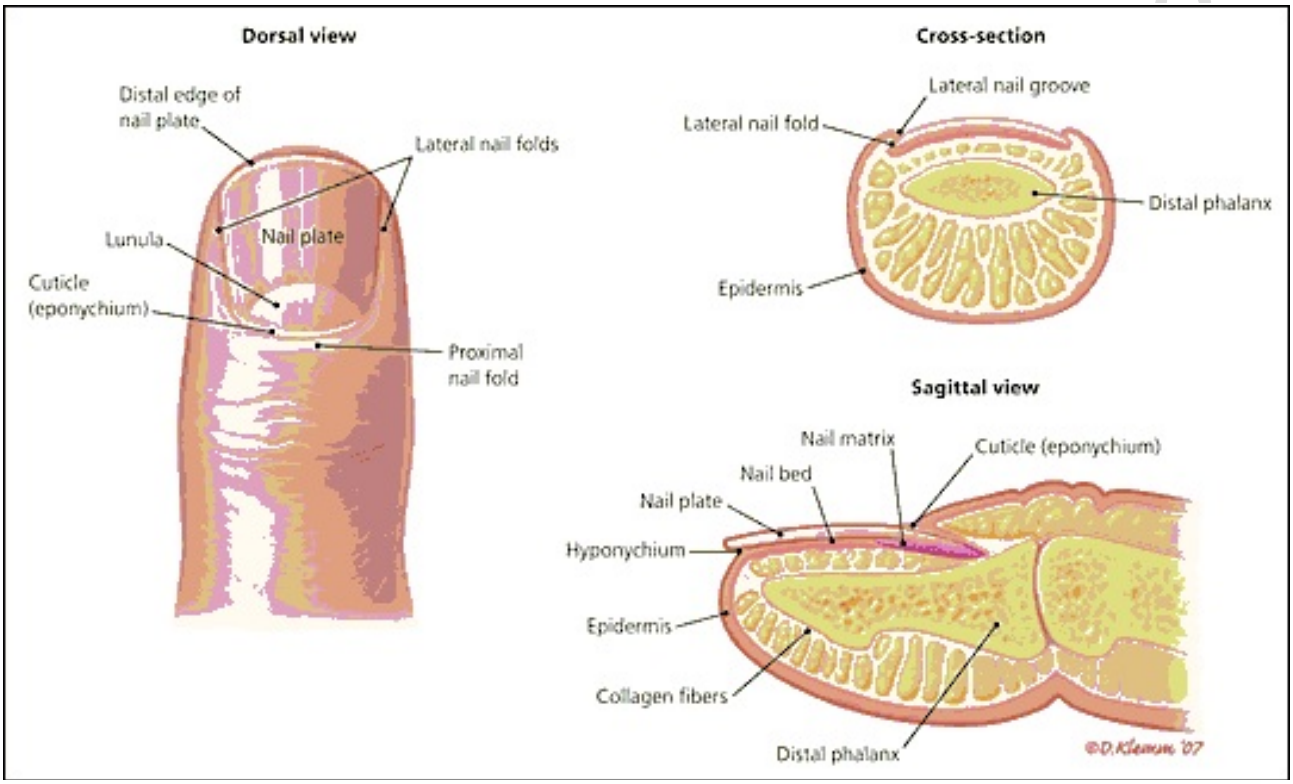
There are two types of hair. *Vellus* hairs are the fine hairs located on much of your body's surface. *Terminal* hairs are thicker, more pigmented and are found on your head as well as genitals and axillary region.
Each hair follicle is surrounded by a small sebaceous gland. They secrete an oily substance known as sebum. Sebum is secreted in response to contraction of the arrector pili muscle. Sebum contains triglyceride, protein, cholesterol and some electrolytes. Sebum makes the hair more flexible and hydrated.



Sweat Glands

Sweat glands (sudoriferous glands) are also located in the dermis. There are two types of sweat glands. Apocrine sweat glands secrete their substances into the hair follicles and can develop an odour. The odour can increase because the secretion acts as a nutrient for bacteria that enhance the smell. Apocrine glands begin to secrete substances at puberty and are located in the axilla and genital regions.
Eccrine sweat glands secrete their substances directly onto the surface of the skin. They are coiled tubular glands that secrete a substance that mostly consists of water with a few electrolytes and a peptide with antibiotic properties. The eccrine sweat glands primary function is to help to regulate body temperature. Sweat can evaporate and carry away heat. The sweat also excretes water and electrolytes.

Nails



Nails...what an important extension of the skin they are. Actually, they're an extension of the stratum lucidum, the clear layer of the dermis. They consist of horny flattened cells which have undergone a process of keratinization; this is what makes the nail hard. The visible part of the nail is dead and has no blood supply, no lymph or nerves. All needed nutrients are supplied by the dermis.
The nails exist at the distal portions of the fingers and toes. The nail body is the visible portion of the nail that sits over the nail bed. The nail begins deep in the skin proximal to where it is seen. It extends distally to beyond an area of thickened epidermis called the hyponychium. The nail begins to grow at the nail root which is close to the bone. A portion of the superficial epidermis (stratum corneum) extends over the proximal portion of the nail forming the eponychium or cuticle. Blood vessels deep to the nail give it a pink colour. These vessels may be obscured leaving a white area known as the lunula.
Facts about nails:

- Nails begin to grow long before birth – before the foetus is four months.
- Growth rate is individual from person to person, and from nail to nail. The index fingernail grows faster than all the others.
- Fingernails grow faster than toenails.
- Your nails grow faster in the summer when cells divide quicker when exposed to the sun's ultraviolet rays.

- Good sources to nourish your nails: calcium and protein.

The keratinized cells that are pushed from the root to the distal portions. The nails can reflect health problems. Some of these include:

- Bluish nails = circulatory problems.
- White nail = anaemia.
- Pigmented spot under nail = possible melanoma.
- Horizontal grooves = malnutrition.
- Clubbing = heart, lungs, liver problems.
- Red streaks = rheumatoid arthritis, ulcer, high blood pressure.
- Spoon nails = iron deficiency anaemia.

Common Pathologies of Skin, Hair & Nails

Sebaceous glands disorders

Acne vulgaris – chronic inflammatory disorder of the sebaceous glands.

Rosacea – facial chronic inflammatory disease where the skin looks abnormally red.

Sebaceous cysts – round lesion which develops from sebaceous glands, usually on the face, neck, scalp or back.

Seborrhoea – overactivity of the sebaceous glands characterised by excessive secretion of sebum or an alteration in its quality, resulting in an oily coating, crusts, or scales on the skin. In infants, this is called cradle cap.

Hyperhidrosis – excessive sweat production, usually affecting hands, feet and armpits.

Bacterial infections

Boils – an inflamed nodule which forms a pocket of bacteria at the base of a hair follicle or a skin lesion.

Conjunctivitis – bacterial infection of the conjunctiva of the eye.

Folliculitis – bacterial infection in the hair follicles of the skin.

Stye – acute inflammation of a gland at the base of an eyelash.

Viral infections of the skin

Herpes simplex – cold sores, usually forms on the face or around the mouth.

Herpes zoster – shingles, a painful infection in the sensory nerves, caused by the virus that also causes chickenpox.

Warts – a benign growth caused by an infection with human papillomavirus (HPV).

Fungal infections

Ringworm – fungal infection of the skin.

Tinea capitis – a type of ringworm on the scalp.

Tinea pedis – better known as Athlete's foot. A highly contagious fungal infection.

Infestation disorders of the skin

Pediculosis – lice

Scabies – contagious parasitic skin condition caused by female mites.

Pigmentation disorders

Albinism – an inherited condition where pigments are absent. The hair is white, and eyes and skin are pink.

Chloasma – a pigmentation disorder with irregular increased pigmentation, often on the face.

Ephelides – better known as freckles.

Lentigo – commonly known as liver spots.

Naevus – birthmarks or malformations of the skin; port wine stain, spider naevi and strawberry naevi are some of the more common ones.

Vitiligo – lack of pigmentation where the basal cells stop producing melanin.

Inflammatory skin conditions

Contact dermatitis – caused by an irritant that causes the skin to become red, dry and inflamed.
Eczema – from mild to chronic, this condition causes itchiness and redness with small blisters that can be dry or wet.
Psoriasis – chronic inflammatory skin condition.
Seborrhoeic dermatitis – mild to chronic inflammatory disease in hairy areas with sebaceous glands.
Auto-immune disorders of the skin
Systemic lupus erythematosus (SLE) – chronic inflammatory disease of the connective tissues. Affects skin as well as internal organs.

Module Three: The Skeletal System

Part 1: Functions of the Skeleton

Learning objectives

In this module, you will learn:

- Function of the skeleton.
- Structure of bone.
- Growth and development of bone.
- Different types of bones in the body.
- Different types of joints and their range of movement.

Introduction

Your body is made up of 206 individual bones, forming the framework for your body. Bones provide support and protect the body and must be linked together to facilitate movement and protection. The connecting links are the joints. Joints have two main purposes: they hold bones together with the help of ligaments, making the joint stable and they give added flexibility, facilitating movement, assisted by muscles and tendons.

Functions of the skeleton

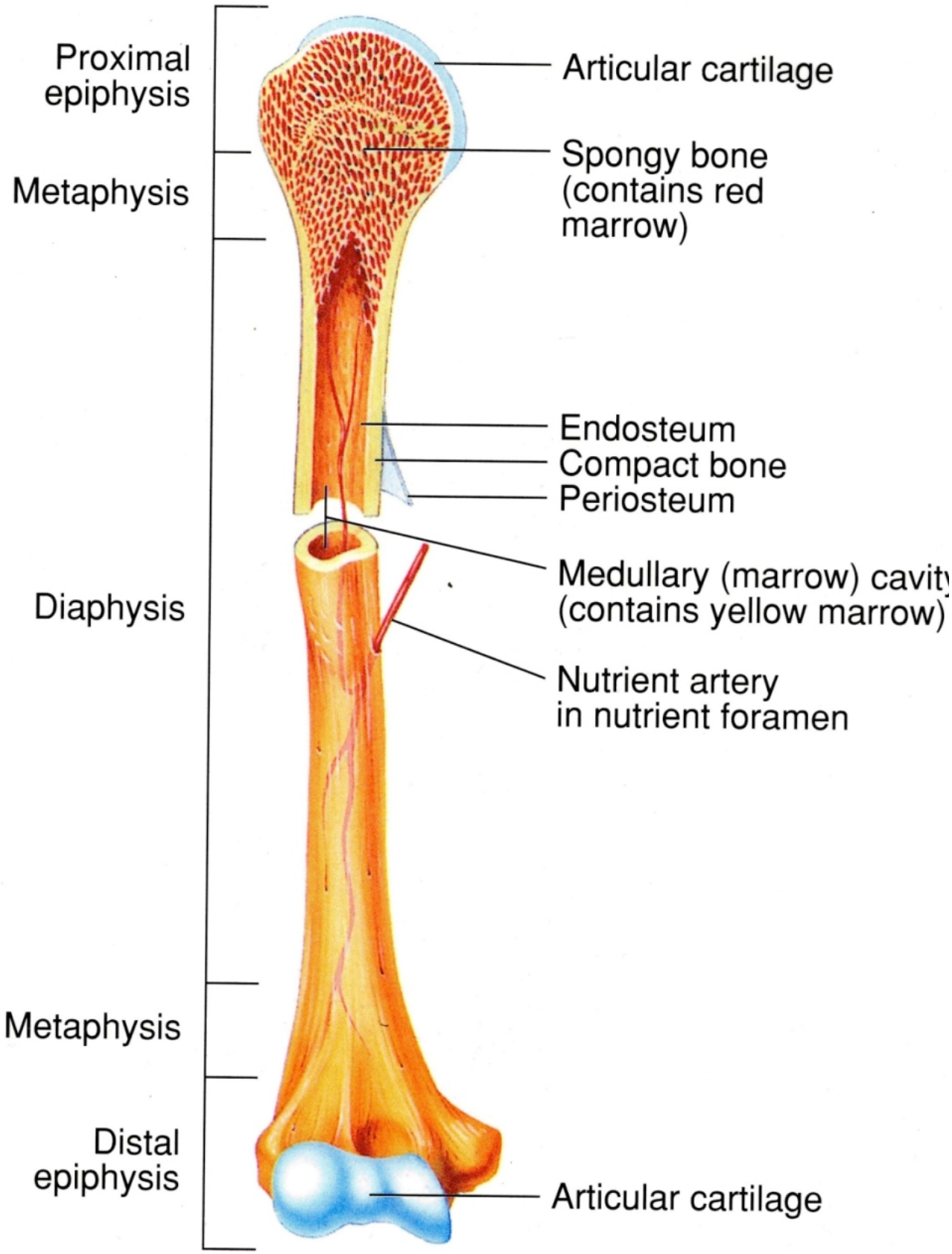
Support – without the skeleton, you just wouldn't be able to stand up. The vertebral column, the pelvis, feet and legs support all the weight of the body.
Shape – the bones shape structures like the skull, thorax and the limbs.
Protection – vital organs and delicate tissue are safely covered; the rib cage protects the heart and lungs, and the vertebral column protects the spinal cord.
Anchor – attachment for muscles and tendons.
Movement – a coordinated effort between muscles, joints and bones, where the bones are the levers for the muscles.
Blood cell formation – formed deep down in the red bone marrow of the cancellous bone.
Mineral store – the skeleton is your reservoir form minerals like calcium, released when needed for muscle contraction and conduction of nerve impulses.

Bone structure

Fully developed bone is one of the hardest types of connective tissue in the body and consists of water, calcium salts and organic matter. Bone tissue is a living tissue made from cells called osteoblasts.
There are two types of bone tissue: compact and cancellous. All bones consist of both types, but the amount of each varies according to the type of bone.

Compact (dense) bone

This is the main shaft of long bones and the outer layer of all other bones. It protects the spongy bones and gives a firm framework for both bones and body. Compact bone cells are called osteocytes are located in concentric rings around the central canal (Haversian canal) in which blood, lymphatic vessels and nerves pass through.



Cancellous (spongy) bone
This lighter bone has a spongy, open appearance and is located at the ends of long bones and in the centre of other bones. There is no Haversian canal; instead, it consists of web-like structures which are filled with red bone marrow separated by thin bones (the

web structure). There are blood vessels through every layer of cancellous bone, distributing nutrients and oxygen.

Bone marrow

There are two types of bone marrow, yellow and red.

Yellow marrow is mostly found in the central cavities of long bones.

Red marrow manufactures red blood cells and is found at the end of long bones and at the centre of other bones in the thorax and pelvis.

Bones are covered with a thin membrane of connective tissue, called the periosteum, except at the surfaces of the joints. The outer layer of the periosteum is densely populated by a large number of blood vessels. The inner layer has fewer blood vessels and contains osteoblasts. Muscles, tendons and ligaments attach to the periosteum.

Development of bone

The process by which bone is developed is called *ossification*. Foetal bones are made of cartilage rods that are changed by ossification into bone as the child develops and grows. This process starts in the embryo towards the end of the second month and is complete at about the age of 25.

There are three stages of ossification:

- Cartilage forming cells, chondrocytes, enlarge and arrange themselves in rows similar to the shape of the bone they will eventually become.
- Calcium salts are added by special bone-building cells, osteoblasts.
- Another set of cells, osteoclasts, known as cartilage-destroying cells, starts an antagonistic action, allowing for the absorption of any unwanted bone.

It's a finely tuned balance by which the activity of osteoblasts and osteoclasts help maintain the formation of normal bone. *Osteocytes* are mature bone cells, maintaining bones throughout your lifetime.

Cartilage

This is a dense connective tissue consisting of collagen and elastin fibres housed in a strong, gel-like substance. A durable and flexible type of tissue, which cushions and acts as a shock absorber, preventing direct conduction to the bones.

There are three types of cartilage:

- Hyaline – covers articular bone surfaces
- Fibrous – strong rigid form of cartilage in the space between the spinal discs
- Elastic – a flexible type of cartilage in the auditory canal in the ear

There is no blood supply to the cartilage, which therefore doesn't repair or renew itself as easily as bone.

Ligaments

These are dense, flexible and strong bands made from white fibrous connective tissue, linking bones together at joints. They are flexible but not elastic giving strength to the joint allowing for free and safe movement for the bones.

Tendons

Tendons are connective tissue of white, fibrous cords attaching muscles to the periosteum of a bone (layer of connective tissue on the outside of the bone). Tendons give the bones the ability to move when skeletal muscles contract.

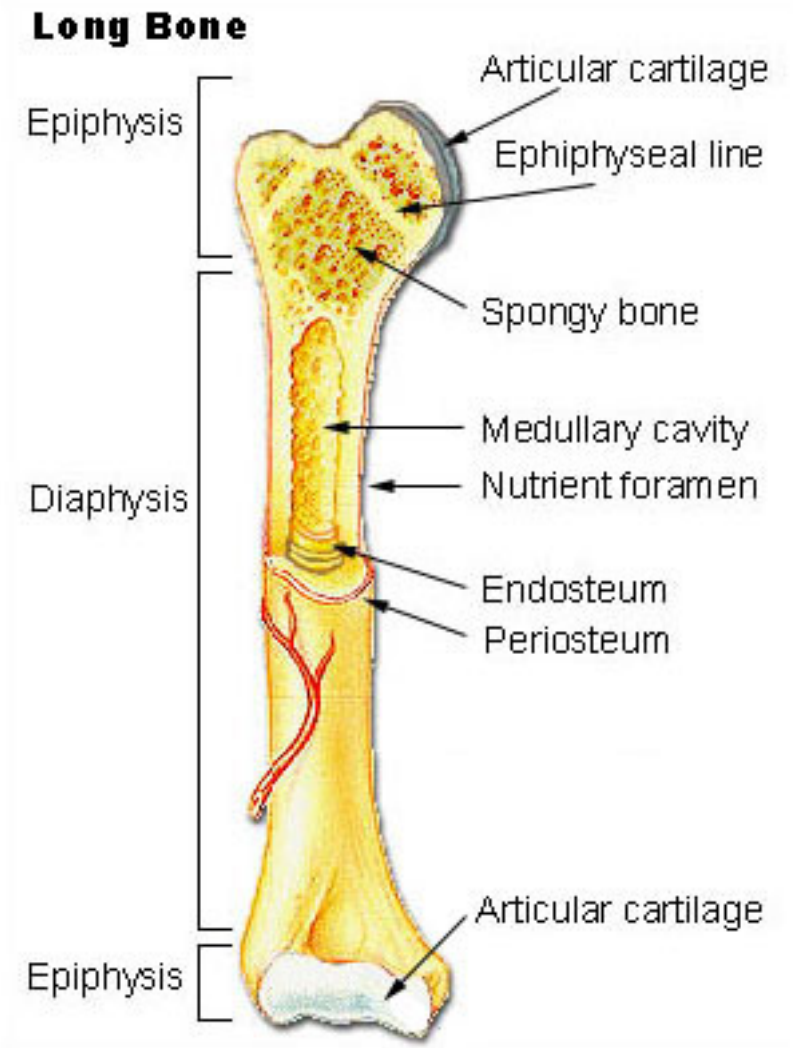
Part 2: Types of Bones

The shape of bones determines their classification:

- Long bones
- Short bones
- Flat bones
- Irregular bones

- Sesamoid bones

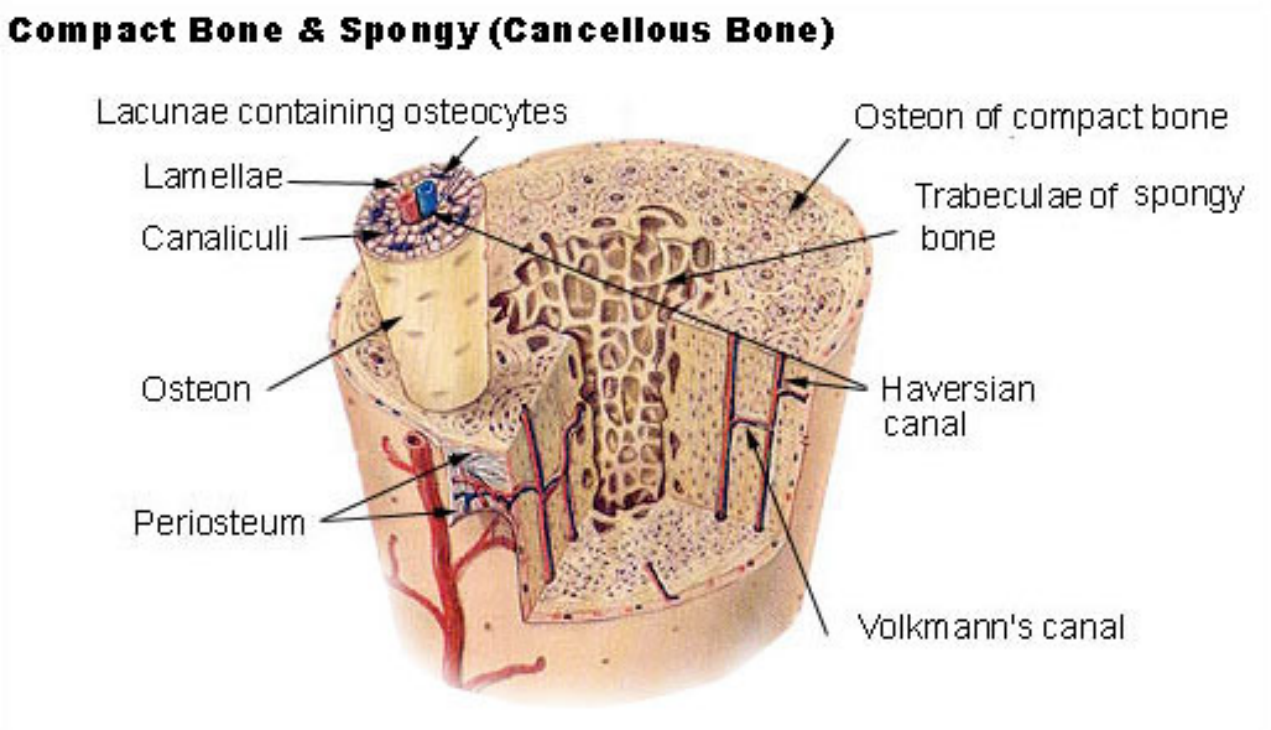
Long bones



Long bones grow primarily by elongation of the diaphysis (the central shaft), with an epiphysis at each end of the growing bone. The ends of epiphyses are covered with hyaline cartilage (articular cartilage). When growth stops, the epiphyses fuse to the diaphysis, thus obliterating the intermediate area known as the epiphyseal plate or growth plate. The long bones in the body are as follows:

- Legs: The femur, tibia, and fibula.
- Arms: The humerus, radius, and ulna.
- The clavicles or collar bones.
- Metacarpals, metatarsals, phalanges.

The outside of the bone consists of a layer of connective tissue called the periosteum, as mentioned above. The outer shell of the long bone is compact bone, below which lies a deeper layer of cancellous bone (spongy bone), as shown in the following figure. The interior part of the long bone is called the medullary cavity; the inner core of the bone cavity is composed of marrow.

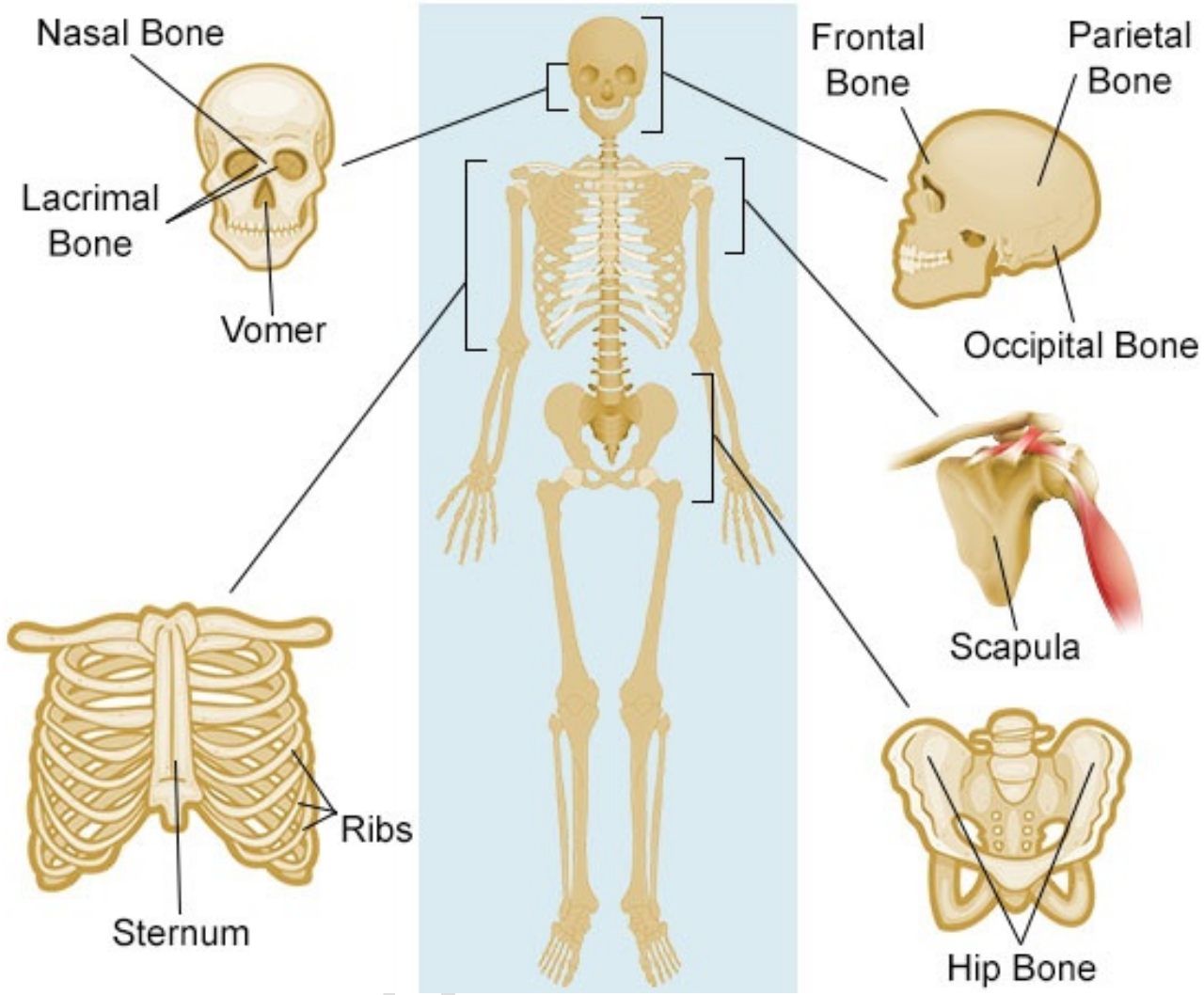


Short bones

Short bones are often cube-shaped with roughly equal width and length. Wrist and ankle bones are examples of short bones.

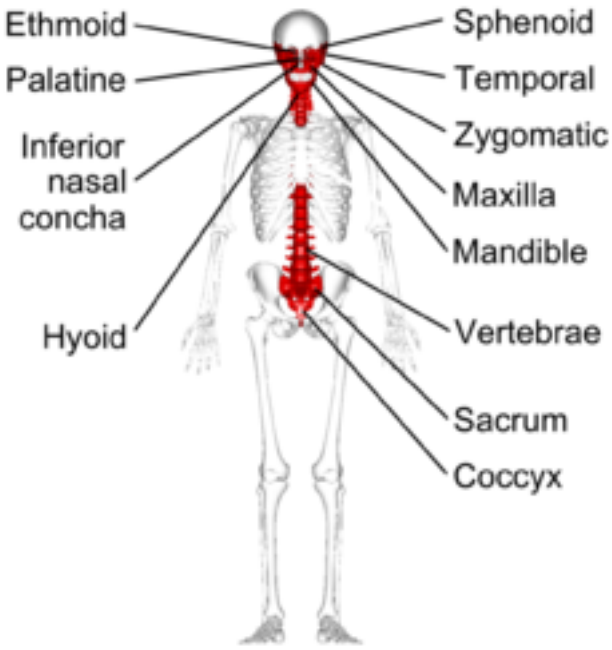
Flat bones

Flat bones are plate-like with broad surfaces:



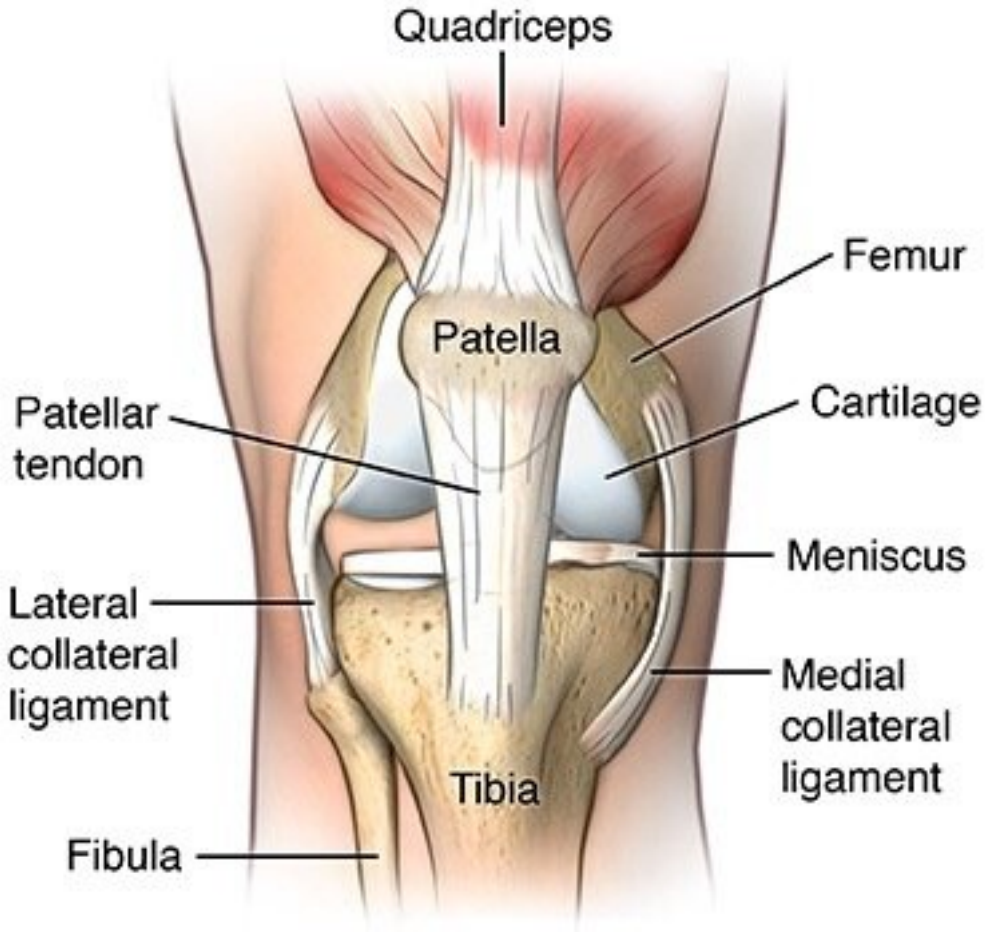
Irregular bones

The name is quite self-explanatory – different shapes, for example, your vertebrae and some of the facial bones.



Sesamoid bones

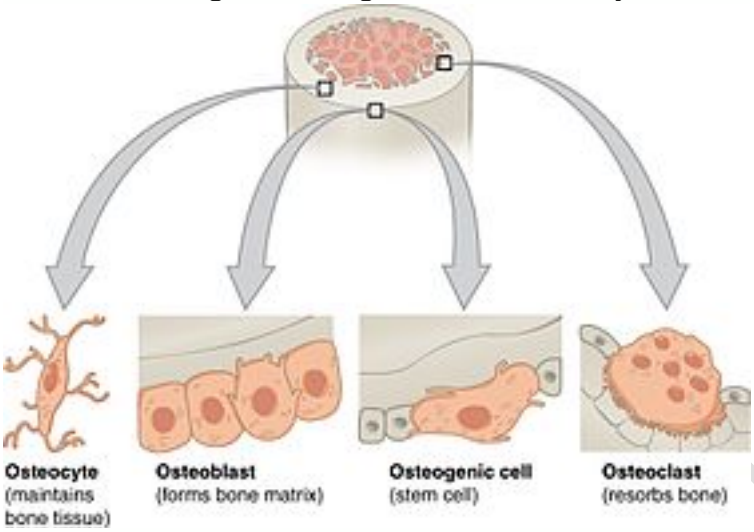
A sesamoid bone is a small, round bone that, as the name suggests, looks a little like a sesame seed. These bones form in tendons (the tissue that connects bones to muscles) where a significant amount of pressure is put on the joint. The sesamoid bones protect tendons by helping them overcome the force of the pressure.



Sesamoid bones vary in number and placement from person to person but are typically found in tendons associated with the feet, hands, and knees. The patella (kneecap) is the only sesamoid bone every person has in common.

Bone Cells and Tissue

Bone contains a small number of cells embedded in a matrix of collagen fibres that provide a surface for inorganic salt crystals to attach to. These salt crystals form when calcium phosphate and calcium carbonate combine to create hydroxyapatite, which incorporates other inorganic salts like magnesium hydroxide, fluoride and sulphate as it calcifies on the collagen fibres. The hydroxyapatite crystals make bones hard and strong, while the collagen fibres give them flexibility so that they are not brittle.



Although bone cells only constitute a small amount of the bone volume, they are crucial to the function of bones. Four types of cells are found in bone tissue:

- Osteoblasts
- Osteocytes
- Osteogenic cells
- Osteoclasts

The embryo's skeleton consists of fibrous membranes and hyaline cartilage in the early stages of embryonic development. The actual process of bone development, ossification (osteogenesis), begins by the sixth or seventh week of embryonic life.

There are two osteogenic routes—intramembranous ossification and endochondral ossification—but bone is the same whichever way it is produced.

Cartilage Templates

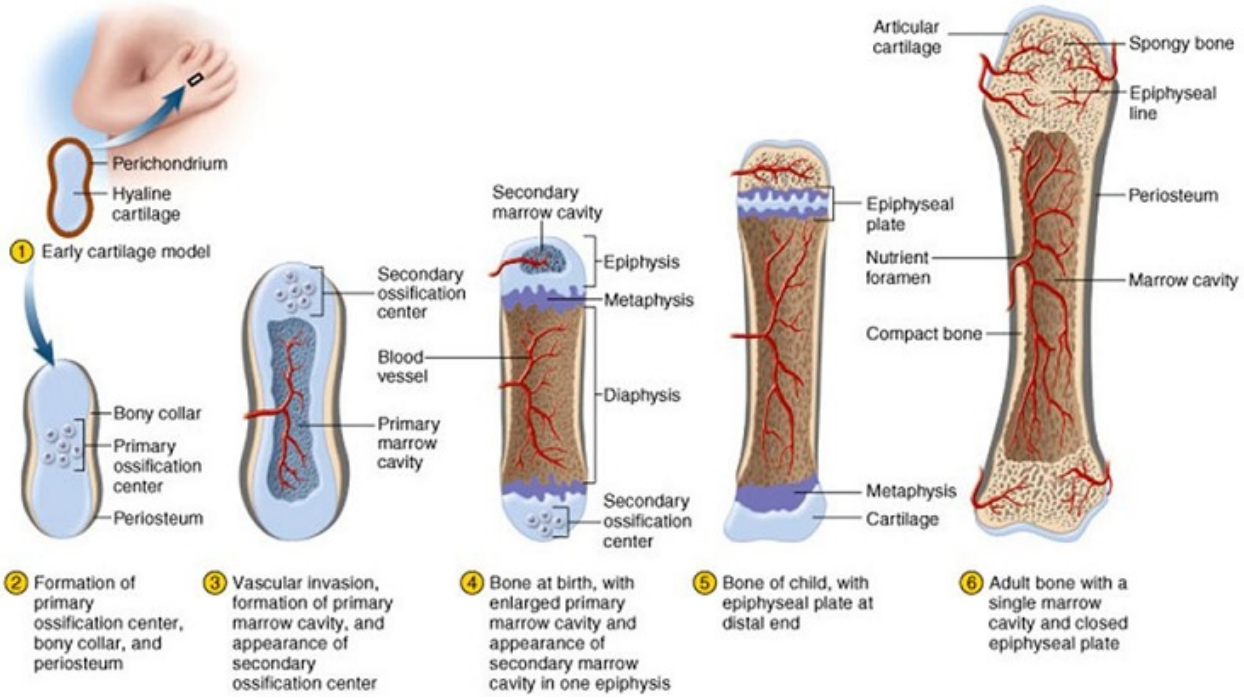
Bone is a replacement tissue; that is, it uses a model tissue on which to lay its mineral matrix down. For skeletal development, cartilage is the most common template.

As the foetus develops, a framework is laid down that determines exactly where bones will form. This framework is a flexible, semi-solid matrix produced by chondroblasts and is made up of hyaluronic acid, chondroitin sulphate, collagen fibres, and water. As the matrix surrounds and isolates chondroblasts, they are called chondrocytes.

Unlike most other connective tissues, cartilage has no blood vessels supplying nutrients and removing metabolic waste. Instead, all of those functions are carried out by diffusion through the matrix. This is why damaged cartilage does not readily repair itself as most other tissues do.

Throughout foetal development and further, into childhood growth and development, bone forms on the cartilaginous matrix. By the time a foetus is born, most of the cartilage has been replaced with bone. Some more cartilage will be replaced during the course of childhood, and some cartilage will remain in the adult skeleton.

Part 3: Intramembranous Ossification



During intramembranous ossification, compact and spongy bone develops directly from sheets of undifferentiated (mesenchymal) connective tissue. The flat bones of the face, most of the bones in the cranium and the clavicles (collarbones) are formed via intramembranous ossification.

The process begins when mesenchymal cells in the embryonic skeleton group together and begin to separate into specialised cells. Some of these cells will change into capillaries, while others will become osteogenic cells and then osteoblasts. Although they will ultimately be distributed by the formation of bone tissue, early osteoblasts appear in a cluster called an ossification centre.

The osteoblasts secrete osteoid, which is the uncalcified matrix, this then calcifies within a few days as mineral salts are deposited on it, locking the osteoblasts within.

Once enmeshed, the osteoblasts become osteocytes. As osteoblasts transform into osteocytes, osteogenic cells in the surrounding connective tissue become new osteoblasts. Osteoid (semi-liquid bone matrix) secreted around the capillaries become a trabecular matrix, while osteoblasts on the surface of the spongy bone become the periosteum. The periosteum then creates a protective layer of compact bone outermost to the trabecular bone. The trabecular bone gathers nearby blood vessels together, which eventually concentrates into red marrow.

Intramembranous ossification begins during foetal development and continues on into adolescence. At birth, the skull and clavicles are not fully ossified and the sutures of the skull aren't fully closed. This allows the skull and shoulders to be flexible and malleable during passage through the birth canal. The last bones to ossify via intramembranous ossification are the flat bones of the face, which reach their adult size at the end of the adolescent growth spurt.

Endochondral Ossification

In endochondral ossification, bone develops by replacing hyaline cartilage. Cartilage does not become bone. Instead, cartilage serves as a template to be completely replaced by new bone. Endochondral ossification takes much longer than intramembranous ossification. Bones at the base of the skull and long bones are formed through endochondral ossification.

In a long bone, as an example, at about 6 to 8 weeks after conception, some of the mesenchymal cells separate into chondrocytes (cartilage cells) that form a cartilaginous skeletal substance. Soon after, the perichondrium, a membrane that covers the cartilage, appears.
As more matrix is produced, the chondrocytes in the centre of the cartilaginous model grow in size. As the matrix calcifies, nutrients can no longer reach the chondrocytes. This results in their death and the disintegration of the surrounding cartilage.
Blood vessels move into the resulting spaces, not only increasing the size of the cavities but also carrying osteogenic cells with them, many of which will become osteoblasts. These expanding spaces eventually combine to become the medullary cavity.
As the cartilage grows, capillaries permeate it. These capillaries initiate the change of the perichondrium into the bone-producing periosteum. Here, the osteoblasts form a periosteal collar of compact bone around the cartilage of the diaphysis. By the second or third month of foetal development, bone cell formation and ossification intensifies and creates the primary ossification centre, a region deep in the periosteal collar where ossification begins.
While these profound changes are happening, chondrocytes and cartilage continue to grow at the ends of the bone (the future epiphyses), which increases the length of the bone and at the same time replaces cartilage in the diaphyses. By the time the foetal skeleton is fully formed, cartilage only remains at the joint surface as articular cartilage and between the diaphysis and epiphysis as the epiphyseal plate. This plate is responsible for the longitudinal growth of bones. After birth, this same sequence of events (matrix mineralisation, death of chondrocytes, invasion of blood vessels from the periosteum, and seeding with osteogenic cells that become osteoblasts) occurs in the epiphyseal regions, and each of these centres of activity is known as a secondary ossification centre.

Common Pathologies

Ankylosing spondylitis – systemic joint disease
Arthritis: gout – joint disorder due to the excessive deposition of uric acid crystals accumulating in joints, usually the big toe.
Arthritis: osteoarthritis – breakdown of articulate cartilage; degenerative arthritis
Arthritis: rheumatoid – chronic inflammation of peripheral joints
Bunion – swelling of the joint between the big to a and first metatarsal
Bursitis – inflammation of a bursa
Dupuyteren's contracture – forward curvature of the fingers, usually the ring and little fingers
Fracture – complete or incomplete breakage of a bone. There are six types of fractures:

- Simple fracture, clean break without damage to the skin or tissues
- Compound fracture, open fracture where bone protrudes through the skin
- Comminuted fracture, bone has splintered at the site of impact and smaller bone fragments lie between the two main fragments
- Greenstick fracture, only occurs in children. Partial fracture where one side of the bone is broken and the other side bends
- Impacted fracture, one bone fragment is driven into the other
- Complicated fracture, when a bone fracture damages organs and/or tissues around it

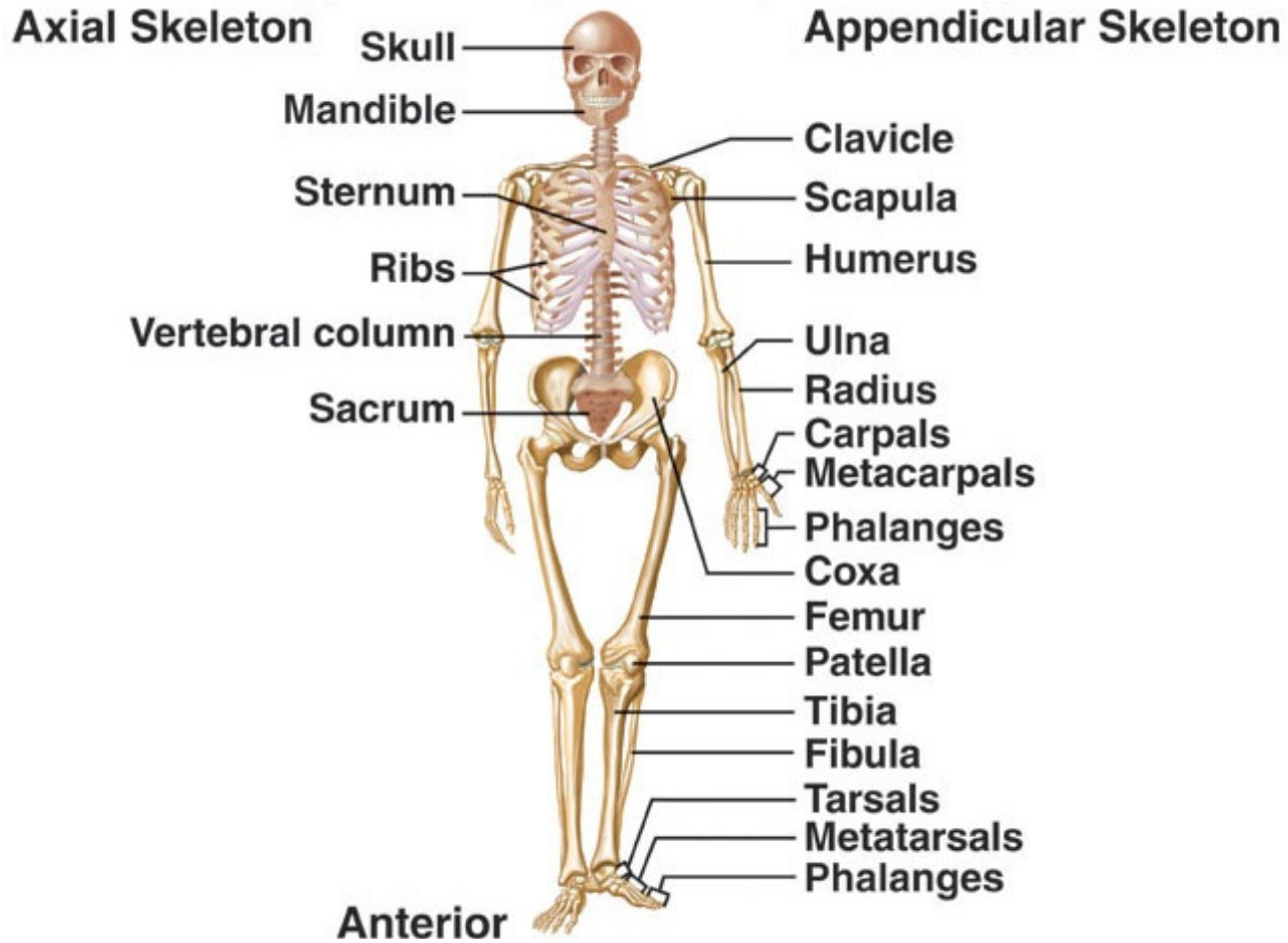
Frozen shoulder (adhesive capsulitis) – chronic condition of the shoulder joint
Osteoporosis – caused by brittle bones, usually due to ageing, but can also be inherited
Spina bifida – congenital defect of the vertebral column
Sprain – injury to a ligament caused by overstretching or tearing

Stress – any factor which affects physical or emotional health. Examples here: poor posture, repetitive strain injuries stiff joints
Synovitis – inflammation of a synovial membrane in a joint
Temporomandibular joint tension (TMJ syndrome) – collection of symptoms and signs produced by disorders of the temporomandibular joint
Whiplash – damage to muscles, joints, ligaments, intervertebral discs or nerve tissues of the cervical region

Module Four: Divisions of the Skeletal System

Part 1: The Axial Skeleton
Learning objectives
In the module, you will learn:
- The structure and function of the axial skeleton.
- The structure and function of the appendicular skeleton.

The axial skeleton

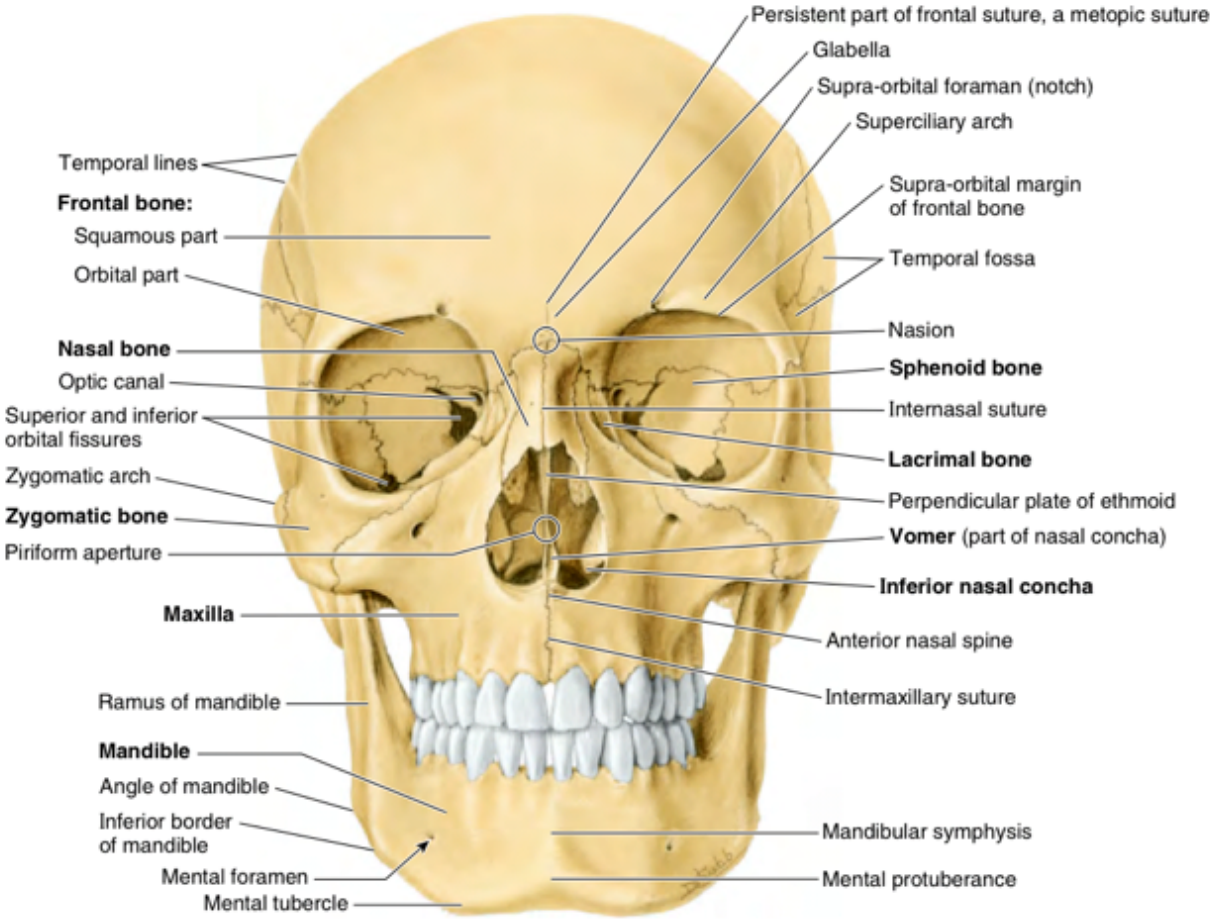


The skeleton is subdivided into two major parts—the axial and appendicular.
The axial skeleton forms the vertical, central part of the body and includes all bones of the head, neck, chest, and back. It serves to protect the brain, spinal cord, heart, and lungs. It also provides the attachment site for muscles that move the head, neck, and back, and for muscles that function across the shoulder and hip joints to move those limbs.
The adult axial skeleton consists of 80 bones, including the skull, the vertebral column, and the thoracic cage. The skull is formed by 22 bones. Also connected to 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 coccyx and the sacrum. The thoracic cage has 12 pairs of ribs and the sternum – the flat bone on the anterior chest.

The skull

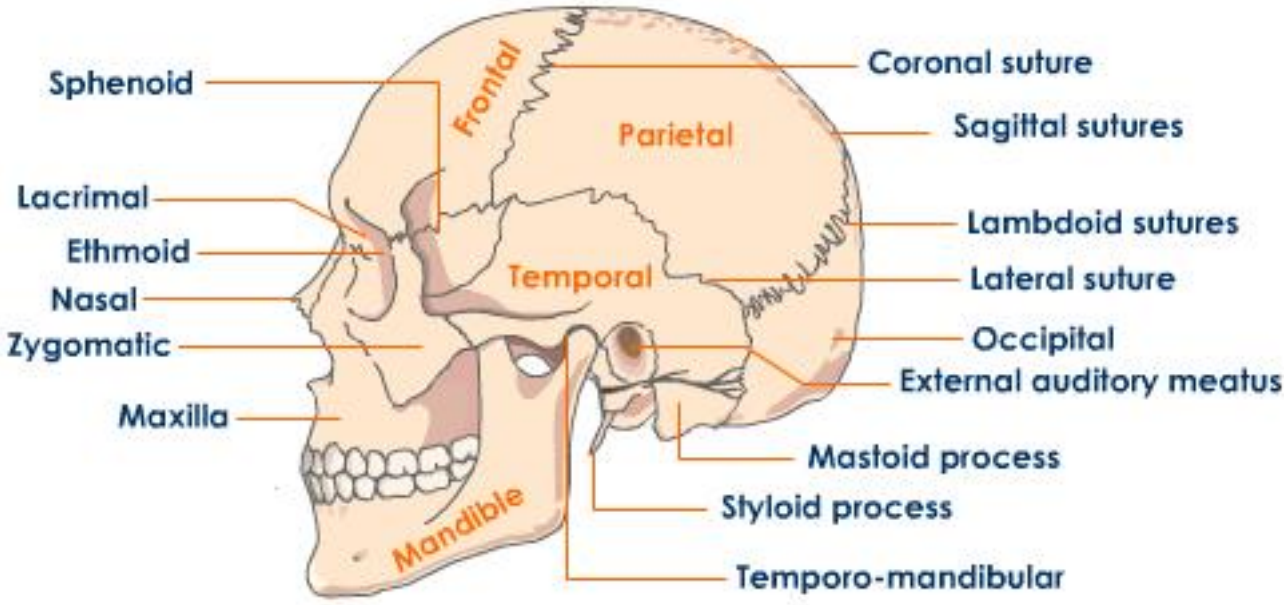
The cranium, or skull, is the skeletal framework of the head that supports the face and protects the brain. It is subdivided into facial bones and brain case, or cranial vault. The facial bones are the basis for the facial structures. They form the nasal cavity, enclose the eyeballs and support the teeth in both the upper and lower jaws. The rounded brain case surrounds and protects the brain and houses the middle and inner ear components.



The adult skull consists of 22 individual bones, 21 of which are immobile and joined into a single unit. The 22nd bone is the mandible (lower jaw), which is the only movable bone of the skull.

Anterior view of skull

The anterior skull comprises of the facial bones and provides the bony support for the eyes and structures of the face. This perspective of the skull is dominated by the openings of the orbits and the nasal cavity. Also seen are the upper and lower jaws, with the teeth.

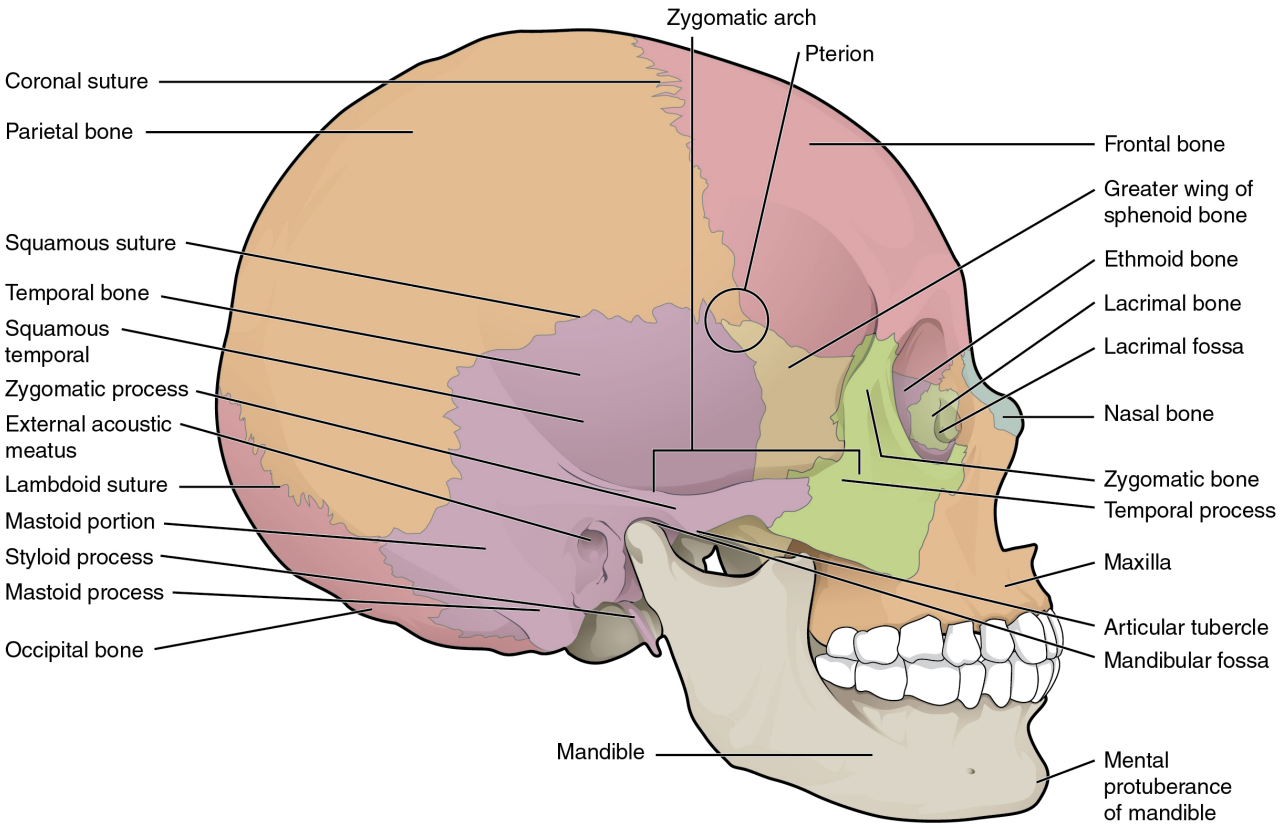


The orbit is the bony socket that contains the eyeball and muscles that move the eyeball or open the upper eyelid. The upper edge of the anterior orbit is the supraorbital margin. Located near the midpoint of the supraorbital margin is a small opening called the supraorbital foramen. This provides for passage of a sensory nerve to the skin of the forehead. Below the orbit is the infraorbital foramen, which is the point of emergence for a sensory nerve that supplies the anterior face below the orbit.

Inside the nasal area of the skull, the nasal cavity is divided into two parts by the nasal septum. The uppermost part of the nasal septum is formed by the vertical plate of the ethmoid bone and the lower part is the vomer bone. Each side of the nasal cavity is triangular in shape, with a wide lower space that becomes more narrow further up. When looking into the nasal cavity from the front of the skull, two bony plates are seen projecting from each wall. The larger of these is the inferior nasal concha, an independent bone of the skull. Located just above the inferior concha is the middle nasal concha, which is part of the ethmoid bone. A third bone plate, also part of the ethmoid bone, is the superior nasal concha. It is much smaller and not visible, above the middle concha. The superior nasal concha is located just to the side of the vertical plate, in the upper nasal cavity.

Part 2: Lateral View of Skull

A side view of the skull is dominated by the large, rounded brain case above, and the upper and lower jaws with their teeth below. Separating these areas is the bridge of bone called the zygomatic arch. The zygomatic arch is the bony arch on the relative side of the skull that spans from the area of the cheek to just above the ear canal. It is formed by the junction of two bony processes: a short anterior component, the temporal process of the zygomatic bone (the cheekbone) and a longer posterior portion, the zygomatic process of the temporal bone, extending forward from the temporal bone. Thus the temporal process (anteriorly) and the zygomatic process (posteriorly) join together, like the two ends of a drawbridge, to form the zygomatic arch. One of the major muscles that pulls the mandible upward during biting and chewing arises from the zygomatic arch.



Right lateral view

On the lateral side of the braincase, above the level of the zygomatic arch, is a shallow space called the temporal fossa. Below the level of the zygomatic arch and deep to the vertical portion of the mandible is another space called the infratemporal fossa. Both the temporal fossa and infratemporal fossa contain muscles that act on the mandible during chewing.

Bones of the brain case

The brain case houses and protects the brain. The interior space that is almost completely occupied by the brain is called the **cranial cavity**. This cavity is bordered superiorly by the rounded top of the skull, which is called the **calvaria** (skullcap), and the lateral and posterior sides of the skull. The bones that form the top and sides of the braincase are usually referred to as the “flat” bones of the skull.

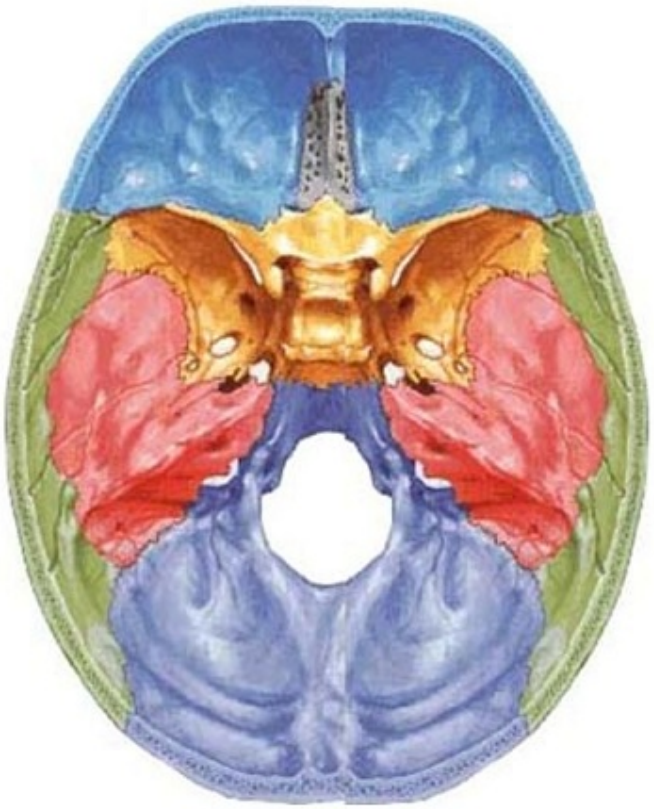
The floor of the brain case is referred to as the base of the skull. This is a complex area that varies in depth and has many openings for the passage of cranial nerves, blood vessels, and the spinal cord. Inside the skull, the base is subdivided into three large spaces:

- **anterior cranial fossa**
- **middle cranial fossa**
- **posterior cranial fossa**

Anterior cranial fossa

Middle cranial fossa

Posterior cranial fossa



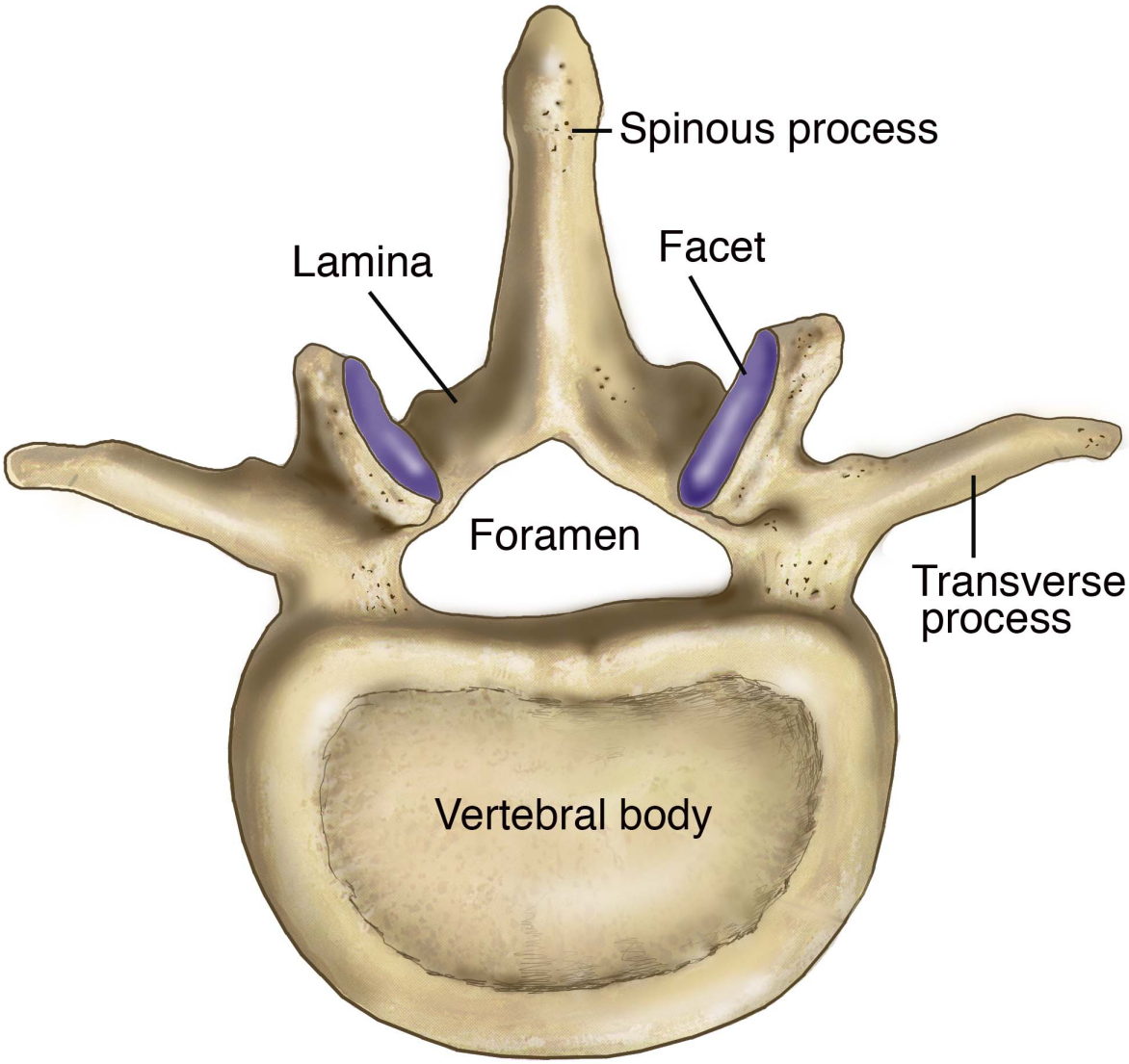
From front to back, they increase in depth. The shape and depth of each fossa correspond to the shape and size of the brain region that each holds.
Fossa = a trench or a ditch.

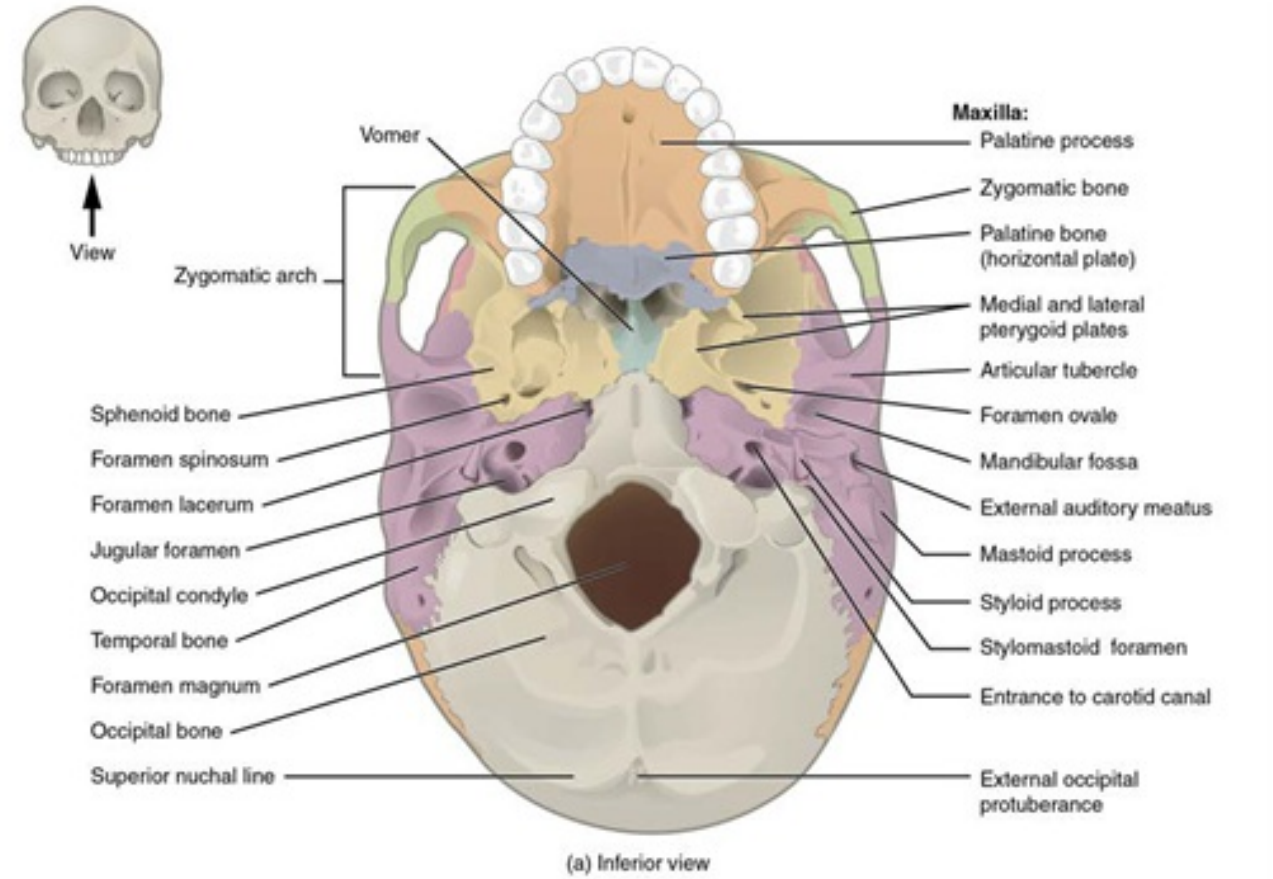
Important landmarks of the temporal bone:

- **External acoustic meatus** (ear canal)—This is the large opening on the lateral side of the skull that is associated with the ear.
- **Internal acoustic meatus**—This opening is located inside the cranial cavity, on the medial side of the petrous ridge. It connects to the middle and inner ear cavities of the temporal bone.
- **Mandibular fossa**—This is the deep, oval-shaped depression located on the external base of the skull, just in front of the external acoustic meatus. The mandible (lower jaw) joins with the skull at this site as part of the temporomandibular joint, which allows for movements of the mandible during opening and closing of the mouth.
- **Articular tubercle**—The smooth ridge located immediately anterior to the mandibular fossa. Both the articular tubercle and mandibular fossa contribute to the temporomandibular joint, the joint that provides for movements between the temporal bone of the skull and the mandible.
- **Styloid process**—Posterior to the mandibular fossa on the external base of the skull is an elongated, downward bony projection called the styloid process, so named because of its resemblance to a stylus (a pen or writing tool). This structure serves as an attachment site for several small muscles and for a ligament that supports the hyoid bone of the neck.
- **Stylomastoid foramen**—This small opening is located between the styloid process and mastoid process. This is the point of exit for the cranial nerve that supplies the facial muscles.

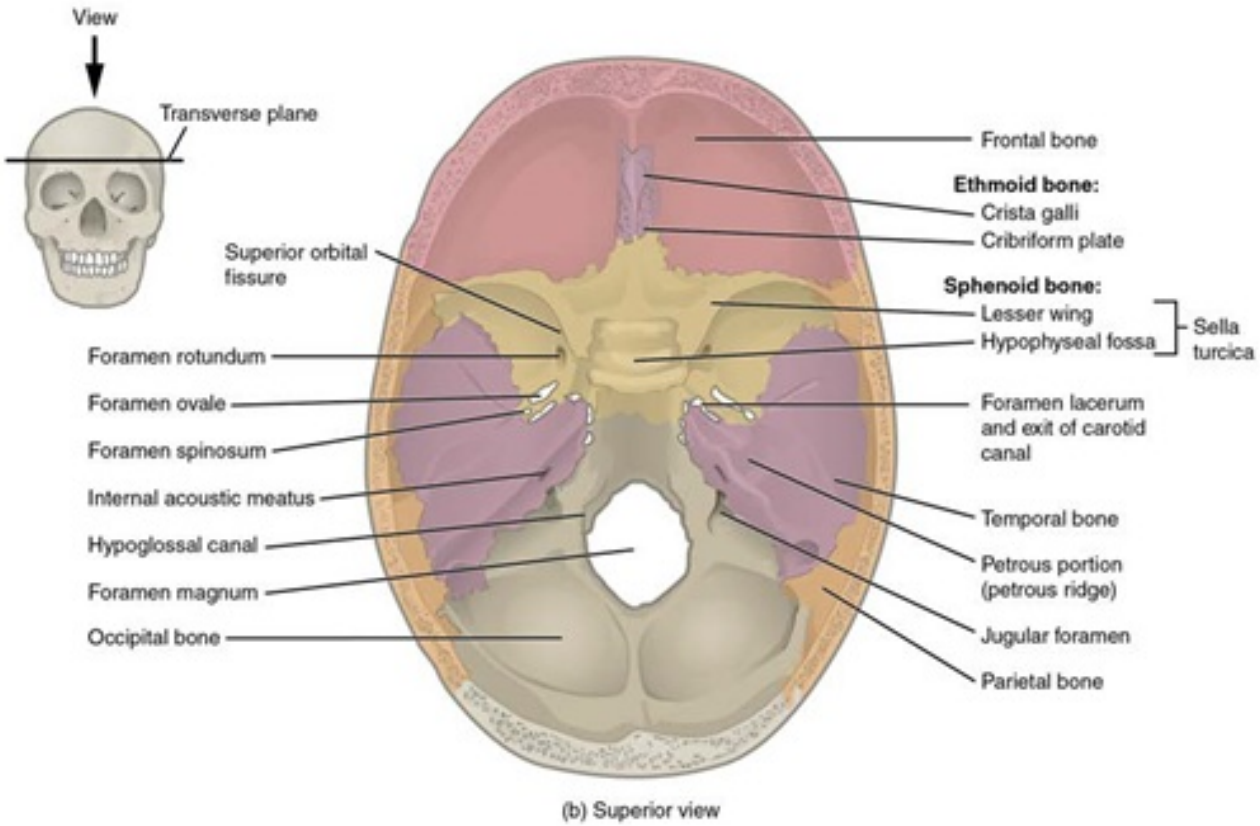
- **Carotid canal**—The carotid canal is a zig-zag shaped tunnel that provides a passage through the base of the skull for one of the major arteries that supplies the brain. Its entrance is located on the outside base of the skull, anteromedial to the styloid process. The canal then runs anteromedially within the bony base of the skull and then turns upward to its exit in the floor of the middle cranial cavity above the foramen lacerum.

Parts of a Vertebrae





(a) Inferior view



(b) Superior view

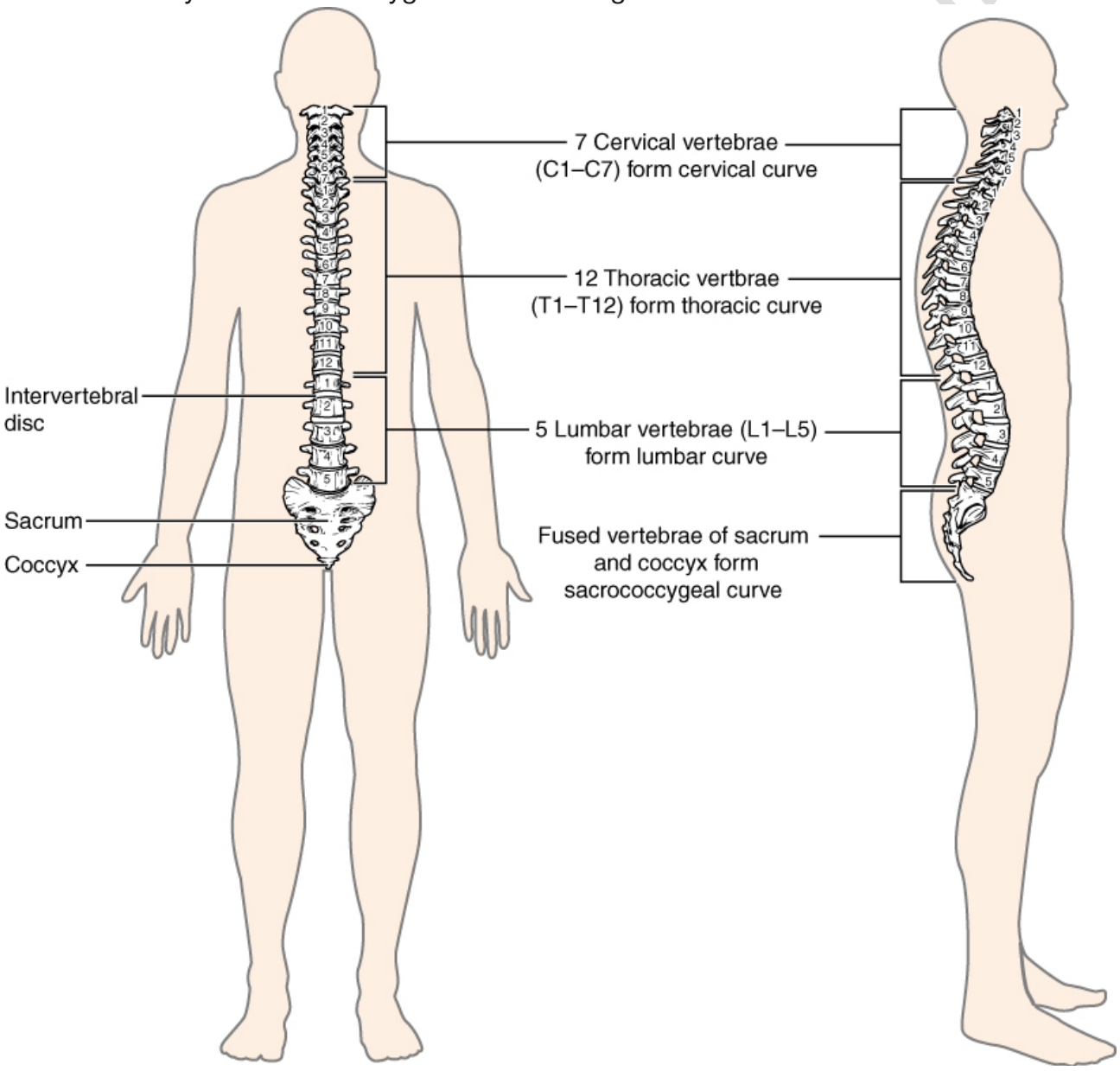
Vertebral column (spine)

The vertebral column, or spine, is made up of a vertical series of bony blocks called vertebrae. These vertebrae are joined together in such a way as to form a semi-flexible rod. The spine is the central support for the trunk, yet allows trunk movements. Anatomically and functionally, a typical vertebra is constructed of two major parts:

- The vertebral body is a drum-shaped cylindrical mass. Its superior and inferior surfaces are flat. Its function is primarily weight-bearing.
- The neural arch extends posteriorly, arching over and protecting the spinal cord of the central nervous system. From the neural arch are several processes. These processes serve as attachment areas for the trunk muscles. They also act as levers during various trunk motions.

The vertebral column has 32-33 vertebrae, one on top of the other. These vertebrae are arranged in regions. The vertebrae of each region have a characteristic shape. The regions are as follows:

- Cervical (neck) region, with seven cervical vertebrae
- Thoracic (chest) region, with 12 thoracic vertebrae
- Lumbar (low back) region with five lumbar vertebrae
- The sacrum, which is a bony fusion of five sacral vertebrae
- The coccyx with 3-4 coccygeal vertebrae together



The vertebrae are held together in two ways:

- The intervertebral disc holds the bodies of adjacent vertebrae together. The intervertebral disc is a fibrous ring with a soft centre. This disc allows the vertebral

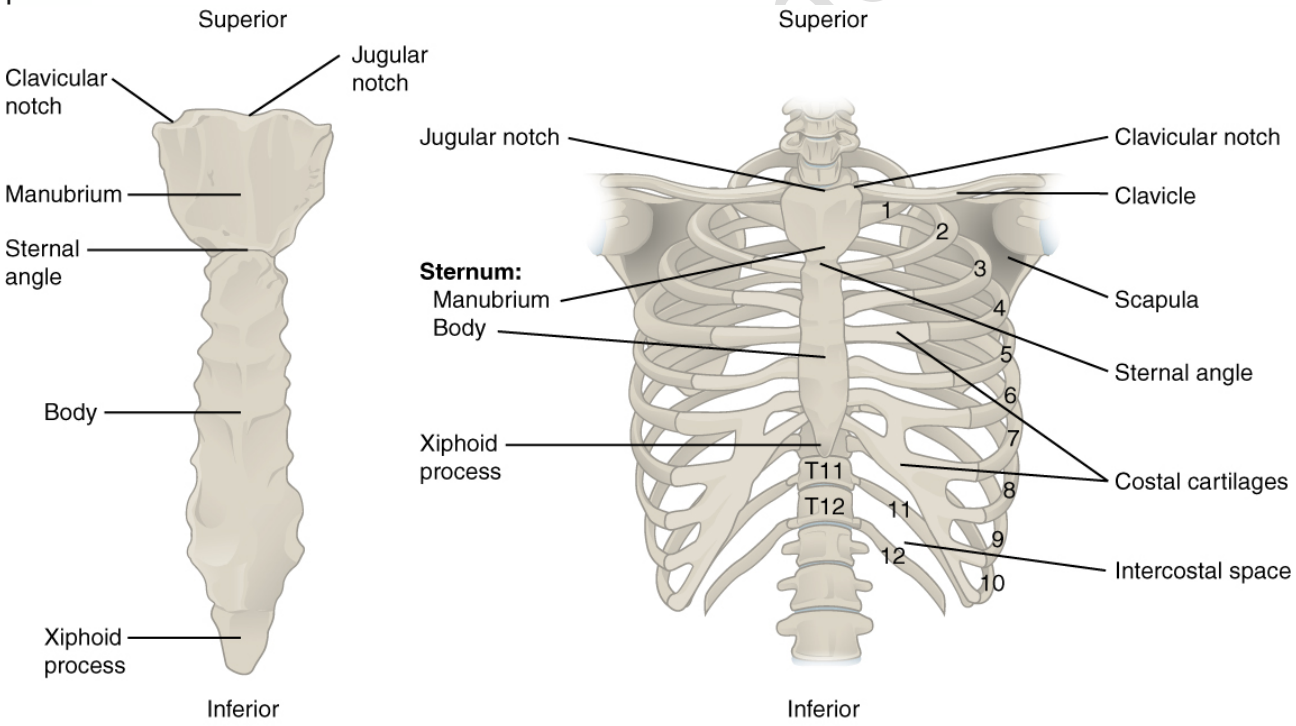
bodies to move on one another. This joint between the vertebral bodies is a plane-type joint.

- The various parts of adjacent vertebrae are held together by ligaments. A ligament is a dense FCT structure which extends from bone to bone. These ligaments extend along the vertebral column from the base of the skull all the way down to the coccyx.

The spine has four curvatures in the adult human. In the cervical region and the lumbar region, the spine curves forward. In the thoracic (chest) region and the sacrococcygeal (pelvic- sacrum and coccyx) region, the spine curves backwards.
When you examine the back of a person by sight and feel (palpation), certain landmarks can be observed:

- At the upper shoulder region in the midline, a knob can be seen and felt. This is the tip of the spinous process of the seventh cervical vertebra. Since this is the first vertebra from the top that can be easily palpated, this bony landmark is called the vertebra prominens.
- From the vertebra prominens down to the beginning of the sacrum, one can feel the tip of the spinous process of each vertebra.

The thoracic cage (rib cage)
The rib cage forms a protective enclosure for the vital organs contained within the thorax (chest) such as the heart and lungs. It also allows the movements of breathing to take place.



(a) Anterior view of sternum (b) Anterior view of skeleton of thorax

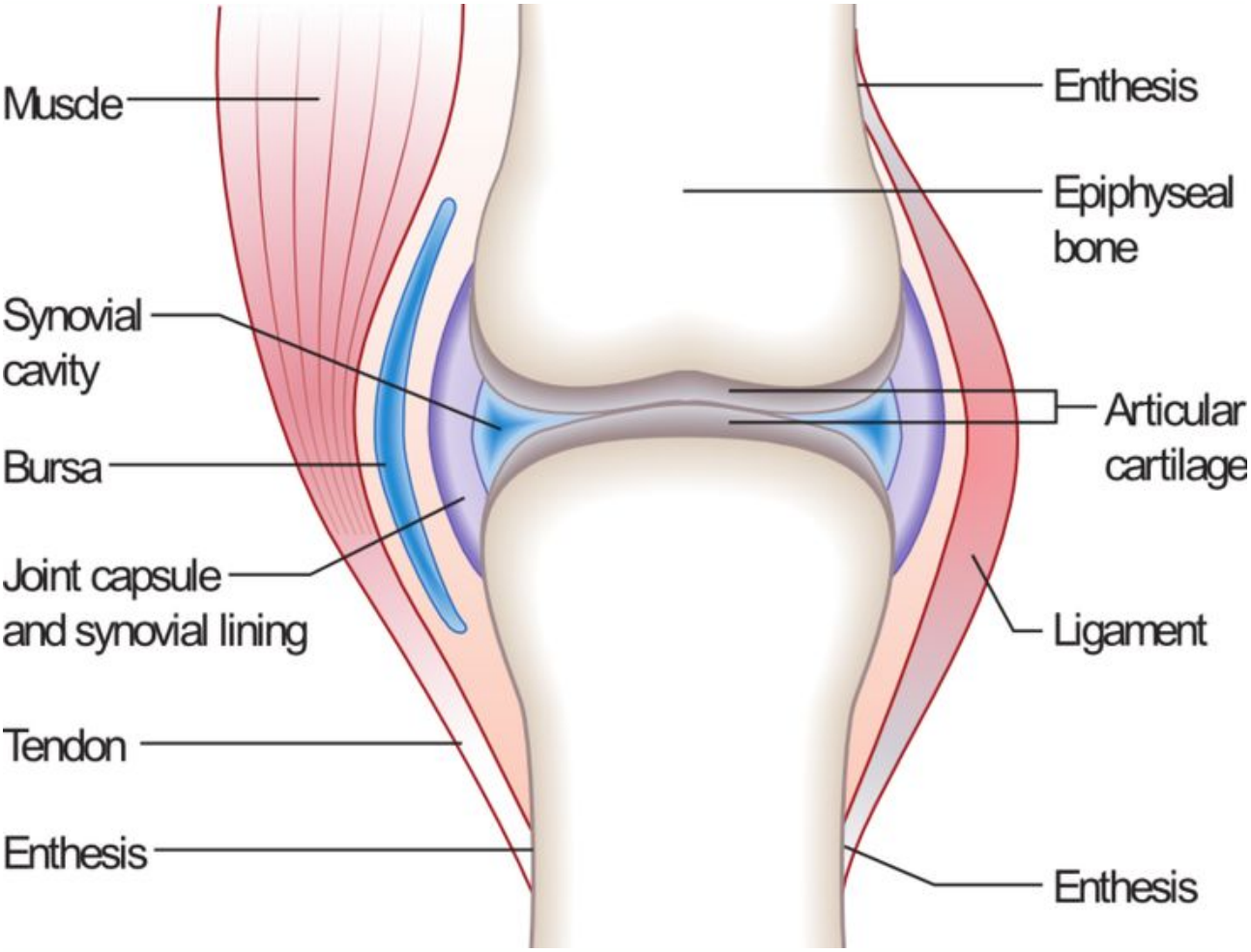
The sternum lies in the midline of the thorax anteriorly. It is made up of three parts: The manubrium at the top, the body as the main part, and the xiphoid process below. On the top of the manubrium is the jugular (sternal) notch, a common landmark.
The junction between the manubrium and the body is a joint called the sternal angle. This sternal angle is an important landmark clinically because the second rib attaches to the sternum at this junction.
The rib cage consists of the 12 thoracic vertebrae, 12 pairs of ribs, and the sternum. Each rib is curved laterally from back to front. All 12 pairs of ribs are attached posteriorly to the thoracic vertebrae. The upper six pairs of ribs are attached directly to the sternum by their

costal cartilages. The seventh through tenth pairs of ribs are attached indirectly to the sternum through their costal cartilages (by attaching to the costal cartilage of the rib above). Rib pairs 11 and 12 do not attach to the sternum. Instead, they are embedded in the trunk wall muscles.

Part 3: Joints

A joint, or articulation, is the location where two or more bones meet. Joints are classified according to the kind of material holding the bones together and the relative freedom and kind of motion at the particular joint.

- Fibrous joints. Varying degrees of motion, from none to some, are possible in fibrous joints.
- Syndesmosis. When the bones are held together by fibrous connective tissue (FCT), the joint is referred to as a syndesmosis. Example: The inferior tibiofibular joint.
- Suture. When the bones are quite close together with a minimum of FCT, the joint is known as a suture. Example: the joints between the cranial bones.
- Bony joints. Should the bones be united by bony material, the joint is referred to as a synostosis. Example: The frontal bone. (The frontal bone of the skull is actually a bony fusion of two bones. Approximately 10 percent of the time, this fusion fails to take place; the original suture between the bones remains and is called a metopic suture.)
- Cartilaginous joints. These are also non-movable joints.
- Synchondrosis. A cartilaginous joint in which the bones are held together by hyaline cartilage. Example: Epiphyseal plate.
- Symphysis. A cartilaginous joint in which the bones are held together by a disc of fibrocartilage. Example: Pubic symphysis.
- Synovial joints. In the synovial type of joints, the bones move on one another so as to allow various motions of the body parts. The "ovial" part of the name refers to the fact that the fluid substance seen in this type of joint appeared to the old anatomists to be like raw egg white (ovum = egg).



A "typical" synovial joint is one which has parts common to all of the synovial joints. In a sense, it is imaginary. It is not actually a specific synovial joint. It is a composite. The "typical" synovial joint has the following parts:

- Bones are the levers of motion. They are the site of attachment for skeletal muscles.
- Articular cartilages. The "contact" points of the bones are usually covered with a layer of lubricated cartilage. Where these cartilages end, the synovial membranes begin. Cartilages provide a smooth surface to reduce friction.

Classification of synovial joints

Synovial joints are further classified according to the kind of motion and the number of axes of motions used.

Uni-axial synovial joints

- In uni-axial synovial joints, motion occurs in only one plane. The joints of the fingers (interphalangeal) flex and extend in the sagittal plane. These are commonly referred to as hinge joints.
- If a single rotatory (rotational) motion occurs around a post-like structure, the joint is a pivot joint. The atlas vertebra rotating around the dens (tooth-like projection) of the axis vertebra at the top of the neck (base of the skull) is a pivot joint.

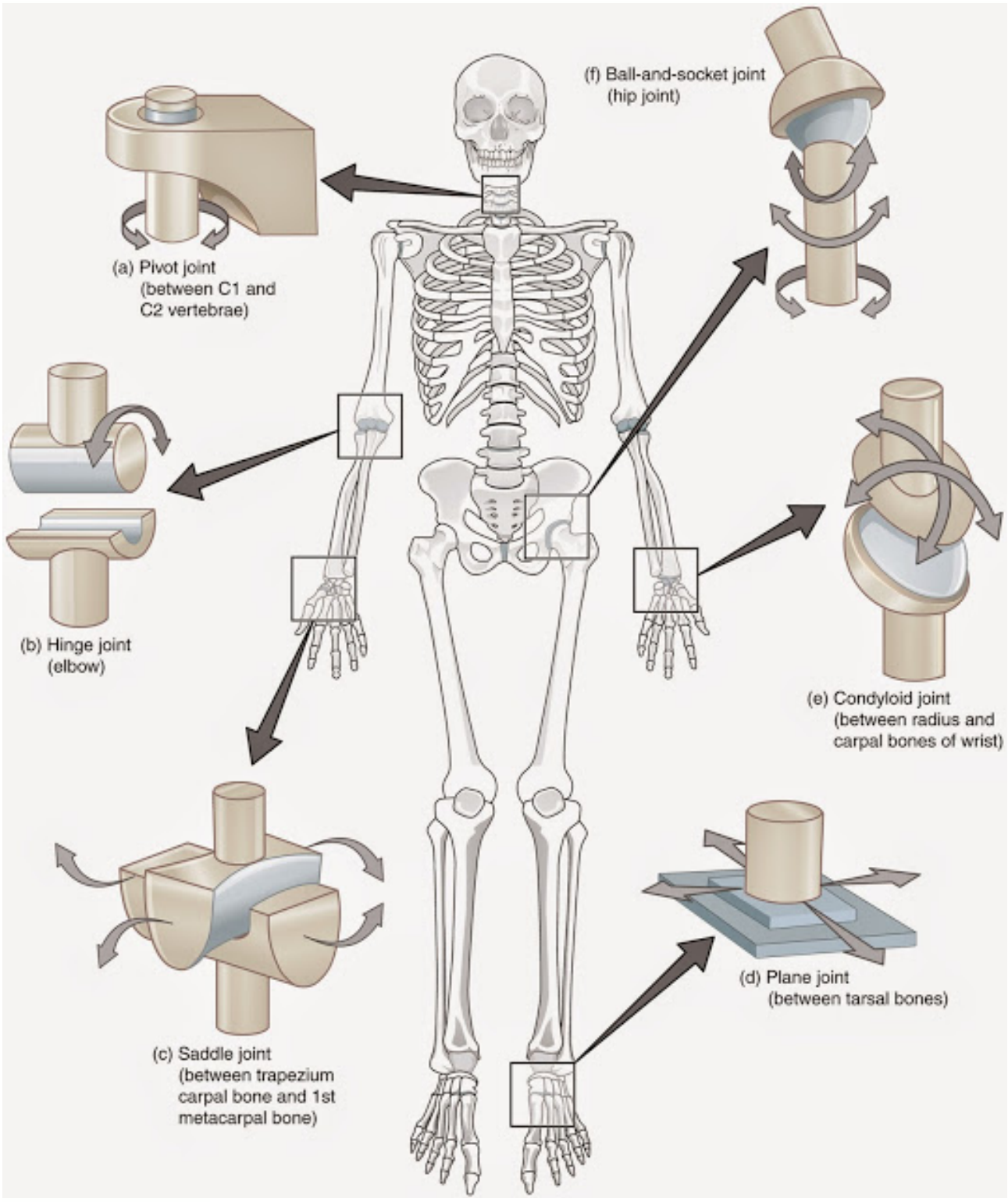
Bi-axial synovial joints

- In bi-axial synovial joints, motion between the bones occurs in two planes. Here the surface in contact is curved or rounded in two directions.
- The proximal phalanx of a finger can flex and extend and move from side to side on the rounded head of the metacarpal bone. This is the MP or metacarpophalangeal joint.
- When the two surfaces are curved in directions at right angles to each other, a shape similar to that of a riding saddle is formed. This type of synovial joint is called

a saddle joint. In the human body, the saddle joint is located at the base of the thumb.

Multi-axial synovial joints:

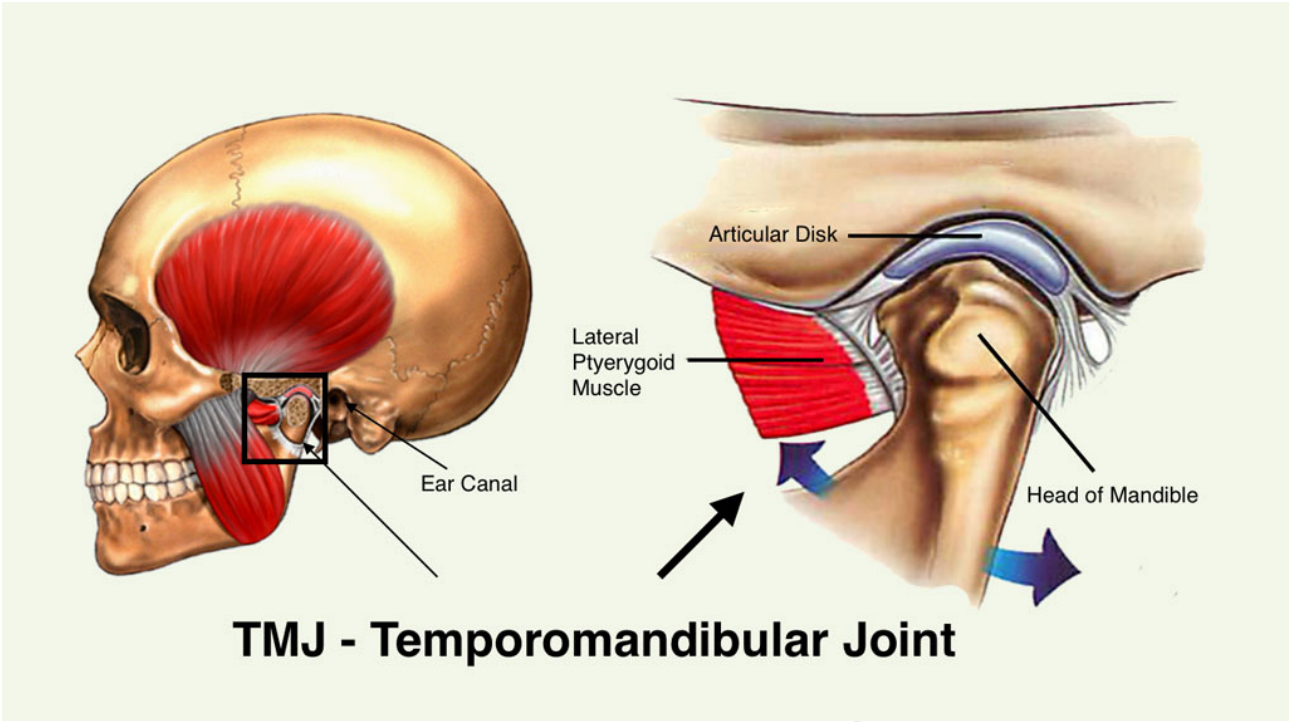
- In multi-axial joints, motion is possible in all three planes of space.
- The ball-and-socket-type synovial joint has the freest motion in all directions. A spherically rounded head (ball-like) fits into a receiving concavity (socket). The hip joint is an example of the ball-and-socket type, with the spherical head of the femur fitting into the cup or socket (acetabulum) of the pelvic bone.
- In the plane joint, the contact surfaces of the bones are essentially flat. These flat surfaces slide on one another (also called translatory motion). The acromioclavicular joint of the shoulder region is an example of a plane joint.



The articular disc

In three of the synovial joints of the human body, a special addition is seen. This addition is known as an articular disc. The joints with articular discs are the temporomandibular joint of the lower jaw, the sternoclavicular joint (at the sternum (breastbone)), and the ulnocarpal joint of the distal end of the forearm.

An articular disc is a fibrocartilage plate. It is inserted between the articular surfaces of the bones of a synovial joint. In this way, it divides the synovial space into two spaces. Joints having an articular disc are capable of having several different motions occurring at the same time. Mechanically, there are really two joints together here.

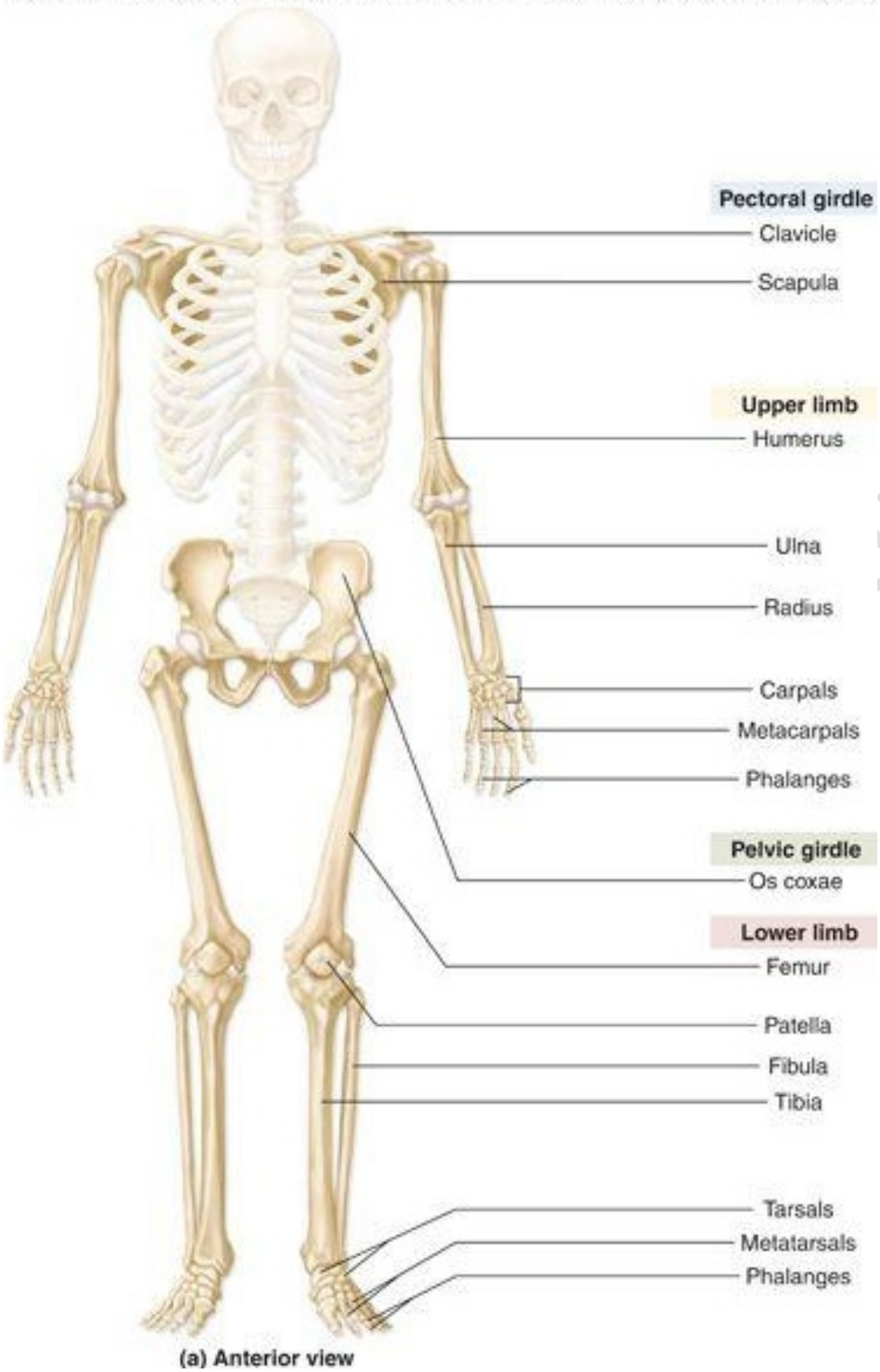


The appendicular skeleton

The appendicular skeleton is made up of the skeletal elements of the upper and lower members (often incorrectly referred to as the "extremities"). These members are appended (attached) to the axial skeleton.

The general pattern of construction of the upper and lower members is the same as follows:

- The girdle is the actual attaching part. It attaches (appends) the limb (the member less the girdle) to the axial skeleton.
- Proximal limb segment. The proximal segment of the limb has a single long bone.
- Middle limb segment. The middle segment of the limb has two long bones parallel with each other.
- Distal limb segment. The distal segment of the limb is made up of many long and short bones. These bones are arranged into a five-rayed pattern - the digits.



(a) Anterior view

Module Five: The Muscular System

Part 1: The Skeletal Muscle

Learning objectives

In this module, you will learn:

- Function of the muscular system.
- Structure and function of the different types of attachments of muscles.
- How muscles contract.
- Position and action of muscles.
- Common pathologies.

The skeletal muscle

Muscle tissues

The cellular elements of muscle tissues are specialised to produce motion by contraction. They also produce body heat.

- Smooth muscle tissue is utilised to make up the muscular portion of the various visceral organs (stomach, blood vessels, etc.)
- Cardiac muscle tissue makes up the muscular wall of the heart - the myocardium.
- Striated muscle tissue is used in the makeup of several types of muscles. The main type of muscle is the skeletal muscle. Other types of muscles made with striated muscle tissue are the facial or integumentary muscles and muscles of the jaw apparatus.

Each skeletal muscle is an individual organ of the human body. Each is made up of several types of tissues - mainly, striated muscle fibres and FCT (fibrous connective tissue). Each is attached to and moves bones. Bones are parts of the skeleton serving as levers.

General construction of a skeletal muscle

The large portion of a muscle is known as its belly or fleshy belly. This muscle is attached to bones by tendons or aponeuroses. Tendons and aponeuroses are similar to each other. However, tendons are cord-like and aponeuroses are broad and flat. The fleshy portion may be directly connected to the bone. If so, it is called a "fleshy attachment."

Muscular NAVL (nerve, artery, vein, lymphatic)

From the main NAVL (nerve, artery, vein, lymphatic), there are branches going to each muscle. These muscular branches are bound together by an FCT sheath to form a neurovascular bundle.

The motor point is that specific location on the surface of the muscle where the neurovascular bundle enters.

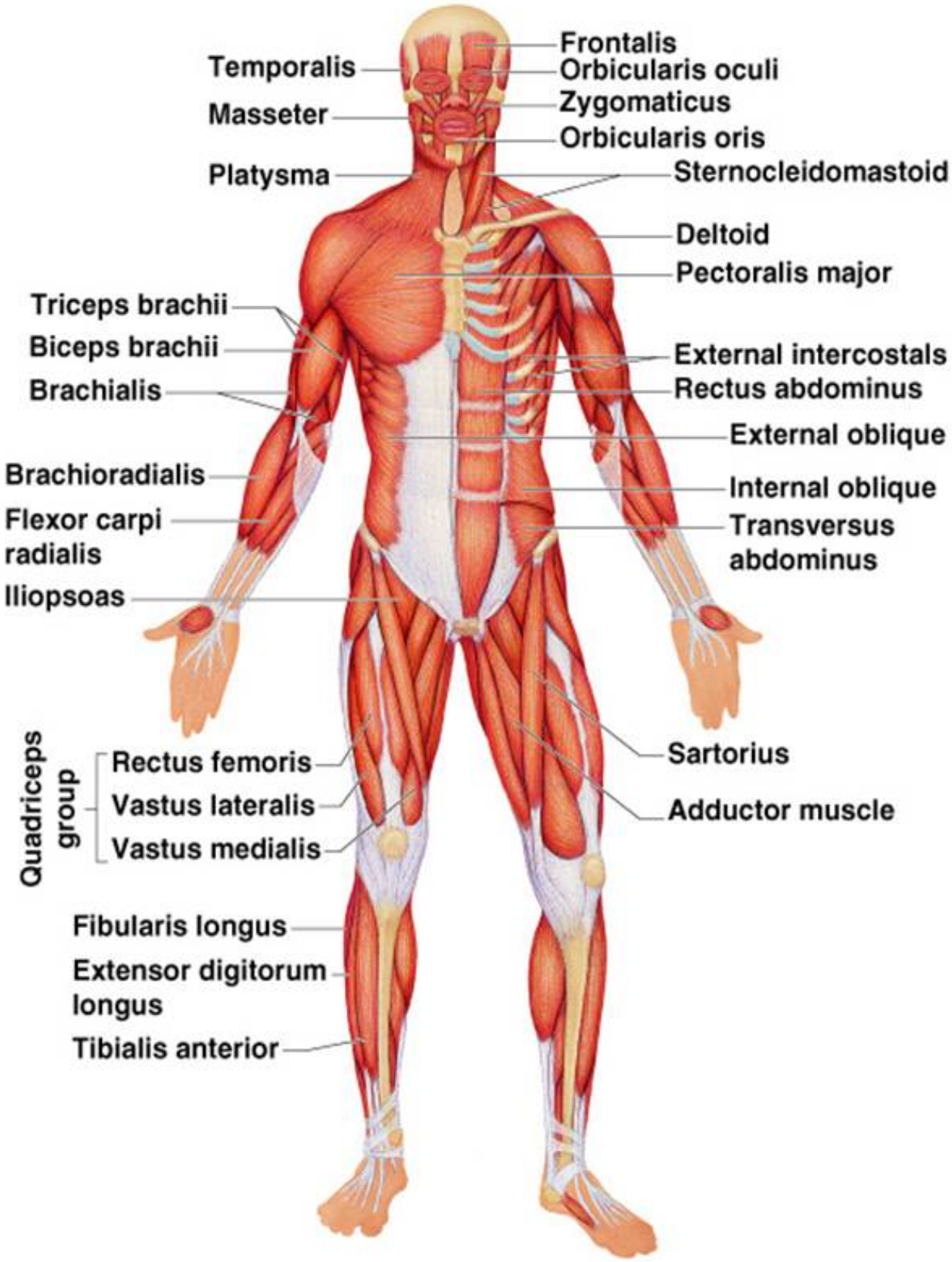
A motor unit is the single motor neurone and the number of striated muscle fibres activated by it (innervation). The importance of the motor unit is that its fibres work in unison. Either all fibres within a unit contract or none contract. When a certain amount of force is needed, one unit after another is recruited until just enough units are available to produce the desired action.

Arrangement of skeletal muscles

Trunk musculature:

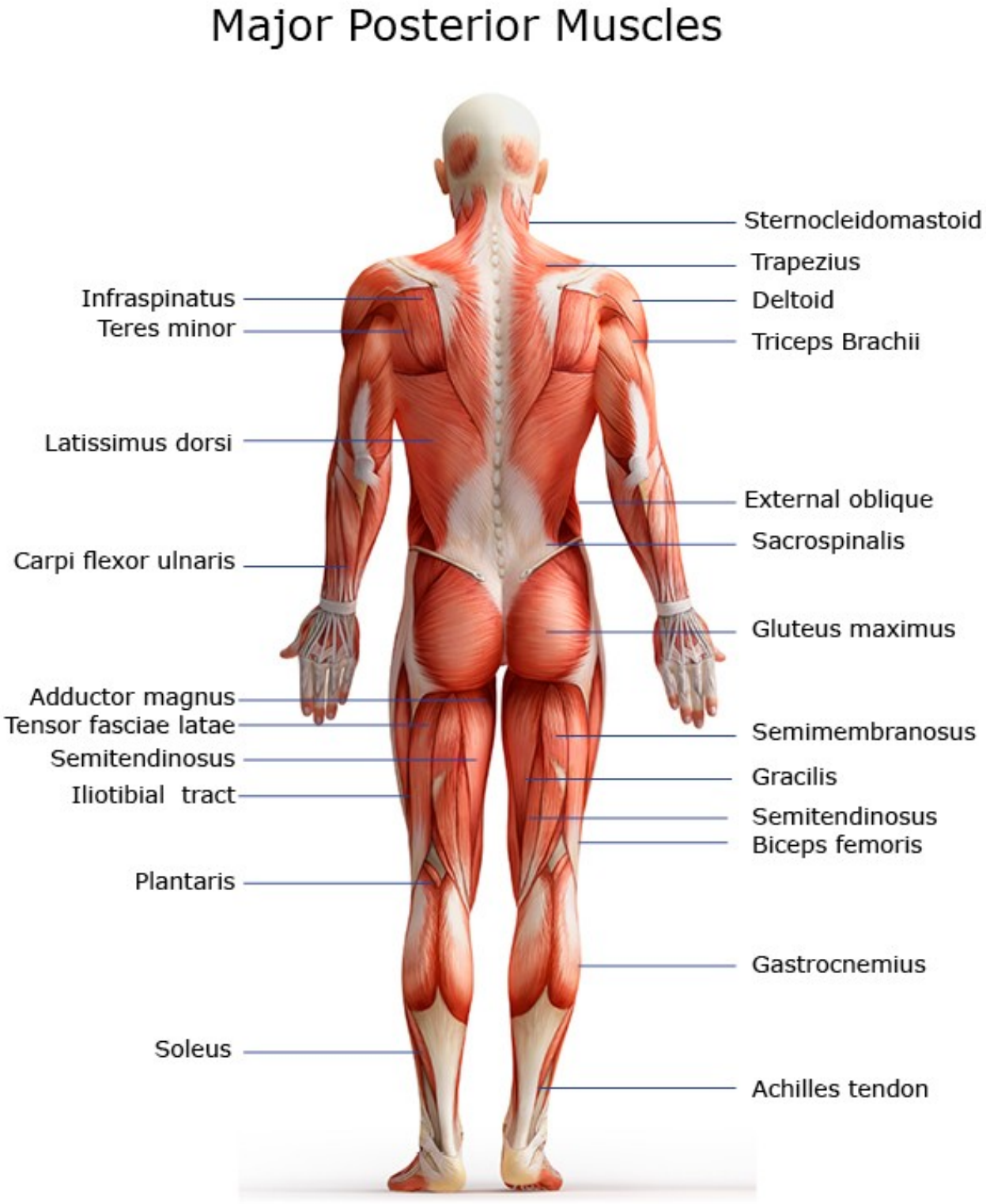
The trunk musculature is arranged in two ways - longitudinal muscles and oblique muscles. Together, they:

- maintain trunk posture.
- move the parts of the trunk.
- adjust the internal pressures of the trunk to perform certain functions- such as breathing.



Limb musculature

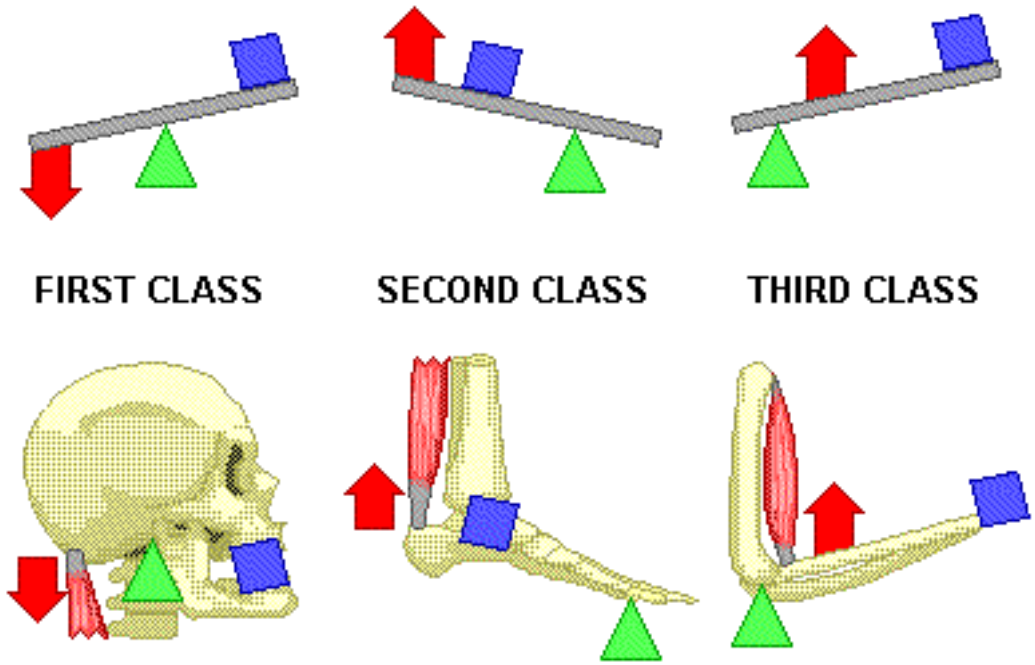
The limb musculature is arranged around the joints to produce the appropriate motions of the limbs. Elementary mechanics are described in the next section to help you to understand typical arrangements of limb musculature.



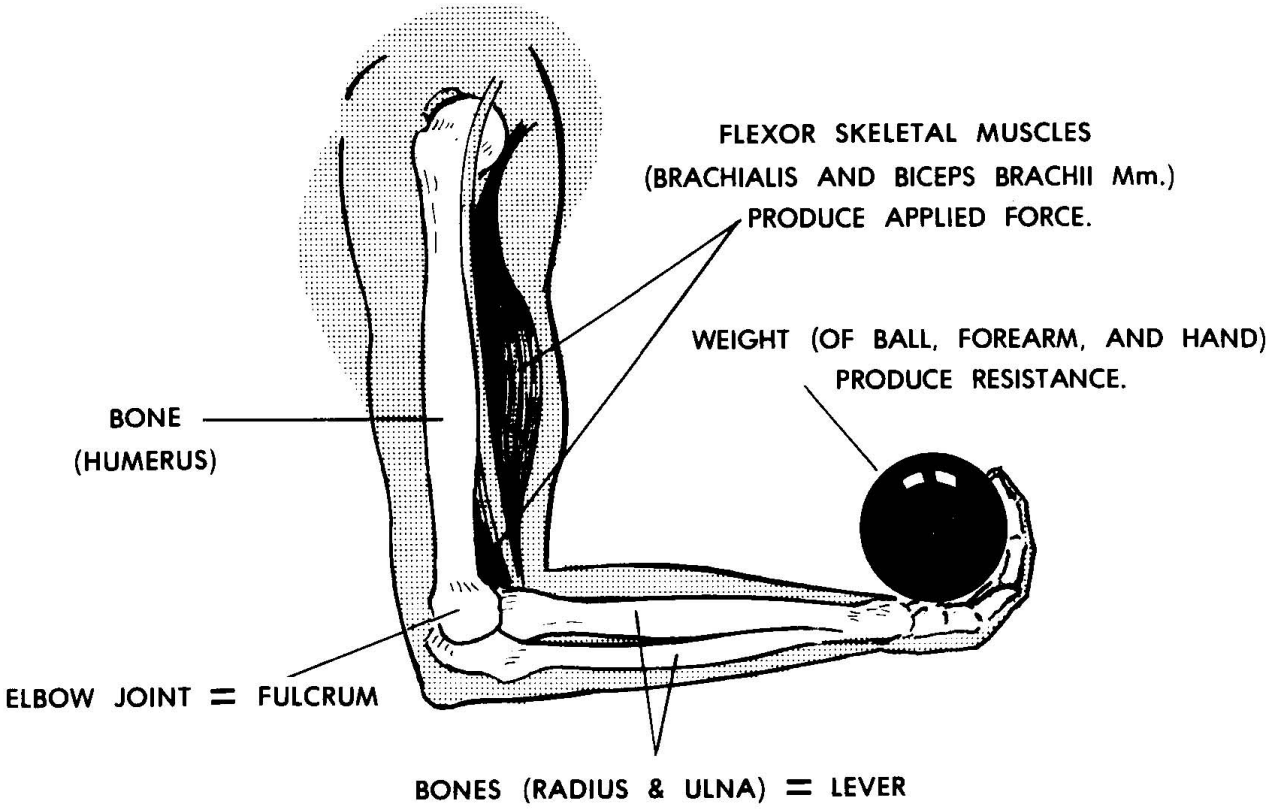
Part 2: Lever Systems

Muscles and bones together work like machines within the laws of physics and chemistry. Lever and pulley systems are examples of simple machines found commonly in the human body.

MUSCLE-LEVER SYSTEMS



First Class
In a first class lever, the weight to be moved is at one end of the lever, the applied force is at the other end, and the fulcrum (the pivot or turning point) is between the two.
Second Class
In a second class lever, the weight to be moved is between the applied force and the fulcrum. This type of lever enables a weight to be moved with less force than would be required without a lever. (Many feel that there are no second class levers in the human body.)
Third Class
In a third class lever, the weight to be moved is at one end of the lever, the fulcrum is at the other end, and the applied force is between the weight and the fulcrum. This type of lever provides speed, but a greater amount of force is required for a given weight. This is the most common type of lever in the human body.
In the human body, when the tendon of a skeletal muscle slides over a round bony surface, the "system" acts like a simple pulley. A simple pulley provides a change in the direction of the force or muscle pull. There is no change in the amount of force produced by the muscle. For example, the knee acts as a simple pulley by which the quadriceps femoris muscle extends the leg.
Sesamoid bones, such as the patella (kneecap), develop in tendons where pressure is applied to the tendon.
The skeletomuscular unit
The skeletomuscular unit is a working concept of muscle and skeleton producing motion. The components of a skeletomuscular unit are bones, a joint, and skeletal muscle(s).



- Bones. Bones act as levers and as attachment sites for skeletal muscles.
- Joint (Articulation). The joint is the centre, fulcrum, point, or axis of motion.
- Skeletal Muscle(s). Skeletal muscles apply the forces for motion. Any given motion utilises a group of muscles working together. A skeletal muscle may serve only one of the three following major roles during a particular motion:

1. Prime mover. The muscle which makes the main effort for a given motion is called the prime mover, or agonist.
2. A synergist is a muscle which assists the prime mover.
3. An antagonist applies a force opposite to that of the prime mover.

By opposing the prime mover, the antagonist helps control the motion.
The antagonist also brings the limb or other part back to its original position.

Common pathologies

Atony – muscles are floppy without normal elasticity
Atrophy – wasting of muscle tissue
Carpal tunnel syndrome – pressure on the median nerve of the wrist
Fibromyalgia – chronic condition causing musculoskeletal pain
Fibrositis – inflammatory condition in the fibrous connective tissue, also known as muscular rheumatism
Myositis – inflammation of a skeletal muscle
Muscle fatigue – loss of the ability of a muscle to contract efficiently
Muscle spasm – increase in muscle tension due to excessive motor nerve activity
Muscle cramp – acute painful contraction of a muscle or group of muscles
Muscular dystrophy – gradual weakening and atrophy of muscles
Rupture – tearing of muscle fascia or tendon
Shin splints – soreness in the front of lower leg due to straining of the flexor muscle
Spasticity – increase in muscle tone and stiffness. Often associated with nervous dysfunction
Strain – partial or complete tear of muscle
Sprain – complete or partial tear in ligaments around a joint

Stress – excessive muscular tension
Tendinitis – inflammation of a tendon
Tennis elbow – inflammation of the tendons that attach the extensor muscles of the forearm at the elbow joint
Torticollis – condition where the sternomastoids (neck muscles) contract involuntarily

Module Six: The Digestive System

Part 1: Major Organs

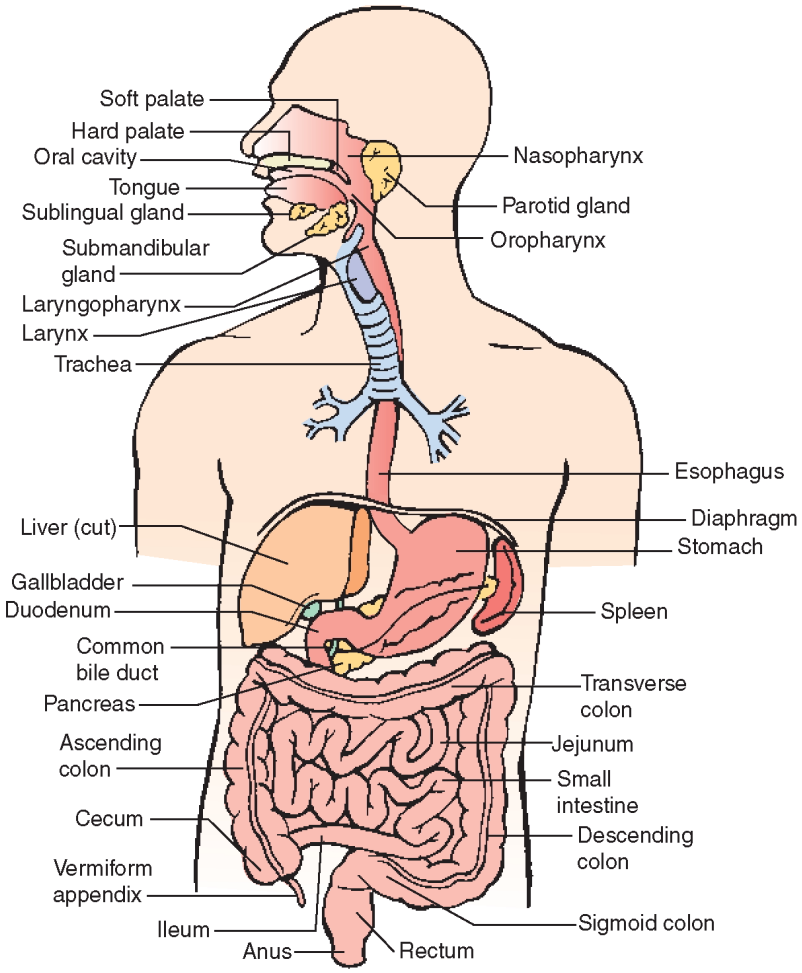
Learning objectives

In this module, you will learn:

- The function of the digestive system.
- Process of digestion from the ingestion of food to the elimination of waste.
- Structure and function of organs associated with digestion.
- Common pathologies.

The human digestive system

The human digestive system is a group of organs designed to take in foods, initially process foods, digest the foods, and eliminate unused materials of food items. It is a hollow tubular system from one end of the body to the other end.



Major organs

The major organs involved in the human digestive system are listed below. They are each discussed later in this lesson.

- Mouth or oral complex.
- Pharynx.
- Oesophagus.
- Stomach.
- Small intestines and associated glands.
- Large intestines.
- Rectum.
- Anal canal and anus.

Digestive enzymes

A catalyst is a substance that accelerates (speeds up)a chemical reaction without being permanently changed or consumed itself. A digestive enzyme serves as a catalyst, aiding in digestion. Digestion is a chemical process by which food is converted into simpler substances that can be absorbed or assimilated by the body. Enzymes are manufactured in the salivary glands of the mouth, in the lining of the stomach, in the pancreas, and in the walls of the small intestine.

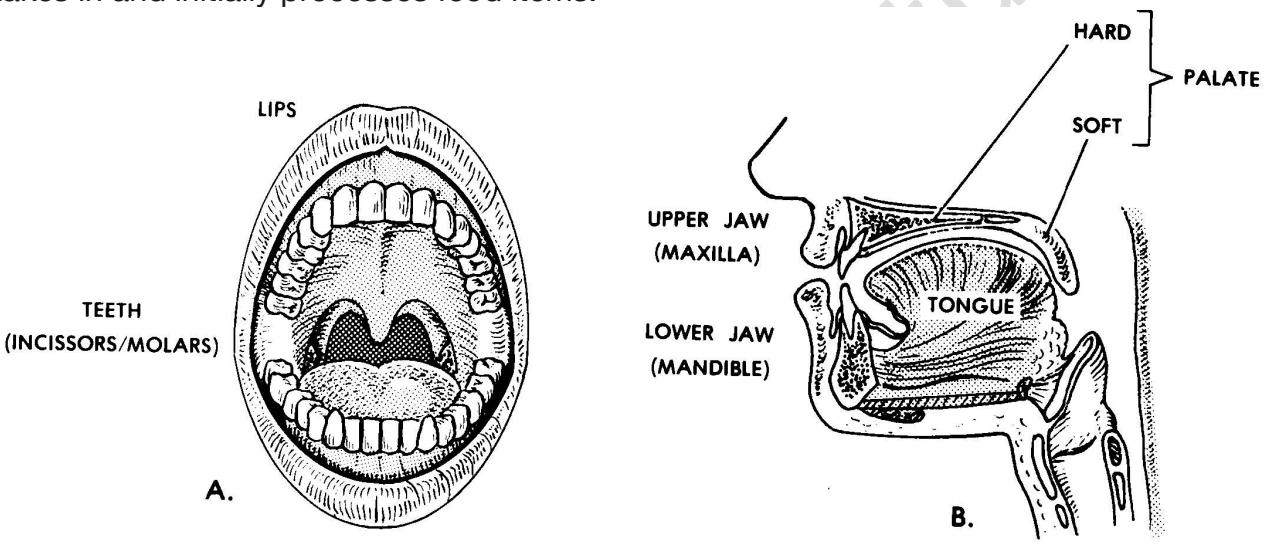
Foods and foodstuffs

Examples of food items are a piece of bread, a pork chop, and a tomato. Food items contain varying proportions of foodstuffs. Foodstuffs are the classes of chemical compounds which make up food items. The three major types of foodstuffs are carbohydrates, lipids (fats and oils), and proteins. Food items also contain water, minerals, and vitamins.

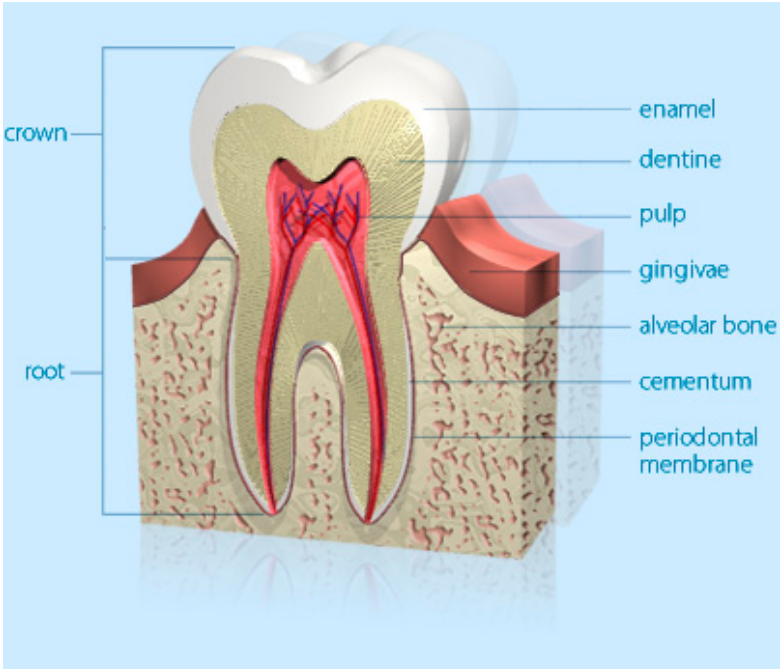
The supragastric structures

Oral complex

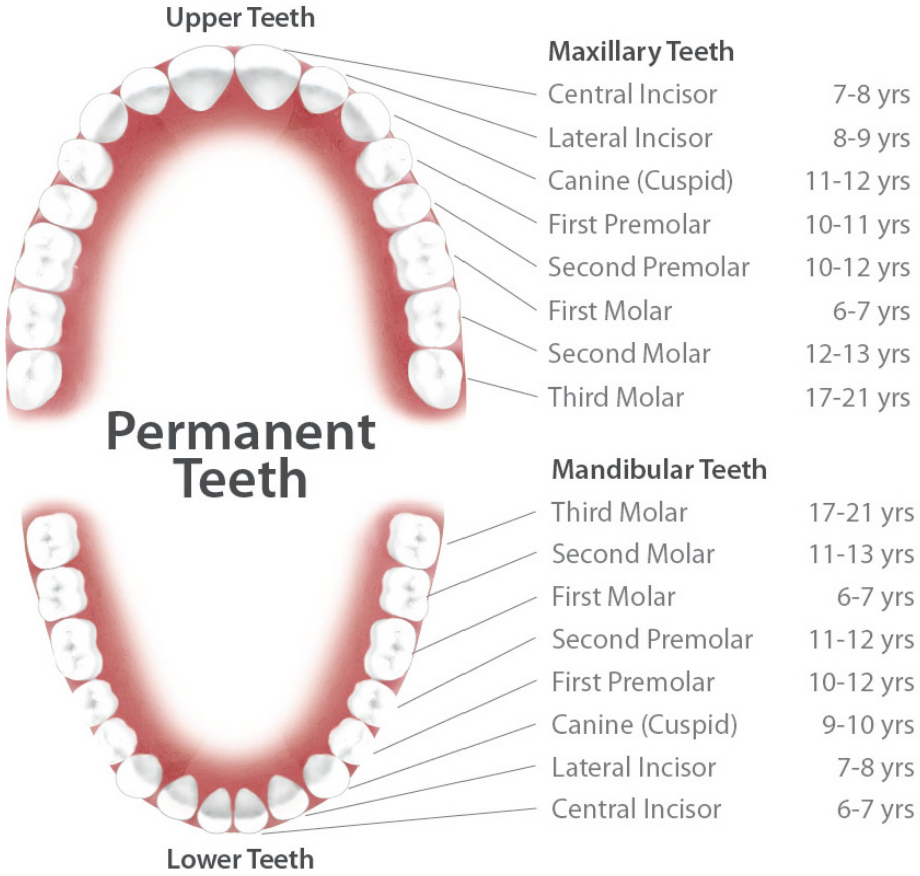
The oral complex consists of the structures commonly known together as the mouth. It takes in and initially processes food items.



Teeth



A tooth has two main parts - the crown and the root. A root canal passes up through the central part of the tooth. The root is suspended within a socket (called the alveolus) of one of the jaws of the mouth. The crown extends up above the surface of the jaw. The root and inner part of the crown are made of a substance called dentin. The outer portion of the crown is covered with a substance known as enamel. Enamel is the hardest substance of the human body. The nerves and blood vessels of the tooth pass up into the root canal from the jaw substance.
There are two kinds of teeth - anterior and posterior. The anterior teeth are also known as incisors and canine teeth. The anterior teeth serve as choppers. They chop off mouth-size bites of food items. The posterior teeth are called molars. They are grinders. They increase the surface area of food materials by breaking them into smaller and smaller particles.
Humans have two sets of teeth--deciduous and permanent. Initially, the deciduous set includes 20 baby teeth.
These are eventually replaced by a permanent set of 32.



Jaws

There are two jaws - the upper and the lower. The upper is called the maxilla. The lower is called the mandible.
In each jaw, there are sockets for the teeth. These sockets are known as alveoli. The bony parts of the jaws holding the teeth are known as alveolar ridges.
The upper jaw is fixed to the base of the cranium.
The lower jaw is movable. There is a special articulation, a temporal-mandibular joint, with muscles to bring the upper and lower teeth together to perform their functions.

Palate

The palate serves as the roof of the mouth and the floor of the nasal chamber above. Since the anterior two-thirds is bony, it is called the hard palate. The posterior one-third is

musculo-membranous and is called the soft palate. The soft palate serves as a trap door to close off the upper respiratory passageway during swallowing.

Lips and cheeks

The oral cavity is closed by a fleshy structure around the opening. Forming the opening are the lips. On the sides are the cheeks.

Tongue

The tongue is a muscular organ, capable of internal movement to shape its body. It is moved as a whole by muscles outside the tongue. Interaction between the tongue and cheeks keeps the food between the molar teeth during the chewing process. When the food is properly processed, the tongue also initiates the swallowing process.

Salivary glands

Digestion is a chemical process which takes place at the wet surfaces of food materials. The chewing process has greatly increased the surface area available. The surfaces are wetted by saliva produced by glands in the oral cavity. Of these glands, three pairs are known as the salivary glands proper.

Taste buds

Associated with the tongue and the back of the mouth are special clumps of cells known as taste buds. These taste buds literally taste the food. That is, they check its quality and acceptability.

Pharynx

The pharynx is a continuation of the rear of the mouth region, just anterior to the vertebral column. It is a common passageway for both the respiratory and digestive systems.

Oesophagus

The oesophagus is a muscular, tubular structure extending from the pharynx, down through the neck and the thorax (chest), and to the stomach. During swallowing, the oesophagus serves as a passageway for the food from the pharynx to the stomach.

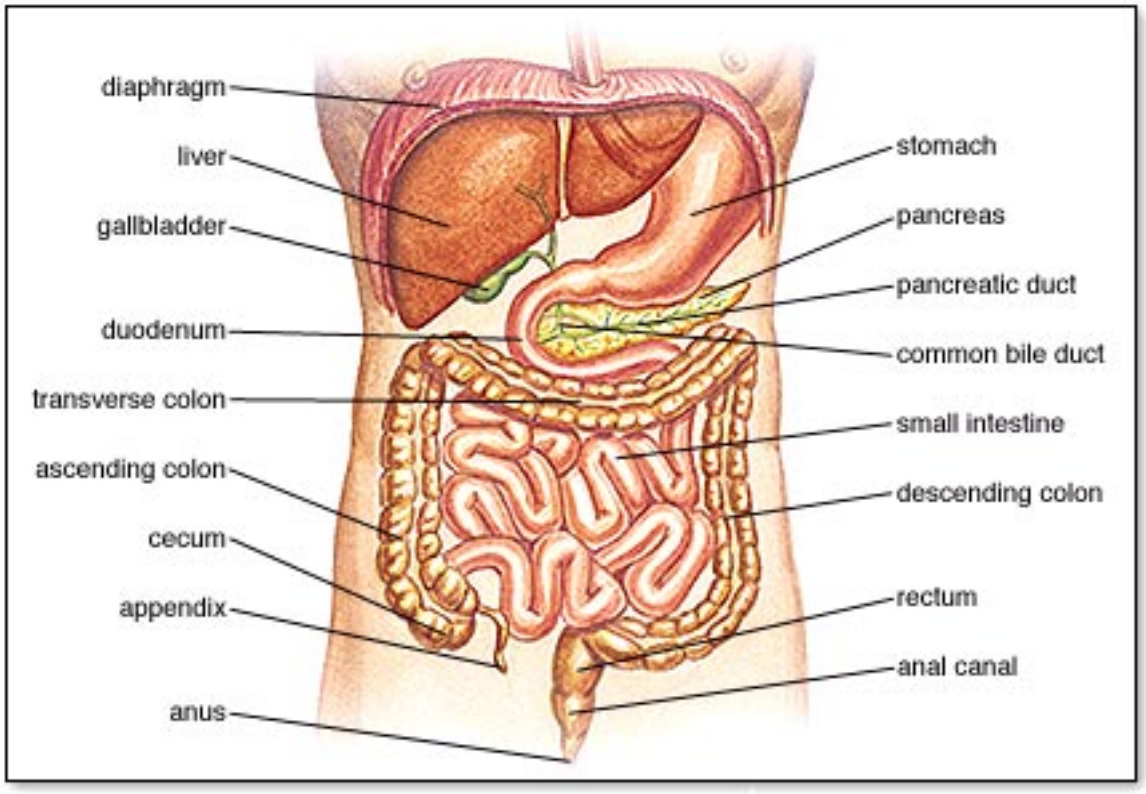
Part 2: The Stomach

Storage function

The stomach is a sac-like enlargement of the digestive tract specialised for the storage of food. Since food is stored, a person does not have to eat continuously all day. One is freed to do other things. The presence of valves at each end prevents the stored food from leaving the stomach before it is ready. The pyloric valve prevents the food from going further. The inner lining of the stomach is in folds to allow expansion.

Digestive function

While the food is in the stomach, the digestive processes are initiated by juices from the wall of the stomach. The musculature of the walls thoroughly mixes the food and juices while the food is being held in the stomach. In fact, the stomach has an extra layer of muscle fibres for this purpose.



When the pyloric valve of the stomach opens, a portion of the stomach contents moves into the small intestine.

The small intestine and associated glands

Digestion is a chemical process. This process is facilitated by special chemicals called digestive enzymes. The end products of digestion are absorbed through the wall of the gut into the blood vessels. These end products are then distributed to body parts that need them for growth, repair, or energy.

There are associated glands - the liver and the pancreas - which produce additional enzymes to further the process.

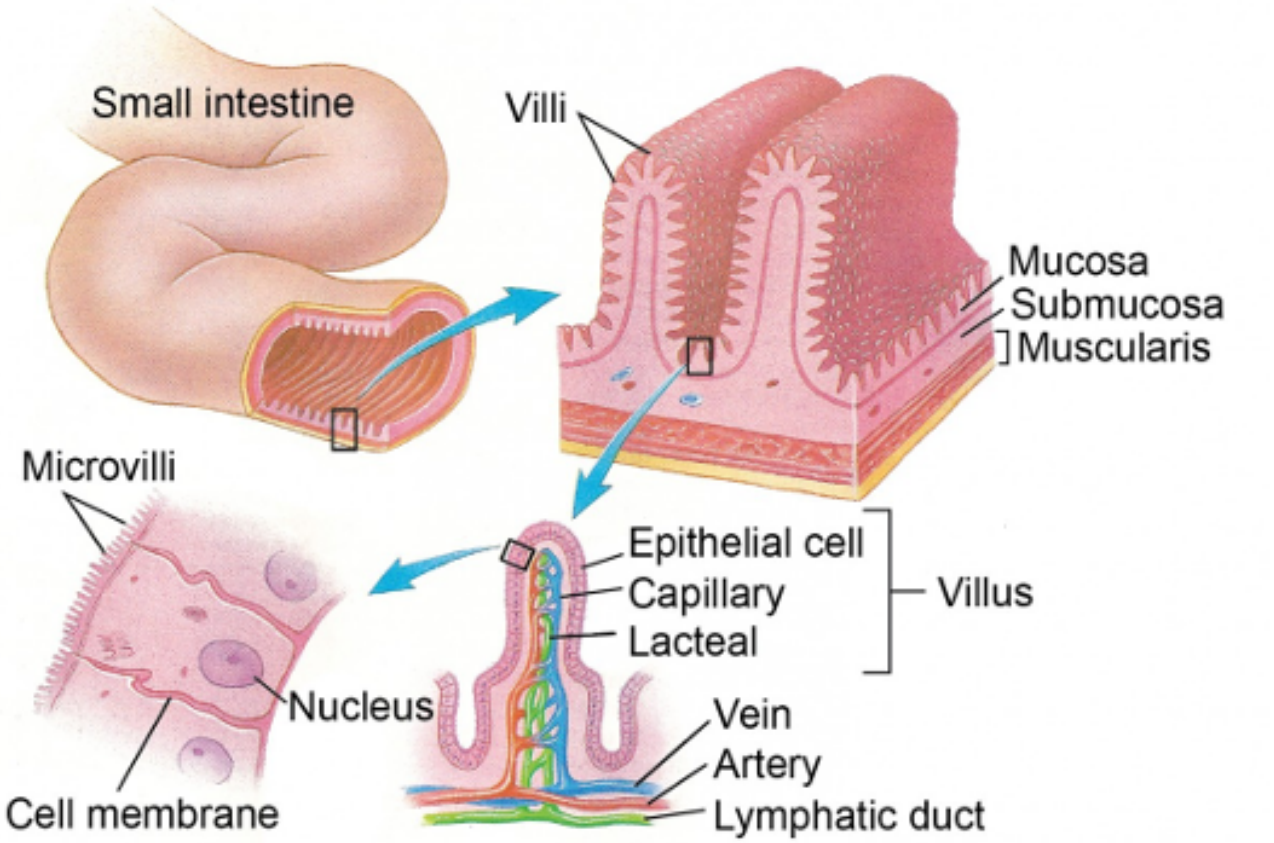
Most digestion and absorption takes place in the small intestines.

Anatomy of the small intestine

The small intestine is classically divided into three areas - the duodenum, the jejunum, and the ileum. The duodenum is C-shaped, about 25 centimetres long in the adult. The duodenum is looped around the pancreas.

The jejunum is approximately 2.4 metres long and connects the duodenum and ileum. The ileum is about 3.6 metres long. The jejunum and ileum are attached to the rear wall of the abdomen with a membrane called a mesentery. This membrane allows mobility and serves as a passageway for nerves and vessels to the small intestines.

The small intestine is tubular. It has muscular walls which produce a wave-like motion called peristalsis moving the contents along. The small intestine is just the right length to allow the processes of digestion and absorption to take place completely.



The inner surface of the small intestine is NOT smooth like the inside of new plumbing pipes. Rather, the inner surface has folds (plicae). On the surface of these plicae are finger-like projections called villi. This folding and the presence of villi increase the surface area available for absorption.

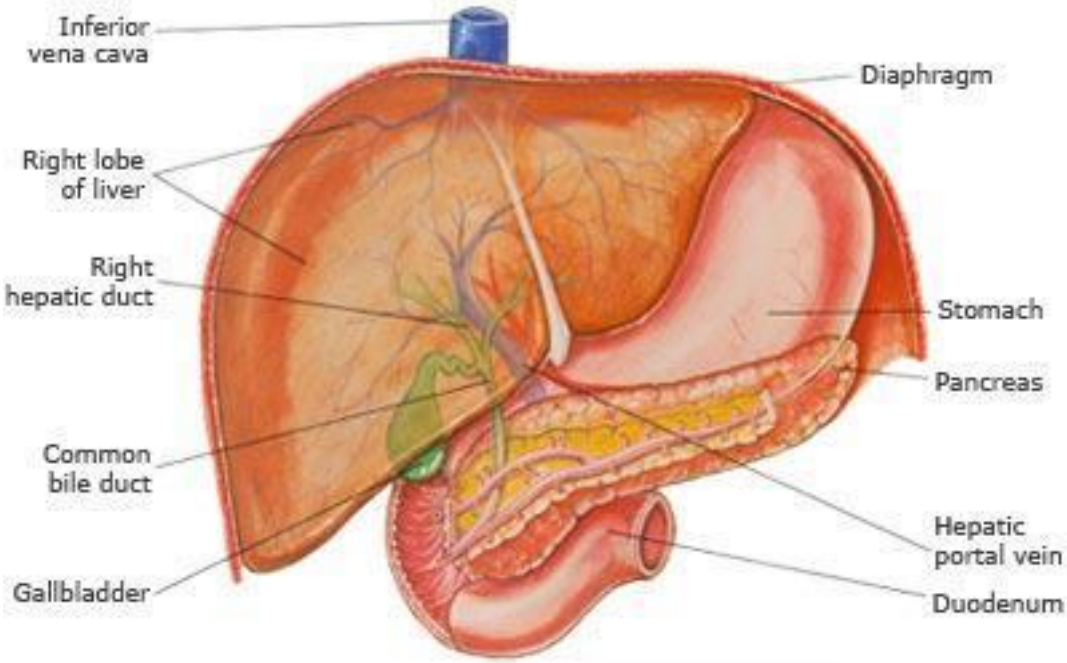
Liver & gallbladder

Liver anatomy

The liver is a large and complex organ. Most of its mass is on the right side of the body and within the lower portion of the rib cage. Its upper surface is in contact with the diaphragm.

Liver functions

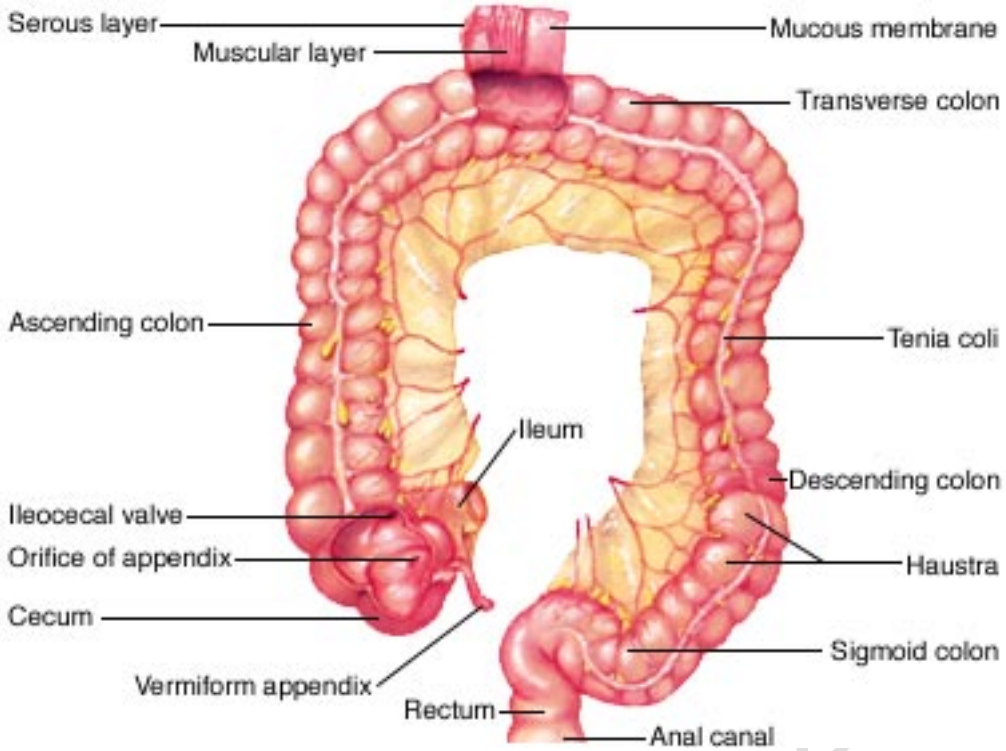
The liver is a complex chemical factory with many functions. These include aspects of carbohydrate, protein, lipid, and vitamin metabolism and processes related to blood clotting and red blood cell destruction. Its digestive function is to produce a fluid called bile or gall.



Gallbladder
Until needed, the bile is stored and concentrated in the gallbladder, a sac on the inferior surface of the liver. Fluid from the gallbladder flows through the cystic duct, which joins the common hepatic duct from the liver to form the common bile duct. The common bile duct then usually joins with the duct of the pancreas as the fluid enters the duodenum.

Pancreas
The pancreas is a soft, pliable organ stretched across the posterior wall of the abdomen. When called upon, it secretes its powerful digestive fluid, known as pancreatic juice, into the duodenum. Its duct joins the common bile duct.

Part 3: The Large Intestine
General function
The primary function of the large intestines is the absorption of water and electrolytes (salts). Most of the end products of digestion have already been absorbed in the small intestines. Within the large intestines, the contents are first a watery fluid. Thus, the large intestines are important in the conservation of water for use by the body. The large intestines remove water until a nearly solid mass is formed before defecation, the evacuation of faeces.



Major subdivisions

The major subdivisions of the large intestines are the caecum (with vermiform or "worm-shaped" appendix), the ascending colon, the transverse colon, the descending colon, and the sigmoid colon. The faecal mass is stored in the sigmoid colon until passed into the rectum.

Rectum, anal canal and anus

Rectum means "straight". However, this six-inch tubular structure would actually look a bit wave-like from the front. From the side, you would see that it was curved to conform to the sacrum (at the lower end of the spinal column). The final storage of faeces is in the rectum. The rectum terminates in the narrow anal canal, which is about 4 centimetres long in the adult. At the end of the anal canal is the opening called the anus. Muscles called the anal sphincters aid in the retention of faeces until defecation.

Associated Protective Structures

General

Within the body, there are many structures that aid in protection from bacteria, viruses, and other foreign substances. These structures include cells that can phagocytose (engulf) foreign particles or manufacture antibodies which help to inactivate foreign substances. Collectively, such cells make up the reticuloendothelial system (RES). Such cells are found in bone marrow, the spleen, the liver, and lymph nodes.

Structures within the digestive system

Lymphoid structures make up the largest part of the RES. Lymphoid structures are collections of cells associated with the circulatory system.

Tonsils are associated with the posterior portions of the respiratory and digestive areas in the head, primarily in the region of the pharynx. The tonsils are masses of lymphoid tissue.

Other lymphoid aggregations are found in the walls of the small intestines.

The vermiform appendix, attached to the cecum of the large intestine, is also a mass of lymphoid tissue. It is the "tonsil" of the intestines.

Common pathologies

Anorexia nervosa – psychological illness in which a person starves themselves by means of vomiting or laxatives to induce weight loss
Appendicitis – acute inflammation of the appendix
Bulimia – psychological illness characterised by binge- eating and purging through self-induced vomiting
Cancer of the colon – varying symptoms depending on the site of the tumour, but usually vague in the first stages
Cancer of the gallbladder – indigestion and colic-type pains may be first signs
Cancer of the liver – usually secondary cancer but can be primary in liver tissue
Cancer, oral – may be caused by chronic irritation of the mucosa or chronic recurring mouth ulcers
Cancer of the pancreas – severe weight loss, lower back pain initially
Cancer of the stomach – signs in early stages chronic pain or discomfort in upper part of abdomen with vague symptoms
Cirrhosis of the liver – distorted or scarred liver as a result of chronic inflammation
Colitis – inflammation of the colon
Constipation – difficulty in passing stools or infrequent evacuation of the bowels
Diabetes mellitus – carbohydrate metabolism disorder and lack of insulin production from the pancreas
Diabetes insipidus – deficiency of the hormone ADHwhich regulates reabsorption of water in the kidneys
Diarrhoea – frequent bowel evacuation of soft or liquid faeces
Gallstones – a hard, pebble-like mass formed within the gallbladder
Haemorrhoids – abnormal dilation of veins in the rectum
Heartburn – caused by regurgitation of acidic stomach contents
Hepatitis – inflammation of the liver, A, B or C as below
Hepatitis A – highly contagious transmitted by faecal/oral route; ingestion of contaminated food, water or milk
Hepatitis B – serum hepatitis, more serious than A and can lead to cirrhosis, cancer or carrier state
Hepatitis C – transmitted through blood transfusion or exposure to blood products often a side- effect of drug use or alcohol intake
Hernia – abnormal protrusion of an organ or part of an organ through the wall of the body cavity in which it normally lies
Hiatus hernia – part of the stomach protrudes into the chest, also the most common type of hernia
Jaundice – excessive bilirubin in the blood caused by a malfunctioning gallbladder or an obstruction in the bile duct
Irritable bowel syndrome – symptoms include diarrhoea, constipation, stomach pain and bloating
Stress – development of ulcers, irritable bowel syndrome and indigestion
Ulcers – break in the skin or break in the lining of the alimentary canal that fails to heal and gets inflamed. Common stomach ulcers are peptic, duodenal and gastric ulcers

Module Seven: The Respiratory System

Part 1: Components and Subdivisions of the Respiratory System

Learning objectives

In this module, you will learn:

- Function of the respiratory system.
- Main structures of the respiratory system and their functions.
- Process of interchange of gases in the lungs.
- Mechanism of breathing.
- Common pathologies.

Introduction

Respiration

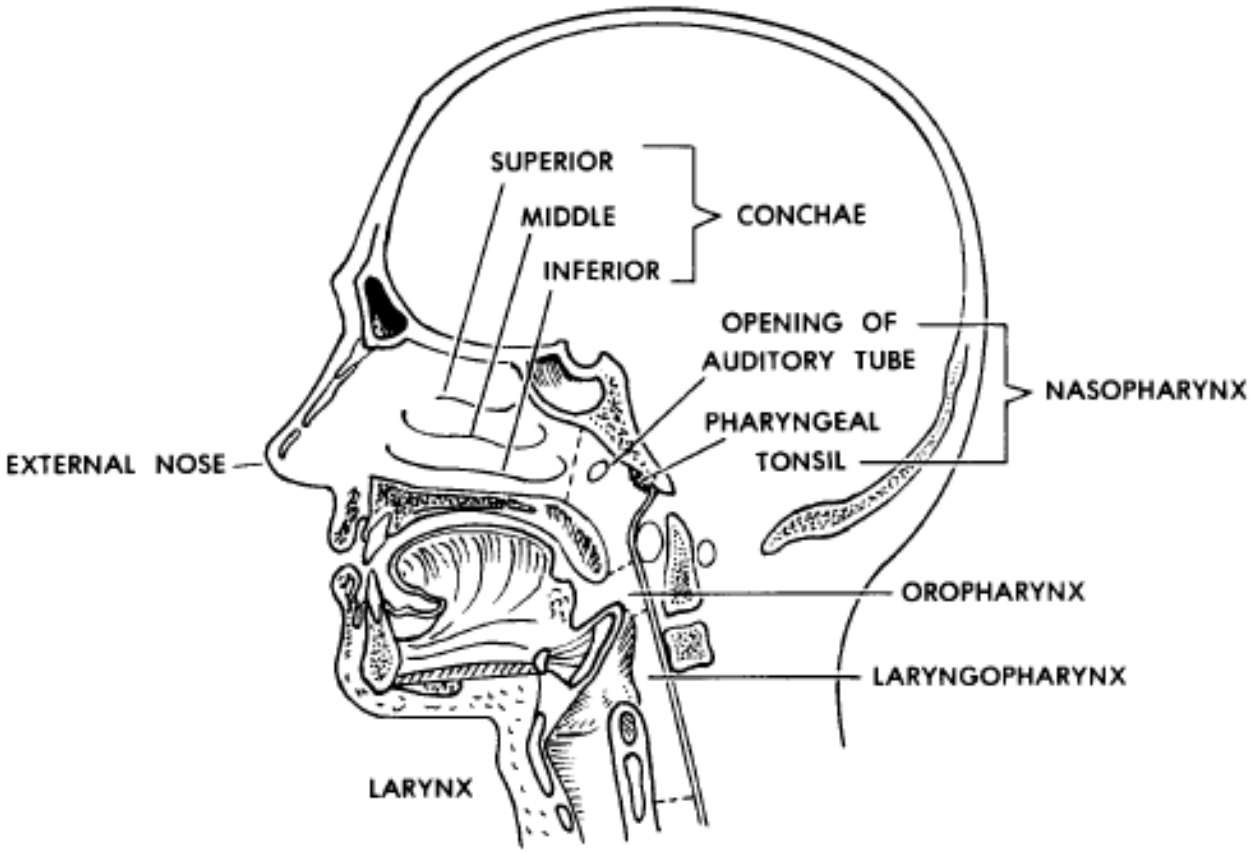
Respiration is the exchange of gases between the atmosphere and the cells of the body. It is a physiological process. There are two types of respiration - external and internal. External respiration is the exchange of gases between the air in the lungs and blood. Internal respiration is the exchange of gases between the blood and the individual cells of the body.

Breathing

Breathing is the process that moves air into and out of the lungs. It is a mechanical process. There are two types of breathing in humans - costal (thoracic) and diaphragmatic (abdominal). In costal breathing, the major structure causing the movement of the air is the rib cage. In diaphragmatic breathing, interaction between the diaphragm and the abdominal wall causes the air to move into and out of the lungs.

Components and subdivisions of the respiratory system

The components of the human respiratory system consist of air passageways and two lungs. Air moves from the outside of the body into tiny sacs in the lungs called alveoli.



Supralaryngeal systems

External nose

The external nose is the portion projecting from the face. It is supported primarily by cartilages. It has a midline divider called the nasal septum, which extends from the internal nose. Paired openings (nostrils) lead to paired spaces (vestibules). Guard hairs in the nostrils filter in-flowing air.

Internal nose/nasal chambers

Behind each vestibule of the external nose is a nasal chamber. The two nasal chambers together form the internal nose. These chambers are separated by the nasal septum.

Mucoperiosteum

The walls of the nasal chambers are lined with a thick mucous-type membrane known as the mucoperiosteum. It has a ciliated epithelial surface and a rich blood supply, which provides warmth and moisture. At times, it may become quite swollen.

Ciliated = provided with cilia, hair-like projections which move fluids to the rear.

Conchae

The lateral wall of each chamber has three scroll-like extensions into the nasal chamber which help to increase the surface area exposed to the inflowing air. These scroll-like extensions are known as conchae.

Olfactory epithelium

The sense of smell is due to special nerve endings located in the upper areas of the nasal chambers. The epithelium containing the sensory endings is known as the olfactory epithelium.

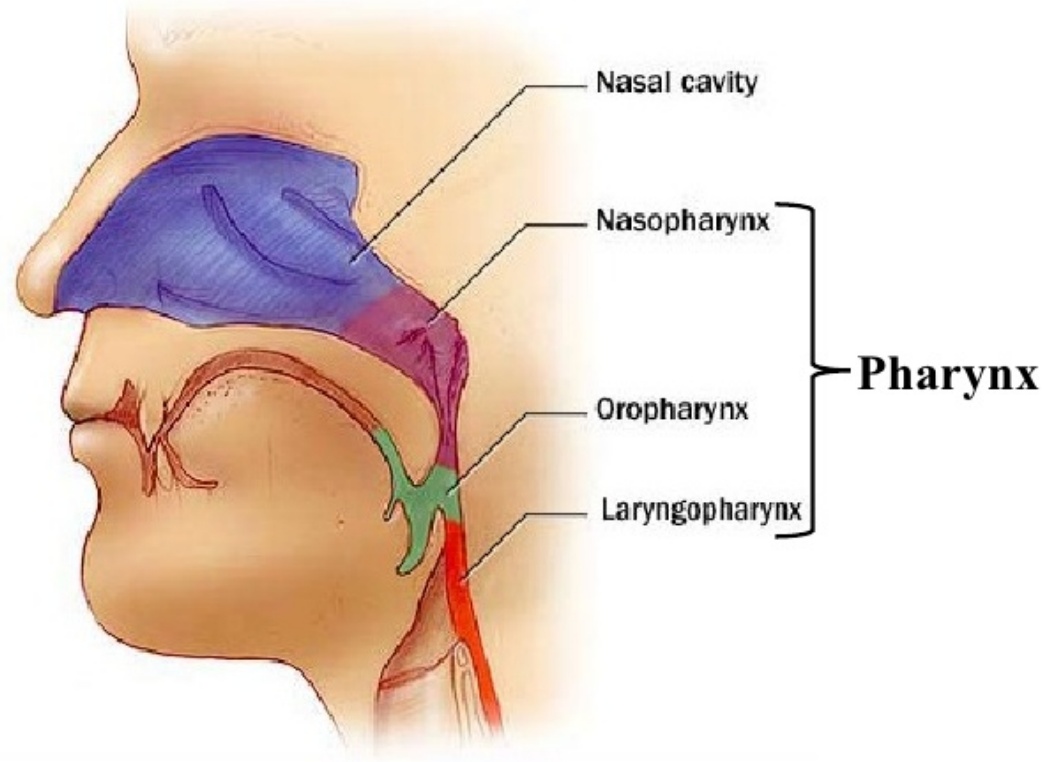
Paranasal sinuses

There are air "cells" or cavities in the skull known as paranasal sinuses. The paranasal sinuses are connected with the nasal chambers and are lined with the same ciliated mucoperiosteum. Thus, these sinuses are extensions of the nasal chambers into the skull bones. For this reason, they are known as paranasal sinuses.

Pharynx

The pharynx is the common posterior space for the respiratory and digestive systems.

The Pharynx

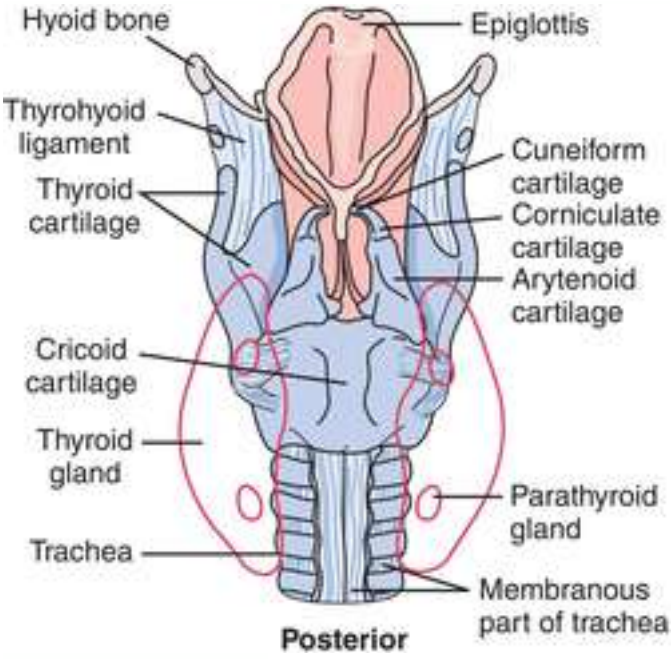


Nasopharynx
That portion of the pharynx specifically related to the respiratory system is the nasopharynx. It is the portion of the pharynx above the soft palate. The two posterior openings (nares) of the nasal chambers lead into the single space of the nasopharynx. The auditory (eustachian) tubes also open into the nasopharynx. The auditory tubes connect the nasopharynx with the middle ears (to equalise the pressure between the outside and inside of the eardrum). Lying in the upper posterior wall of the nasopharynx are the pharyngeal tonsils (adenoids). The soft palate floor of the nasopharynx is a trapdoor which closes off the upper respiratory passageways during swallowing.

Oropharynx
The portion of the pharynx closely related to the digestive system is the oropharynx. It is the portion of the pharynx below the soft palate and above the upper edge of the epiglottis. (The epiglottis is the flap that prevents food from entering the larynx (discussed below) during swallowing.)

Laryngopharynx
That portion of the pharynx which is common to the respiratory and digestive systems is the laryngopharynx. It is the portion of the pharynx below the upper edge of the epiglottis. Thus, the digestive and respiratory systems lead into it from above and lead off from it below.

Larynx
The larynx, also called the Adam's apple or voice box, connects the pharynx with the trachea. The larynx, located in the anterior neck region, has a box-like shape. Since the voice box of the male becomes larger and heavier during puberty, the voice deepens. The adult male's voice box tends to be located lower in the neck; in the female, the larynx remains higher and smaller and the voice is a higher pitch.



Parts and spaces

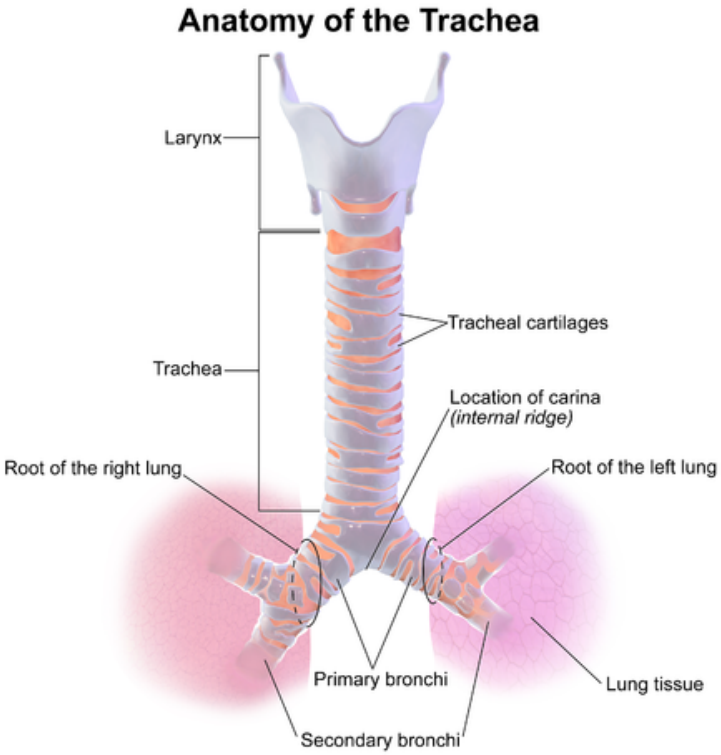
The larynx has a vestibule which can be covered over by the epiglottis. The glottis itself is the hole between the vocal cords. Through the glottis, air passes from the vestibule into the main chamber of the larynx (below the cords) and then into the trachea. The skeleton of the larynx is made up of a series of cartilages.

Muscles

The larynx serves two functions and there are two sets of muscles - one for each function.

- One set controls the size of the glottis. Thus, it regulates the volume of air passing through the trachea.
- The other set controls the tension of the vocal cords. Thus, it produces vibrations of selected frequencies (variations in pitch) of the moving air to be used in the process of speaking.

Intralaryngeal structures



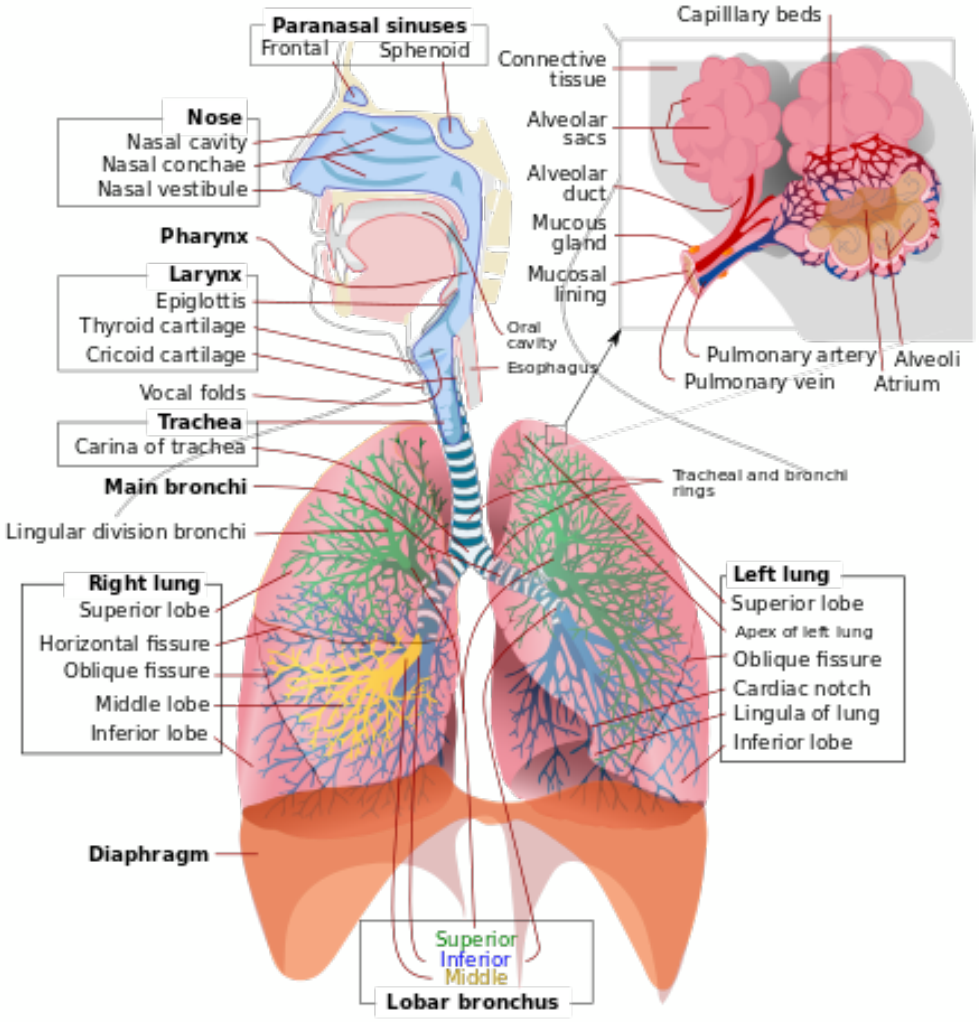
Trachea and bronchi

The respiratory tree is the set of tubular structures which carry the air from the larynx to the alveoli of the lungs. Looking at a person UPSIDE DOWN, the trachea is the trunk of the tree and the bronchi are the branches. These tubular parts are held open by rings of cartilage. Their lining is ciliated to remove mucus and other materials that get into the passageway.

Alveoli

The alveoli are tiny spherical sacs which are connected to the larger tubes of the lungs by tiny tubes known as alveolar ducts and bronchioles. The alveoli are so small that there are billions in the adult lungs. This very small size produces a maximum surface area through which external respiration takes place. External respiration is the actual exchange of gases between the air in the alveolar spaces and the adjacent blood capillaries through their walls.

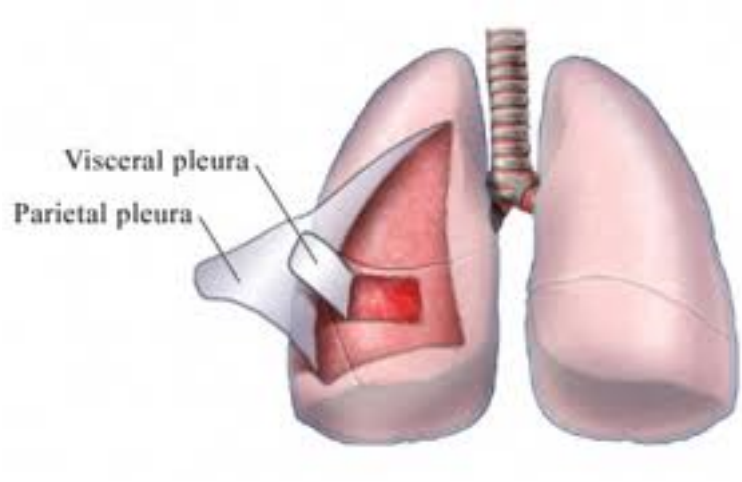
Lungs



A lung is an individual organ composed of tubular structures and alveoli bound together by fibrous connective tissue (FCT). In the human, there are two lungs - right and left. Each lung is supplied by a primary or mainstem bronchus leading off of the trachea. The right lung is larger in volume than the left lung. The left lung must leave room for the heart. The right lung is divided into three pulmonary lobes (upper, middle, and lower) and 10 bronchopulmonary segments. The left lung is divided into two pulmonary lobes (upper and lower) and eight bronchopulmonary segments. A pulmonary lobe is a major subdivision of a lung marked by fissures (deep folds). Each lobe is further partitioned into bronchopulmonary segments. Each lobe is supplied by a secondary or lobar bronchus. Each segment is supplied by a tertiary or segmental bronchus, a branch of the lobar bronchus.

Pleural cavities

In the case of the lungs, the inner membrane is known as the visceral pleura, which very closely covers the surface of the lungs. The outer membrane is known as the parietal pleura, forming the outer wall of the cavity. The pleural cavities are the potential spaces between the inner and outer membranes. The pleural cavities allow the lungs to move freely with a minimum of friction during the expansion and contraction of breathing.



Part 2: Breathing and Breathing Mechanisms

Introduction

We can compare the human trunk to a hollow cylinder. This cylinder is divided into upper and lower cavities by the diaphragm. The upper is the thoracic cavity and is essentially gas-filled. The lower is the abdominopelvic cavity and is essentially water-filled.

Costal (thoracic) breathing

Inhalation

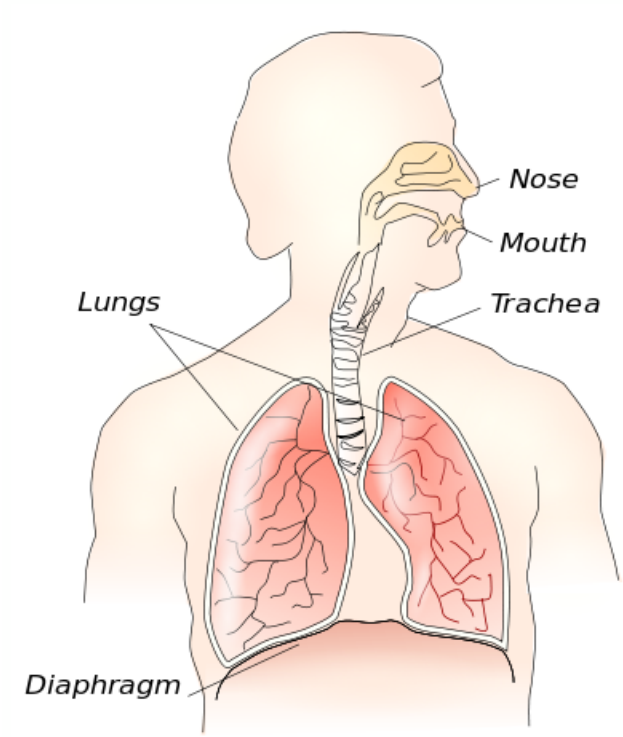
Muscles attached to the thoracic cage raise the rib cage. A typical rib might be compared to a bucket handle, attached at one end to the sternum (breastbone) and at the other end to the vertebral column. The "bucket handle" is lifted by the overall movement upward and outward of the rib cage. These movements increase the thoracic diameters from right to left (transverse) and from front to back (A-P). Thus, the intrathoracic volume increases.

Exhalation

The rib cage movements and pressure relationships are reversed for exhalation. Thus, intrathoracic volume decreases. The intrathoracic pressure increases and forces air outside the body.

Diaphragmatic breathing

The diaphragm is a thin, but strong, dome-shaped muscular membrane that separates the abdominal and thoracic cavities. The abdominal wall is elastic in nature. The abdominal cavity is filled with soft, watery tissues.



Inhalation
As the diaphragm contracts, the dome flattens and the diaphragm descends. This increases the depth (vertical diameter) of the thoracic cavity and thus increases its volume. This decreases air pressure within the thoracic cavity. The greater air pressure outside the body then forces air into the lungs.
Exhalation
As the diaphragm relaxes, the elastic abdominal wall forces the diaphragm back up by pushing the watery tissues of the abdomen against the underside of the relaxed diaphragm. The dome extends upward. The process of inhalation is thus reversed.
Common pathologies
Asthma – spasms or swelling to the bronchial tubes caused by hypersensitivities to allergens
Bronchitis – chronic or acute inflammation of the bronchial tubes
Cancer of the lung – may be caused by inhalation of cancer-producing air and pollutants, such as asbestos and cigarette smoke
Emphysema – chronic obstructive pulmonary disease. Usually associated with chronic bronchitis, smoking and advancing age
Hay fever – allergic reaction in the mucous passages of the upper respiratory tract and the conjunctiva of the eyes usually caused by allergens or pollen
Pleurisy – inflammation of the pleura of the lung
Pneumonia – inflammation of the lung caused by bacteria
Rhinitis – inflammation of the nasal mucous membrane
Sinusitis – inflammation of the paranasal sinuses
Stress – asthma and increased frequency of colds
Tuberculosis (TB) infectious disease caused by the bacteria mycobacterium tuberculosis

Module Eight: The Cardiovascular System

Part 1: Heart Chambers

Learning objectives

In this module, you will learn:

- The structure and function of the cardiovascular system.
- Major blood vessels of the heart.
- The pulmonary and systemic blood circulation.
- Common pathologies.

Introduction

The cardiovascular system consists of the heart and blood vessels. The heart is located in the chest (thoracic cavity) just under the sternum. It angles toward the left and takes up a bit more space on the left. The lower "point" of the heart is known as the apex and the upper portion is called the base.

The heart pumps blood through the body to the lungs and from the lungs to the body.

The heart has two functions:

1 — the heart pumps blood from the body to the lungs so the blood can get oxygen.

2 — the heart pumps blood from the lungs to the body to deliver oxygen.

Two functions – different sides of the heart

Each function is performed by one side of the heart. The heart has right and left sides that are very similar to each other. Function one, body to the lungs, is performed by the right side of the heart while function two, lungs to the body, is performed by the left side. Since the second function is harder than the first one, the left side is slightly larger than the right side.

Heart chambers

All the pumping occurs inside hollow chambers in the heart. There are two receiving chambers (left and right) called atria. There are also two pumping chambers called ventricles. So blood flows into the atria, on to the ventricles and then out. The left and right atria are separated by a wall of tissue called the interatrial septum. Likewise, the ventricles are separated by the interventricular septum.

Vessels

Vessels are needed to transport the blood to and from the heart. On the right side are the superior and inferior vena cavae which delivers blood to the right atrium. On the left side are the pulmonary veins which deliver blood to the left atrium.

You also have vessels that carry the blood from the ventricles toward their destinations. On the right side there is the pulmonary trunk and on the left side, the aorta.

Valves

The heart valves only allow blood to flow in one direction, to where it's supposed to go. There are valves between the atria and ventricles which include the tricuspid on the right and bicuspid on the left. There are also valves where the exiting vessels attach to the ventricles which include the pulmonary (right) and aortic (left).

Layers and membranes

The heart consists of three tissue layers. These include the endocardium, myocardium, and epicardium. The endocardium is the internal layer consisting of simple squamous epithelium and connective tissue. This layer is consistent with the valves of the heart. The middle myocardium is a thick layer of cardiac muscle. The outer epicardium (aka) visceral pericardium consists of a thin serous membrane.

The heart is surrounded by a double-layered sac consisting of two membranes. The outer membrane consists of fibrous connective tissue and is known as the fibrous or parietal

pericardium. The inner membrane is thinner and consists of simple squamous epithelium. It is known as the visceral or serous pericardium. The visceral pericardium is consistent with the great vessels of the heart and the diaphragm.
Serous fluid known as pericardial fluid exists between the membranes. The fluid helps to reduce friction when the heart beats.

Blood flow through the heart

Blood flows from…

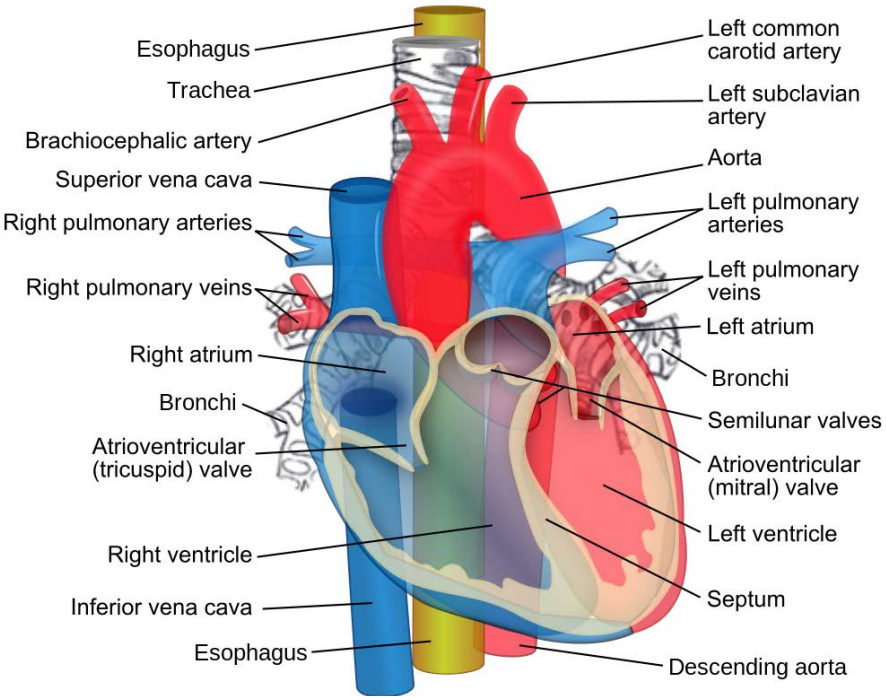
- Superior and inferior vena cava to
- Right atrium past the
- Tricuspid valve to
- Right ventricle past
- Pulmonary valve to
- Pulmonary trunk and arteries to
- The lungs

AND blood flows from the lungs to…

- Pulmonary veins to
- Left atrium past
- Bicuspid valve to
- Left ventricle past
- Aortic valve to
- Aorta to
- The body

Part 2: Heart Structures

The bicuspid and tricuspid valves are connected to the walls of the ventricles via tendon-like structures aptly named chordae tendineae. These connect to papillary muscles on the ventricle walls.
Between the atria is a small dent-like structure which is a remnant of foetal circulation called the fossa ovalis. This used to be a hole with a flap called the foramen ovale but this closes at birth.
The coronary arteries supply the heart muscle with oxygenated blood. The right coronary artery branches off of the aorta and resides in the coronary sulcus (groove). It divides into the right marginal and posterior interventricular arteries. The right marginal supplies the right atrium and ventricle while the posterior interventricular supplies the posterior sides of both ventricles.
The left coronary also branches from the aorta and divides to form the anterior interventricular artery (aka left anterior descending artery), the left marginal artery and circumflex artery. The anterior interventricular artery supplies the anterior side of the ventricles. The left marginal artery supplies the lateral wall of the left ventricle and the circumflex artery supplies the posterior wall of the heart. The left side of the heart muscle is drained by the great cardiac vein and the right side is drained by the small cardiac vein. Both veins empty into the coronary sinus which empties into the right atrium.



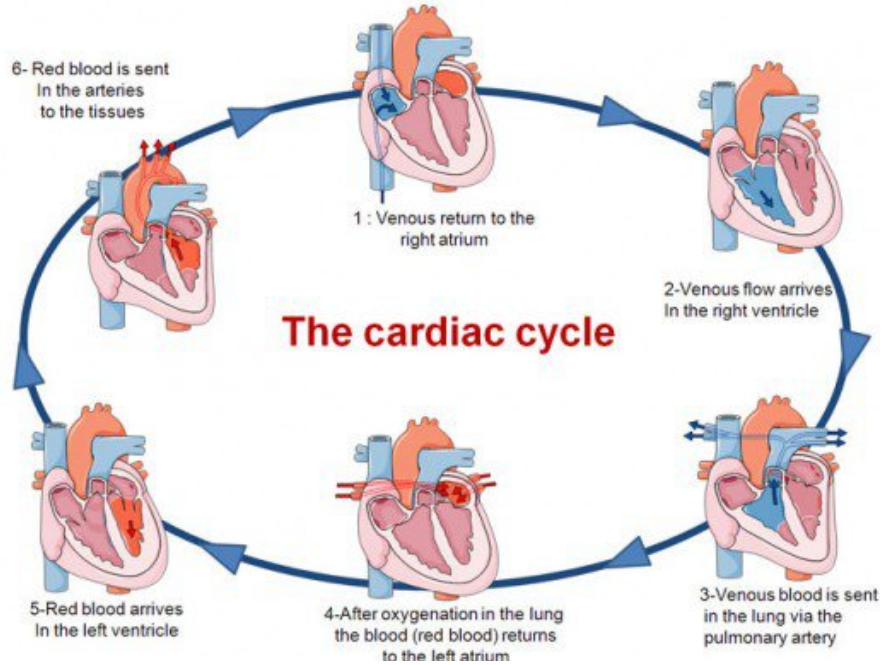
The cardiac cycle

The cardiac cycle consists of 3 phases:

Cardiac diastole: Heart rests and fills up with blood.

Atrial systole: Atria contract pushing blood into ventricles.

Ventricular systole: Ventricles contract pushing blood out.



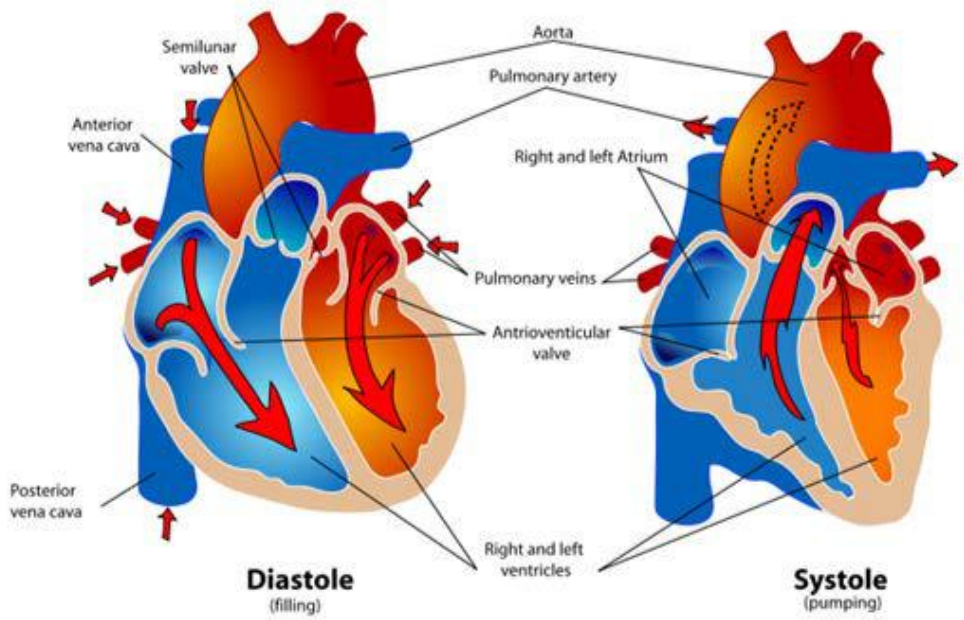
Systole means to contract and diastole means to rest. So we can have atrial or ventricular systole and diastole. We also have to cover the concept that valves open and close by virtue of pressure changes. As for example, when you squeeze something (systole), the pressure inside it builds. Likewise, when you stop squeezing (diastole), the pressure decreases. If you know the direction of blood flow, then you can figure out which valves are open or closed during the different phases.

Cardiac cycles:

Rest phase—atria and ventricles in diastole (resting, but not for long). The bicuspid and tricuspid valves are open and the aortic and pulmonary valves closed. About 70% of the blood flows into the heart during this phase.
Atrial systole and ventricular diastole (phase 2)—atria are contracting so the pressure builds keeping the bicuspid and tricuspid valves open. The pressure in the ventricles is not high enough to cause opening of the aortic or pulmonary valves at this point so they remain closed.
Ventricular systole and atrial diastole (phase 3)—atria are relaxing and ventricles are squeezing. Now the pressure builds up in the ventricles causing the bicuspid and tricuspid valves to close and the aortic and pulmonary valves to open.
When you listen to the heart (auscultation) what you hear is the closing of the valves. There are two points in the cardiac cycles where valves snap shut making an audible sound. The first heart sound known as S1 represents ventricular systole and is produced by the closing of the bicuspid and tricuspid valves.The second heart sound represents ventricular diastole and is produced by the closing of the aortic and pulmonary valves.
Arteries and veins

- **Arteries always move blood away from the heart**
- **Veins always move blood toward the heart**
- **Arteries are thicker than veins**
- **Veins have valves**

Blood is carried throughout the body by arteries and veins. In fact, blood flows from arteries to smaller tubes called arterioles to the smallest capillaries. The capillaries have an arterial and venous side. Blood flows from the venous side of the capillaries to larger structures called venules to veins.
Arteries and veins have similarities and differences. One similarity is that they both have three layers. These layers, from inside to out are called the tunica interna, tunica media, and tunica externa. The difference is that arteries have a thick tunic media while veins have a much thinner middle layer. Another difference is in the direction of blood flow. All arteries carry blood away from the heart while veins carry blood to the heart.
The third main difference is that veins have one-way valves that only allow blood to flow to the heart. The reason for this is that there is not a lot of pressure generated internally in veins. Veins have to rely on external pressure generated by muscular contraction. Muscles contract and veins are squeezed increasing the pressure inside and moving the blood toward the heart via the one-way valves.



Part 3: Arteries and Veins

The main flow

The circulatory system is a lot like a road system. There are major highways (large arteries) that connect with smaller roads (arterial branches) that lead to, for example, your house (organ). You could even give directions starting from the heart and end in a specific organ. Take the aortic arch and follow the thoracic aorta which will become the abdominal aorta. Don't turn off until you see the exit for the renal artery. Turn right and you will run right into the right kidney.

We will begin our arterial system tour with the first branches of the aorta. From right to left these are brachiocephalic, left common carotid and left subclavian. These branches are not symmetric. There is a common branch on the right called the brachiocephalic, but two separate arteries on the left, common carotid and subclavian. One way to remember the brachiocephalic is to look at the words brachio (arm) and cephalic (head). One branch goes to the arm and the other to the head. On the right, there are separate branches for the arm (subclavian) and head (common carotid).The brachiocephalic then divides into the common carotid and subclavian arteries which continue to the head and arm.

Major flow to the left side of the head:

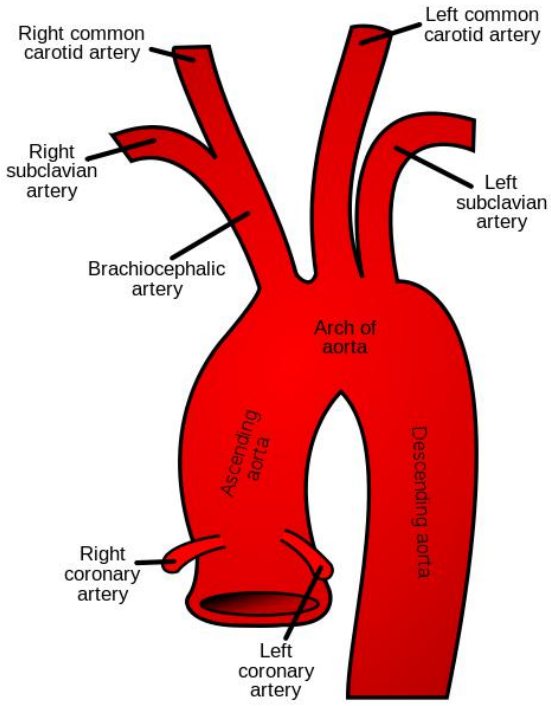
Aorta—brachiocephalic—left common carotid—internal/external carotids

Major flow to the left arm:

Aorta—subclavian—axillary—brachial—ulnar/radial

Major flow to the trunk and leg:

Aorta—arch of aorta—thoracic aorta—abdominal aorta—common iliacs—external iliac—femoral—popliteal—anterior/posterior tibial.



What about veins?

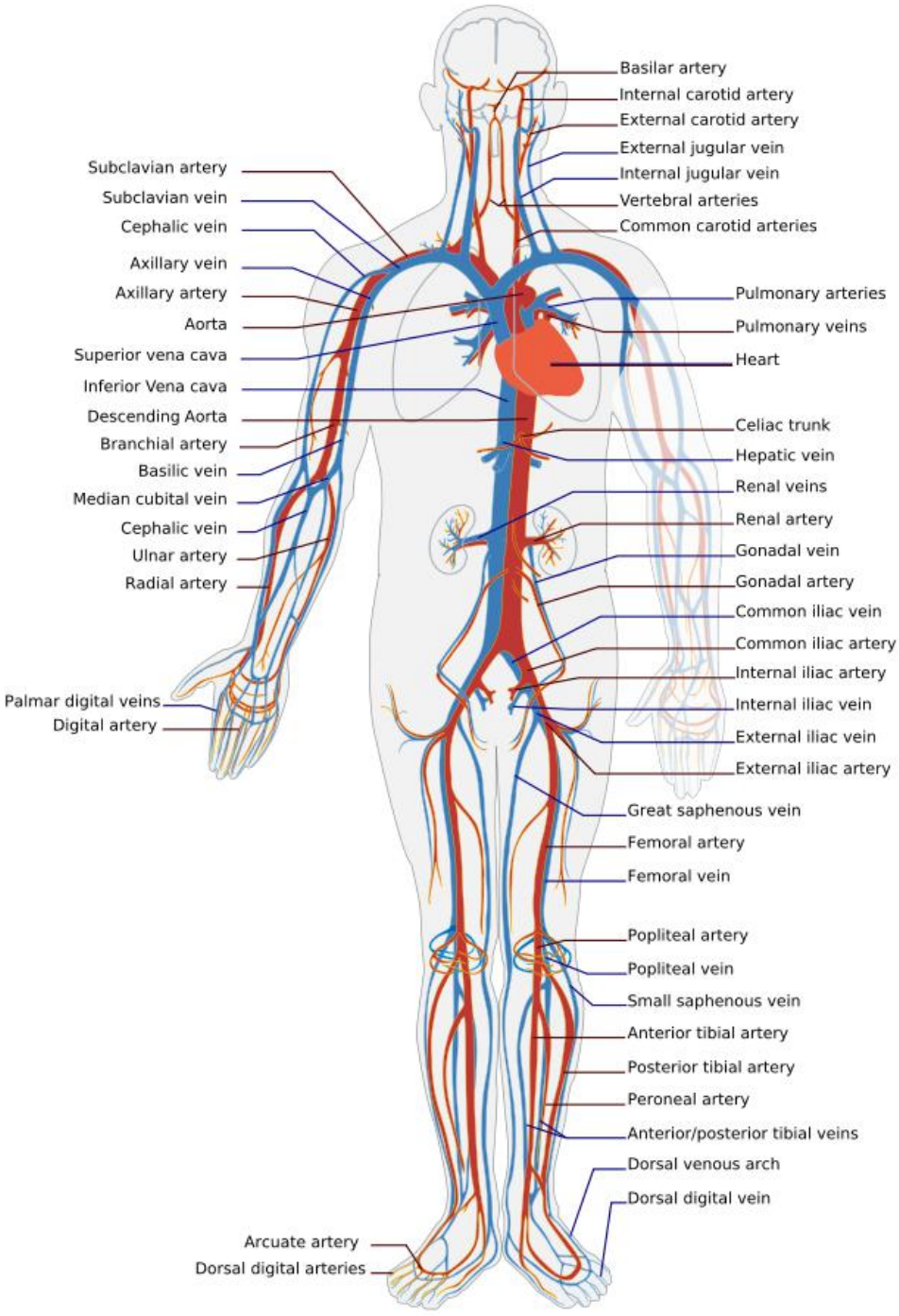
If you begin with the heart, you might remember that the inferior and superior vena cavae bring blood to the right atrium. If you look at the superior vena cava, you'll see that it divides into two brachiocephalic branches. You know that the brachiocephalic will divide into branches for the head and arm. These are the jugular and subclavian.

If you follow the subclavian vein, you'll see that it follows the same naming as the arteries: subclavian—axillary—brachial—radial/ulna.

The difference is that we also have some superficial veins. There is one on the outside of the arm called the cephalic and one on the inside called the basilic. There is also a superficial vein in the elbow called the median cubital.

If we follow the inferior vena cava all the way down to the abdomen, we see that it eventually divides into common iliacs just like the arteries. The naming is the same as the arteries. In fact, these veins run right next to the arteries.

The difference, again, is the superficial veins. There is one important superficial vein that runs down the inside of the leg all the way to the ankle. This is the great saphenous vein.



How does the cardiovascular system work?

Let's begin with heart muscle contraction.

The cardiac muscle contains a special structure called an intercalated disc. These connect the cardiac muscle cells together and help to conduct electrical impulses across the heart.

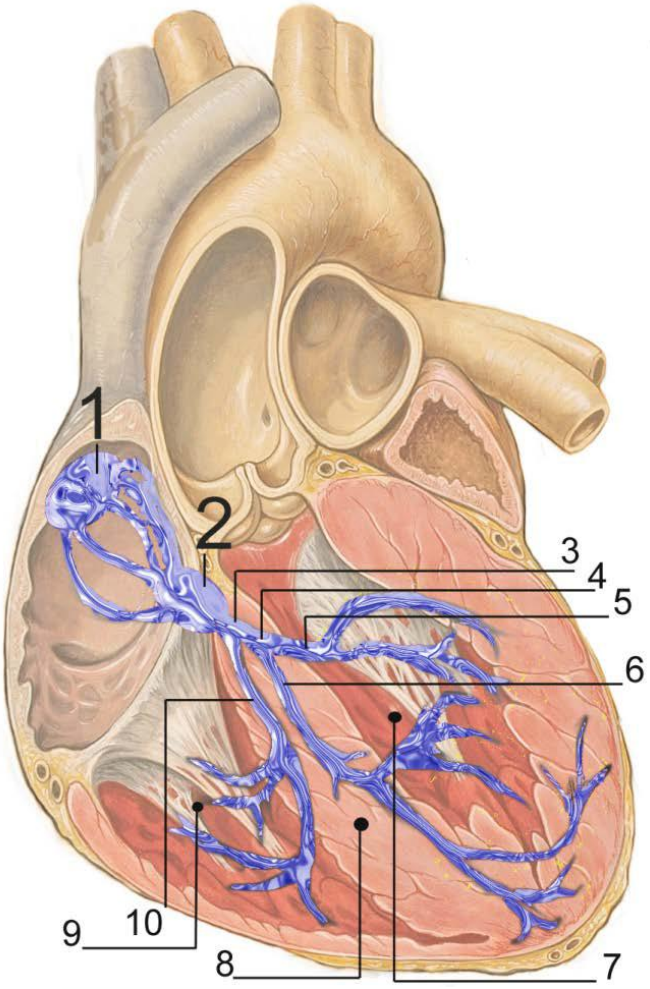
Cardiac conduction

Cardiac tissue contains areas that produce action potentials. In other words, there are self-generating areas right in the heart. This means that theoretically you could take a heart and put it in a solution of electrolytes and it would beat totally on its own, without any signal from the nervous system.

Electrical impulses flow across the heart from node to node.

The nodes are the SA, AV, and AV Bundle.

The self-generating areas of the heart are known as nodes. The main node is located in the posterior wall of the atrium and is called the sinoatrial node (SA node). The SA node is often called the “pacemaker” node because it sets the pace of heart contraction. The SA node can generate impulses totally on its own at 60-100 beats per minute (bpm).
The SA node transmits impulses to the next node called the atrioventricular node (AV node). The AV node is located on the floor of the right atrium. If something goes wrong with the SA node the AV node can take over and generate impulses from 40-60 bpm.
The AV node transmits impulses to the atrioventricular bundle (Bundle of His) located between the atria and ventricles (hence the name atrioventricular). If something goes wrong with the AV node the AV bundle can generate impulses from 20-40 bpm.
The impulses then move down two branches called the right and left bundle branches. These carry the impulses to the ventricles via fast conducting fibres called Purkinje fibres.



1. Sinoatrial Node 2. Atrioventricular Node 3. Bundle of His 4. Left Bundle Branch 5. Left Posterior Fascicle 6. Left Anterior Fascicle 7. Left Ventricle 8. Ventricular Septum 9.Right Ventricle 10. Right Bundle Branch

Even though the heart can contract all on its own, it still needs to be regulated by the nervous system. So, if you’re working out aerobically or sitting on your behind studying, your heart rate needs to be regulated to get just the right amount of oxygenated blood to your tissues.
The heart is regulated by the nervous system via the sympathetic and parasympathetic divisions. In the brain stem in the medulla oblongata is an area known as the cardiac control centre. This sends impulses to the vagus nerve (cranial nerve X) and the cardiac accelerator nerves. The vagus nerve is a parasympathetic nerve that secretes acetylcholine to help slow the heart down while the cardiac accelerator nerves are

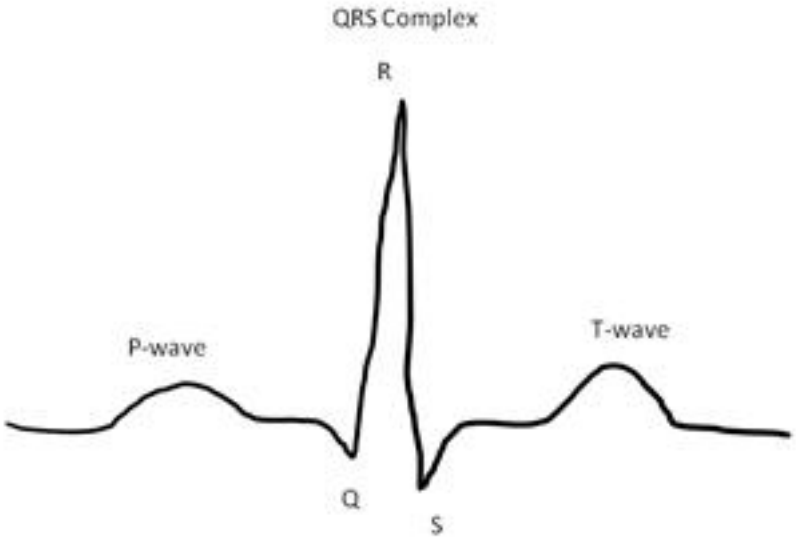
sympathetic nerves that secrete norepinephrine that speeds the heart up. Both work to regulate the heart rate depending on the body's needs.
In order to regulate heart rate, something must be sensed so that the nervous system can respond. There are pressure receptors called baroreceptors located in the aorta and carotid arteries.

Keeping the blood pressure normal
The goal of the cardiovascular system is to get oxygenated blood to the tissues. In order to do this, the system must create a force to push the blood to where it needs to go. That force is pressure. The system must create and maintain what is known as normal blood pressure in order to move the blood.
When you visit your doctor, she takes your blood pressure by wrapping a cuff around your arm and pumping it up with air. She then lets the air out and listens for the familiar 'lub dub 'sound of the heartbeat. The sound she first hears is known as the systolic blood pressure. This one is usually around 120 mm Hg (pressure is measured in millimetres of mercury). She then listens and notes when the sound disappears which should be around 80 mm Hg. This is the diastolic blood pressure.
The systolic pressure then represents the pressure in the system during contraction of the heart or systole. The diastolic pressure represents the pressure in the system when the heart is at rest or diastole.
The main factors that affect blood pressure are:
- Cardiac output
- Blood volume
- Peripheral resistance

These are the major three points when it comes to controlling blood pressure.
Pressure in the capillaries
Capillaries are leaky. The arterial side loses fluid while the venous side gains fluid.
Blood pressure helps capillary function. Remember that the capillaries are the smallest blood vessels and their function is to exchange substances with tissues and cells. In order to achieve this goal, capillaries must operate via some kind of pressure system.
You can think of the capillaries as working like a filter. Think of how a water filter works. For example, a water supply to a house comes from a well. There is a pump that pushes the water through the house and the water moves through a filter to filter out sediment and some minerals. In order for the water to move through the filter, the pressure on one side must be greater than the other side. Water always moves from higher to lower pressure in a system such as this.
The same kind of thing happens in capillaries. Blood must move from higher pressure inside the capillaries to lower pressure outside. The pressure inside the capillaries (blood pressure) is also known as hydrostatic pressure (this means fluid pressure). We can call this pressure capillary hydrostatic pressure (CHP). This pressure must be the highest in order to move fluid from inside to outside the capillary.
Since fluid moves out of the capillary and into the interstitium (tissue surrounding the capillaries) we have to consider any fluid pressure there. The interstitial fluid pressure is called the interstitial hydrostatic pressure (IHP). This pressure is negative (a sucking force) due to the sucking action of the lymphatic capillaries.
There are also substances that act as "salts" in the interstitium. These will also create an osmotic sucking force that pulls fluid back into the interstitium. This pressure is called interstitial colloid osmotic pressure (ICOP).

The various movements of fluid between the capillaries and interstitium maintain a balance. Disrupting this balance can result in oedema.
So, in a nutshell, the arterial side of the capillary loses fluid while the venous side gains fluid.

Part 4: The ECG
In order to learn the ECG, you need to know at least part of the alphabet (P, Q, R, S, T). Each portion of the ECG represents something going on in the heart.
The P wave is the first bump on the ECG and it represents depolarization of the atria. The atria depolarise shortly before they contract so the P-wave represents atrial systole.
The P wave is followed by the QRS complex. The QRS complex represents ventricular depolarization. Atrial repolarization is also occurring during this time but is overshadowed by the powerful ventricular signal. The T wave follows the QRS complex and results from ventricular repolarization.
Some common measurements include the P-R interval and the Q-T interval. The P-R interval extends from the beginning of the P wave to the beginning of the QRS complex. A prolonged P-R interval can indicate a conduction problem. The Q-T interval extends from the end of the P-R interval to the end of the T wave. The Q-T interval represents ventricular systole. A prolonged Q-T interval can indicate heart damage or electrolyte problems.



Common pathologies
Anaemia – when the haemoglobin level in the blood is below normal
Aneurysm – abnormal balloon-like swelling in the wall of an artery
Angina – caused by insufficient blood to the heart muscle. A condition the indicates ischemic heart disease
Arteriosclerosis – circulatory system condition with thickening, narrowing, hardening and loss of elasticity in the walls of the arteries
High blood pressure – a condition when the resting blood pressure is above normal, or consistently exceeding 160/95 mmHg

Low blood pressure – a condition when the blood pressure is below normal, usually 99/59 mmHg
Congenital heart disease – defect in the formation of the heart which decreases its efficiency. Defects may be in as follows:

- **Ventricular septal defects** – non-closure of the opening between left and right ventricle
- **Atrial septal defect** – non-closure of the opening between the right and left atrium
- **Coarctation of the aorta** – narrowing of the aorta
- **Pulmonary stenosis** – narrowing of the pulmonary aorta

Haemophilia – hereditary disorder where the blood clots very slowly due to deficiency of coagulation factors: factor VIII or factor IX
Haemorrhoids – enlargement of the spongy blood-filled cushions in the walls of the anus
Heart attack – myocardial infarction, damage to the heart muscle resulting from blockage to the coronary arteries
Hepatitis – inflammation of the liver which can be from toxic substances, viruses, or immunological abnormalities. Different forms of hepatitis: A, B or C.
High cholesterol – a high blood level of cholesterol is associated with degeneration of the walls of the arteries and an increased risk for thrombosis
Leukaemia – any of a group of malignant diseases in which bone marrow and other blood-forming organs produce an increased number of certain types of immature or abnormal white blood cells
Pacemaker – artificial electrical device implanted under the skin to stimulate and control heart rate
Phlebitis – inflammation of the wall of a vein
Pulmonary embolism – blood clot carried into the lung blocking the flow of blood to pulmonary tissue
Raynaud's syndrome – disorder of the peripheral arterioles
Stress – increased heart beat, high blood pressure, coronary thrombosis, heart attacks
Stroke – blocking the blood flow to the brain by an embolus in a cerebral blood vessel
Thrombosis – when blood changes from liquid to solid and forms a blood clot, obstructing the blood flow to tissues
Varicose veins – when the valves loses their strength and the blood flow becomes reverse or static

Module Nine: The Blood

Part 1: Red Blood Cells

Learning objectives

In this module, you will learn:

- The function of blood.
- Composition of blood.
- Transport of blood.

Introduction

Blood consists of cells suspended in a fluid matrix called plasma. Blood contains red cells, white cells and cell fragments called platelets.

Red Blood Cells

Red blood cells are simple structures that carry oxygen.

First of all, red blood cells (RBC's or erythrocytes) are red. The red comes from a pigment called haemoglobin (Hb). This is important because it carries oxygen. In fact, that's the main function of RBCs - to carry oxygen to our cells and tissues. The cells and tissues need oxygen in order to stay alive.

When oxygen combines with haemoglobin, we get oxyhaemoglobin.

When oxygen breaks away from haemoglobin, we get deoxyhaemoglobin.

Since RBCs carry oxygen, it is important that they have as large a surface as possible to do their job. They have a special shape. It's called a biconcave disc. It looks almost like a doughnut, where the hole didn't go all the way through. The special shape works to increase the surface area to carry more oxygen.

We have lots of RBCs in our blood. In fact, our bodies make nearly 2.5 million every second. We can count the number of RBCs in blood. Here are some average normal values:

- 4,600,000 – 6,200,000 in males
- 4,200,000 – 5,400,000 in females
- 4,500,000 – 5,100,000 in children

Red blood cell count = number of RBCs in a cubic millimetre of blood.

Red blood cells are great workers. They carry oxygen throughout their lives. They have relatively short lives that last about 120 days and then they are recycled.

Here's how it works. The old RBC actually becomes worn out. As it wears out it gets smaller. When it gets small enough, it pops through the capillaries in the liver or spleen where the process of recycling begins.

Once inside the organ (e.g.it's in the liver), it is attacked by white blood cells called macrophages. The macrophages attack and liberate the haemoglobin. The haemoglobin is further broken down into haem and globin portions. The haem gets broken down into iron and biliverdin. The iron moves into the blood and is carried off into storage by a plasma protein called transferrin. The biliverdin gets converted to bilirubin and is secreted by the bile. The globin portion gets recycled as plasma proteins.

A shortage of RBCs is known as anaemia. There are a number of different types of anaemias. Some of the more common are pernicious, iron deficiency and blood loss anaemias.

Pernicious anaemia results from a deficiency of vitamin B12. Usually, the body cannot absorb the vitamin because of problems with the stomach lining. Vitamin B12 is needed for the maturation of RBCs. Without it, the cells are immature and large.

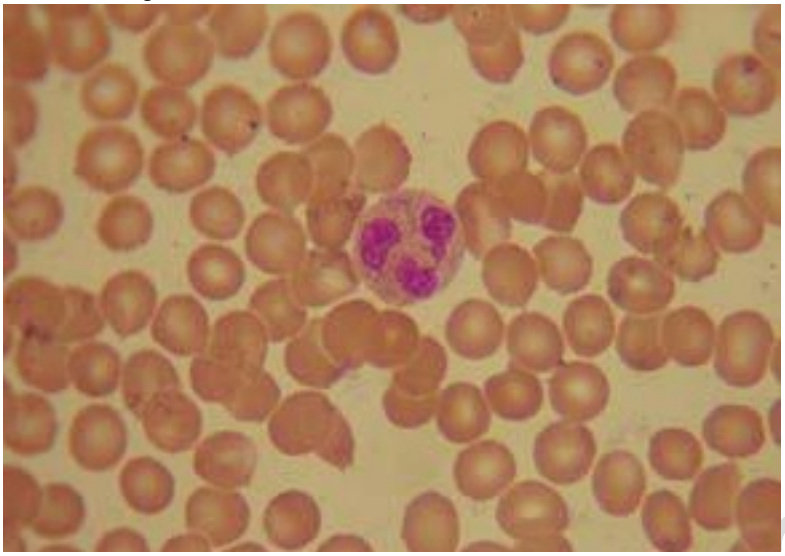
Iron is needed for the haem portion of haemoglobin. Without iron, there may not be adequate haemoglobin. This affects the oxygen carrying capabilities of the cell.

Blood loss anaemia is probably the simplest to understand. As blood is lost so are RBC's. The RBC count decreases and so do blood oxygen levels.

White Blood Cells

There are two kinds of white blood cells: granulocytes and agranulocytes.
White blood cells are called leukocytes. There are two categories of leukocytes. Those with granules in their cytoplasm (granulocytes) and those without (agranulocytes).

Granulocytes

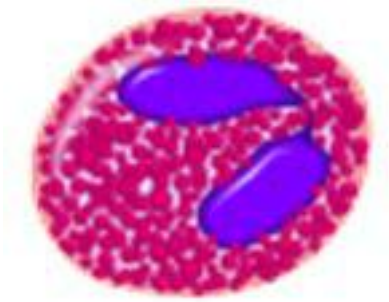


Granulocytestend to be significantly larger than red blood cells. There are three main types of granulocytes. These are the neutrophils, basophils and eosinophils. Granulocytes also have a significantly shorter lifespan - measured in hours - than red blood cells (120 days).

Neutrophils

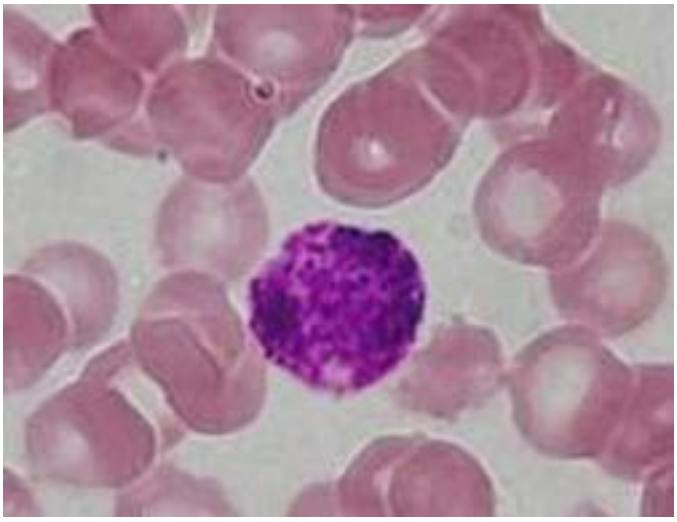
Neutrophils are larger than red blood cells and contain a segmented nucleus. They are the majority of leukocytes. Their function is primarily phagocytosis of bacteria and viruses. They are the first cells to arrive at an infection.

Eosinophils



Eosinophils have a bilobed nucleus and granular cytoplasm. They are relatively rare cells that only make up 1% to 3% of the leukocyte population. Their function is to moderate allergic reactions and defend against parasites.

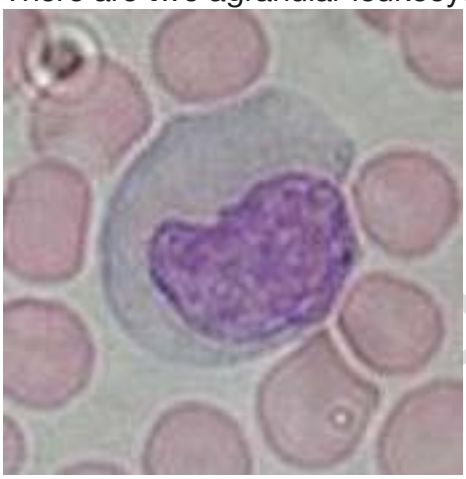
Basophils



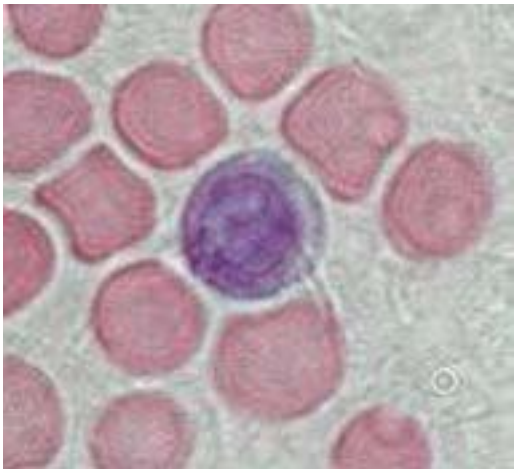
Basophils have the same size and shape of nuclei as eosinophils. They have fewer and much larger granules. The granules release histamine (a vasodilator) and heparin (an anticoagulant). Basophils function in inflammation. Think of the cardinal signs of inflammation; heat, redness, pain and swelling. The basophils release heparin and histamine that function to bring more blood to the area. The additional blood produces the signs of inflammation. Basophils are also relatively rare cells and represent only 1% of the leukocyte population.

Agranular Leukocytes

There are two agranular leukocytes. These include monocytes and lymphocytes.



Monocytes are the largest blood cells. Their nuclei can be spherical, kidney-shaped, oval or lobed. Monocytes have a function very similar to neutrophils. Monocytes work to clean up debris and phagocytize bacteria. They constitute 3% to 9% of the leukocyte population.



Lymphocytes are about the same size as red blood cells. They constitute 25% to 30% of the leukocyte population. There are two main types of lymphocytes. These include T-lymphocytes and B-lymphocytes. Both function in immunity. T-lymphocytes attack pathogens and help activate B-lymphocytes. B-lymphocytes produce antibodies when activated that attack pathogens.

Movement

White blood cells can move between capillary walls and enter the tissue. They do so by a process known as diapedesis. In diapedesis, an appendage of the cell first moves to an area. This is followed by the remainder of the cell.

White blood cells are attracted to an infected area by substances secreted by damaged cells. This is known as chemotaxis. The white blood cells then break up bacteria and form pus.

Part 2: WBC Count

The typical WBC count is about 5000 to 10000 cells per cubic millimetre. A high count is called leukocytosis and can be caused by infection, exercise, loss of body fluids and emotional stress. A low count is called leukopenia and can be caused by viruses such as influenza, measles, mumps, chicken pox and toxins such as lead poisoning. A test that breaks out the relative percentages of WBCs is called a differential.

Platelets

Platelets are fragments of cells that help to stop bleeding.

Platelets are cell fragments called thrombocytes. Haemocytoblasts (stem cells) differentiate into megakaryocytes that fragment into platelets. Platelets are about one-half the size of red blood cells. There are about 130,000 to 360,000 platelets per cubic millimetre of blood.

Platelets help to stop bleeding by sticking together to form plugs and secreting the hormone serotonin which acts to vasoconstrict the vessels. The sticking together of platelets is sometimes called platelet aggregation. Drugs such as aspirin inhibit platelet aggregation.

Blood Plasma

Plasma is the fluid portion of blood that carries the cells and platelets. Plasma is straw-coloured and clear and contains water with a variety of substances. Plasma contains various proteins including fibrinogen, globulins and albumin. Plasma also contains dissolved gases such as carbon dioxide and oxygen and nutrients such as carbohydrates, amino acids and lipids. Lipids are packaged in lipoproteins such as very low-density lipoproteins (VLDL), low-density lipoproteins (LDL), high-density lipoproteins (HDL) and chylomicrons. Other constituents of plasma include electrolytes such as sodium, potassium, calcium, magnesium, chloride, sulphates, phosphates, and

bicarbonate ions and nitrogenous substances such as uric acid, urea, creatine, and creatinine.

Haemostasis

There are three ways the blood system helps to stop bleeding:

- Damaged blood vessels constrict.
- Platelets get sticky and form plugs.
- Clotting.

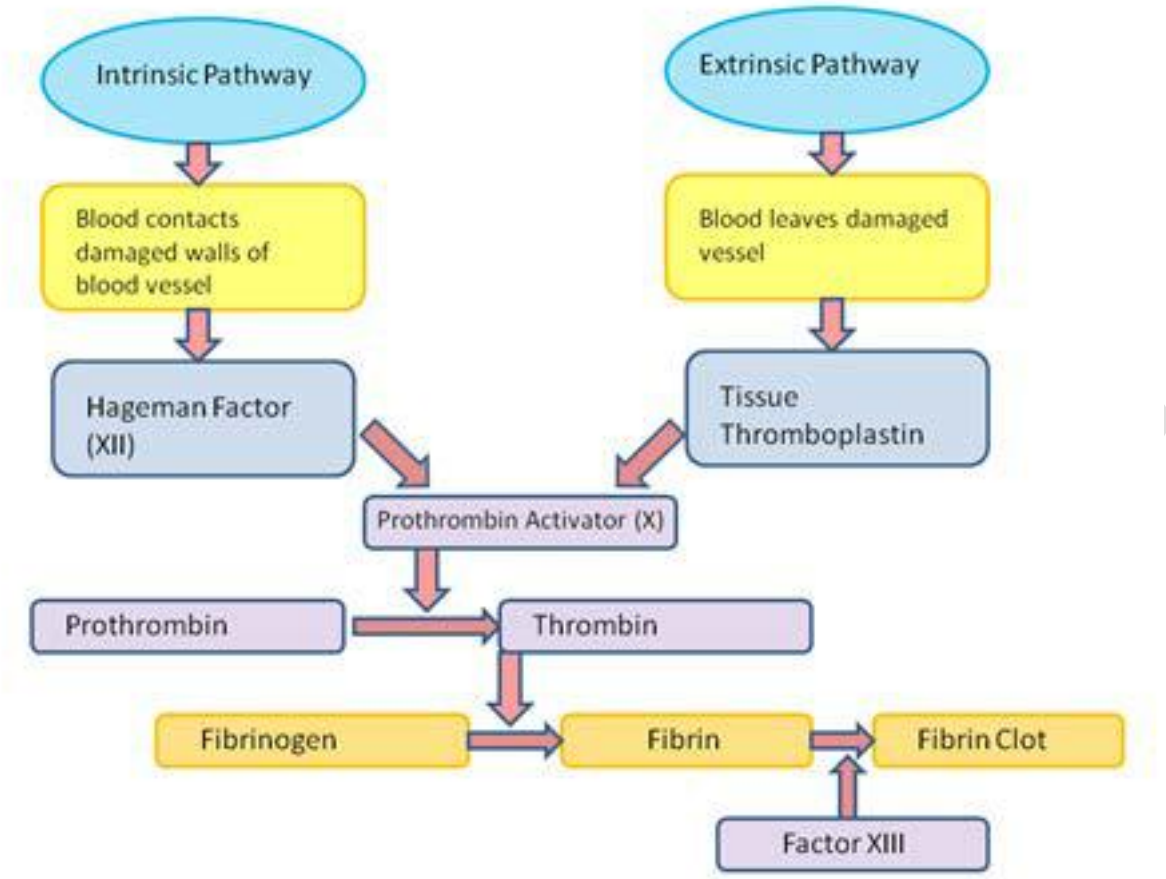
The blood system has some self-protective mechanisms built into it. These come into play during bleeding. The stopping of bleeding is called haemostasis. There are three basic mechanisms of haemostasis. These include blood vessel spasm, platelet plug formation and clotting.

Blood vessel spasm occurs in response to a damaged vessel. Blood vessels have a smooth muscle layer that constricts when the vessel is damaged. Platelets also release serotonin that facilitates constriction of the vessel. This action helps to stop the bleeding.

Platelets become sticky when they contact damaged blood vessels. They can stick together to form a plug. The platelet plugs help to plug small holes in vessels.

Clotting is the third mechanism of haemostasis. There are two pathways consisting of a cascade of reactions involving molecules called clotting factors (designated by Roman numerals). The two pathways are called the intrinsic and extrinsic pathways. Both pathways converge at a common point to form a fibrin clot.

The intrinsic pathway is triggered by blood contacting damaged blood vessel walls. Stasis (no movement) of blood can also trigger the intrinsic pathway which is why you're supposed to take a break and move around when on a long trip or when sitting for extended periods. The extrinsic pathway is triggered when blood leaves a damaged blood vessel and enters the tissue. The first clotting factor activated is in the tissue, known as tissue thromboplastin. Both pathways converge at a common pathway which results in the conversion of the soluble plasma protein fibrinogen to the insoluble protein fibrin. Fibrin threads form and weave together to form the clot.



Clotting Terms

Here are a few terms related to clotting:

- Haematoma—clot resulting from blood leakage
- Thrombus – clot forming in vessel
- Embolus—thrombus broken loose in bloodstream
- Embolism—clot lodged in blood vessel cutting off circulation
- Infarction—clot forming in vessel to organ (heart, lung, brain)
- Atherosclerosis – accumulation of fatty deposits in arterial linings

Blood Typing

Blood comes in different types. We can categorise blood according to the presence or absence of certain antigens on the surface of red blood cells.

There are only three antigens to remember: A, B, and Rh.

- **If your blood only has the type A antigen on the surface of your RBCs, then your blood type is A**
- **If your blood only has the type B antigen on the surface of your RBCs, then your blood type is B**
- **If you have both antigens, your blood type is AB**
- **If you have neither antigen, your blood type is O**
- **If you have a special antigen called the Rh antigen, then you are Rh positive**

Not only do you have antigens on the surface of your RBCs but you also have antibodies that can connect with the opposite antigen.

- If you are type A, you have the antibody that is against type B
- If you are type B, you have the antibody that is against type A
- If you are type AB, you have neither antibody
- If you are type O, you have both antibodies

The last bit of information you need to know is that if you are Rh positive, you can receive Rh positive or Rh negative blood. However, if you are Rh negative, you can only receive Rh negative blood.

Type	A+	A-	B+	B-	AB+	AB-	O+	O-
A+	+	+					+	+
A-		+						+
B+			+	+			+	+
B-				+				+
AB+	+	+	+	+	+	+	+	+
AB-		+		+		+		+
O+							+	+
O-								+

You can see that the type that can receive most of the blood types is type AB. Type AB is called the universal recipient. You can also see the type O can donate to the other types. Type O is called the universal donor.

Common Pathologies are covered in the module for the Cardiovascular System

Module 10: The lymphatic system

Part 1: The Lymphatic System

Learning objectives

In this module, you will learn:

- Functions of the lymphatic system.
- Definition of lymph and how it is formed.
- The connection between lymph and blood.
- The circulatory pathway of lymph.
- Position and drainage of the main lymphatic nodes in the body.

The lymphatic system

The lymph picks up fluid that has moved out of the circulatory system and carries it back into circulation while cleaning it up along the way.

A good portion of the immune system resides in the lymphatic system. A host of white blood cells stands ready to defend against nasty pathogens.

Circulatory system capillaries are leaky. It should be this way because substances should leak out of capillaries and into cells and tissues. The function of capillaries is to bring good things like oxygen and nutrients to tissues so they can survive. The capillaries work much like a filter and we will see that filters work because of changes in fluid pressure. When we calculate the pressures involved in pushing fluid through the capillaries, we find that there is a net loss of fluid from the capillaries into the interstitium. This means that as blood flows through the capillaries some fluid is lost. Something has to collect that fluid or we would swell up. That something is the lymphatic system.

Another important function is related to the digestive system. When you eat a burger, for example, the carbs, fats and proteins get broken down by enzymes in the stomach and intestines. The broken-down substances are then absorbed. Carbs and proteins move directly into the blood via digestive system capillaries. Fat, however, is packaged up in special packages called chylomicrons and gets deposited into the lymphatic system. The lymphatic system then transports the chylomicrons to the blood.

How does it work?

Let's look at how the lymphatic system picks up interstitial fluid. It actually has its own set of capillaries called lymphatic capillaries. These intertwine with circulatory system capillaries and collect the extra fluid. They are designed to allow fluid to flow one way, into them and off to the rest of the lymphatic system.

Part of that special design of lymphatic capillaries is that the layer of epithelial tissue forms a series of one-way valves to only allow fluid in. The fluid flows from the capillaries to a series of vessels. The vessels have three layers of tissue and contain one-way valves that only allow fluid to flow toward the circulatory system. The pressure to push the fluid through the vessels comes from contracting muscles. This acts like a pump to push fluid through the system. So if you want to move lymph fluid then you need to move some muscles.

Another way that lymph fluid moves is a bit trickier. As you inhale the pressure in the thoracic cavity becomes lower (actually it becomes a negative pressure). The lower pressure creates a suction that pulls lymph fluid into the thorax.

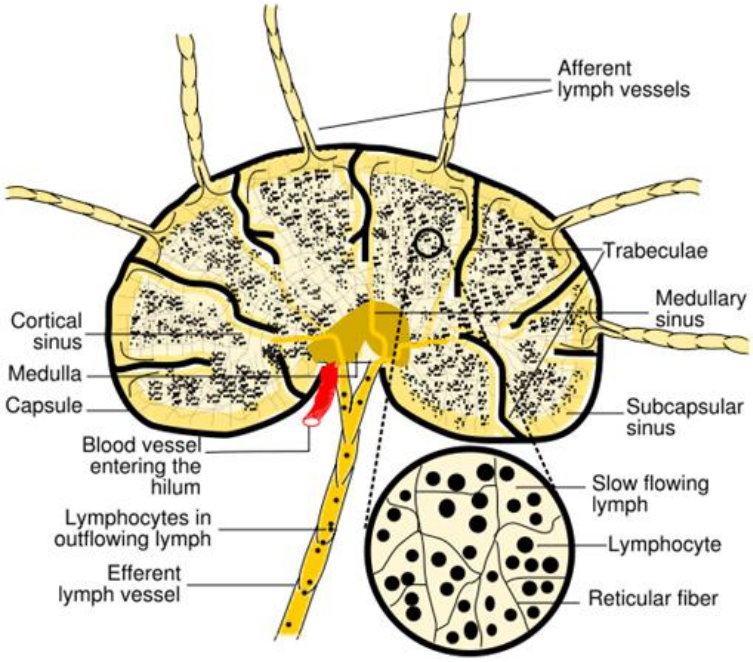
Lymph nodes

If you've visited your doctor for the flu, you would have probably been poked for swollen lymph nodes. The doctor would usually feel your neck and under your jaw for these. This is where some of your lymph nodes are situated - in your neck. You also have them in other locations.

These locations include:

- Axilla (armpit)
- Infraclavicular (under the clavicle)
- Epitrochlear (elbow)
- Inguinal (groin)
- Popliteal (knee)
- Pectoral (chest)

Lymph nodes are oval structures. They have a cortex (outer layer) and medulla (inner layer). Vessels carry fluid into the node (afferent vessels) and out (efferent vessels). There is a “dented” area called the hilus where the efferent vessel exits and blood vessels enter. There is also reticular connective tissue forming a web-like structure throughout the inside of the node.



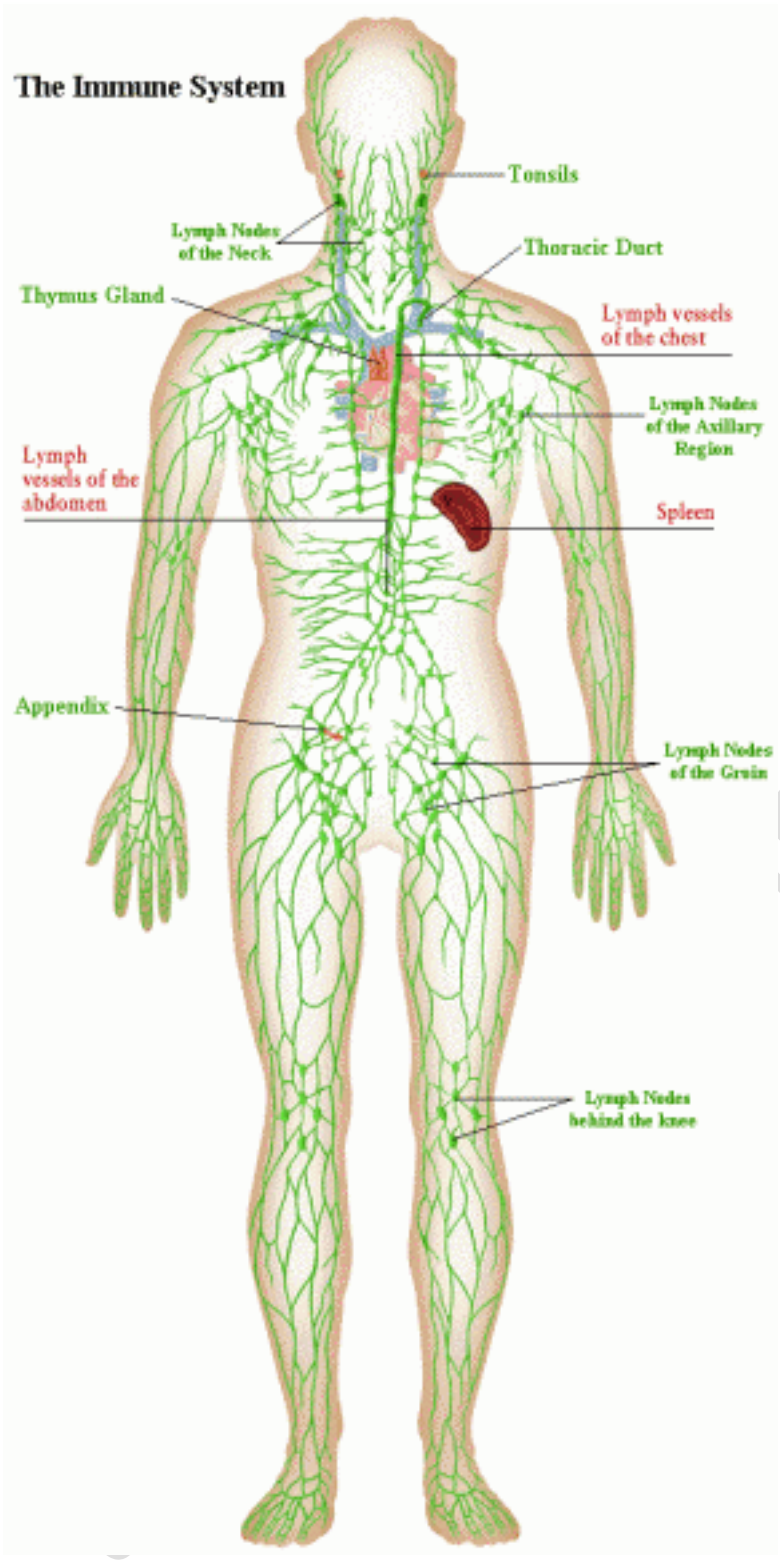
Lymph nodes contain white blood cells that help to “clean up” the fluid that flows through the node. These white blood cells include macrophages and lymphocytes. The macrophages devour pathogens and the lymphocytes also attack pathogens by secreting chemicals that destroy them.

The lymphatic vessels eventually form larger structures known as lymphatic trunks. The lymphatic trunks drain specific portions of the body. The subclavian trunks drain the upper extremities. The jugular trunks drain the head and neck. The bronchomediastinal trunks drain the thoracic area. The intestinal trunks drain the abdomen. The lumbar trunks drain the lower extremities and pelvic area.

The lymphatic trunks connect with larger structures called lymphatic ducts which connect with the venous system at the subclavian veins. There are two ducts including the thoracic duct and right lymphatic duct. The jugular, subclavian and bronchomediastinal trunks connect to either the right internal jugular, right subclavian, or right brachiocephalic trunk. In some people, the three trunks merge to form the right lymphatic duct.

The remaining trunks connect with the thoracic duct. The drainage of lymph fluid is, therefore, asymmetrical with respect to the arrangement of the right lymphatic and thoracic duct. In other words, the right lymphatic duct drains the right side of the head, neck and trunk while the thoracic duct drains the left side of the head, neck and trunk as well as both lower extremities.

In some cases, the intestinal and lumbar trunks merge to form a sac-like structure called the cisterna chyli.

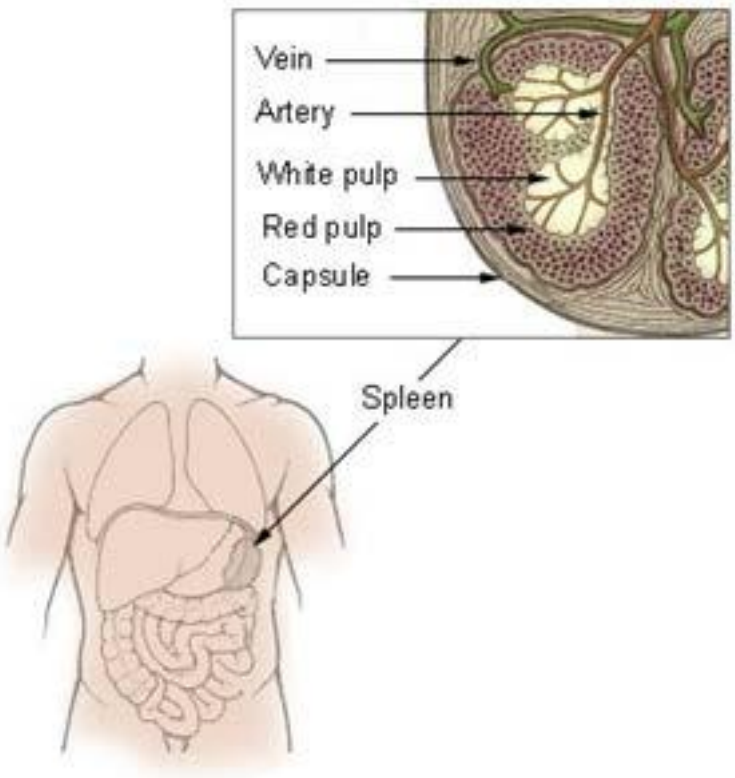


Part 2: Lymphatic System Organs

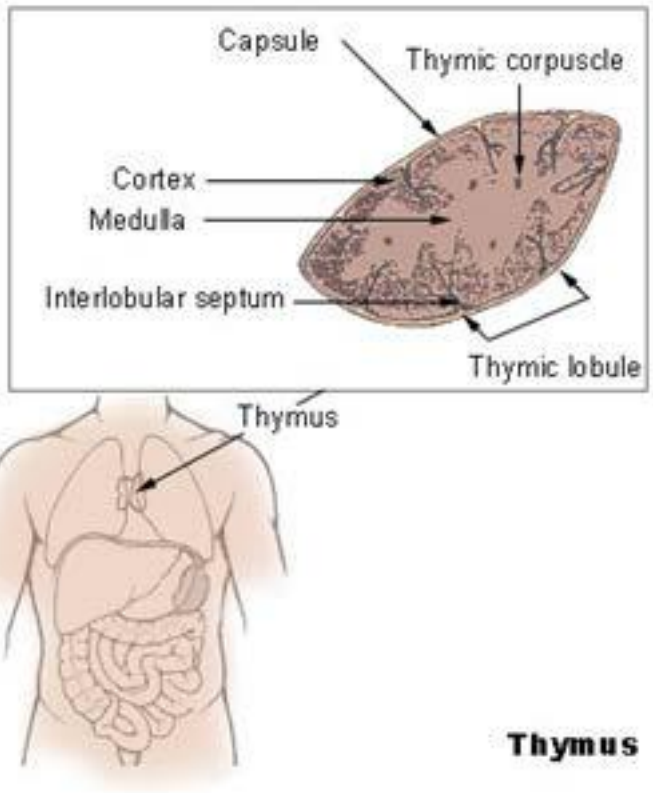
There are two organs associated with the lymphatic system. These are the spleen and thymus. The organs contain lymphatic tissue consisting primarily of the white blood cells we mentioned earlier. As far as the lymphocytes are concerned there are two general types. These are the T and B lymphocytes. Both are produced in the bone marrow and carried to the lymphatic system. Activation of the immune system causes these cells to divide and attack pathogens.

Lymphatic tissue also contains reticular cells that produce reticular fibres. White blood cells connect with these fibres so that fluid moving through the tissue is exposed to the cells. The white blood cells can then destroy bacteria and debris.
Lymphatic tissue resides throughout the lymphatic system. When it is not located in a lymph node or organ such as in the mucous membranes of the digestive, urinary, respiratory and reproductive systems, it has a fancy name known as Mucosa-Associated Lymphoid Tissue (MALT). The tonsils are another example of MALT.

Spleen



The spleen is located in the left upper quadrant of the abdominal area generally close to the diaphragm and is about as large as an adult fist. It consists of an outer connective tissue capsule. The inner portion has a trabeculated structure containing areas of red and white pulp. The spleen also contains venous sinuses.
White pulp consists of lymphatic tissue associated with arteries within lymphatic organs. Red pulp contains both white and red blood cells and is associated with veins.
The splenic artery and vein enter and exit the spleen at the hilum. Blood flows into the spleen and through the trabeculated network. The cells in the spleen work to destroy pathogens. Lymphocytes in the spleen can react to pathogens and trigger the immune system. The spleen also acts as a blood reservoir.



Thymus

The thymus is a gland located just deep to the sternum in the superior portion of the mediastinum. Early in life the thymus is larger and decreases in size with age although it continues to produce white blood cells.
The thymus has two lobes each surrounded by a connective tissue capsule. It contains an outer cortex and inner medulla. The internal region of the thymus is trabeculated and filled with lymphocytes. The thymus produces large numbers of T-lymphocytes that can travel to the blood.

Common pathologies

Acquired Immune Deficiency Syndrome (AIDS) – contracted as a result of the Human Immunodeficiency Virus (HIV) which progressively destroys the immunity of the individual

Hodgkin's disease – malignant disease of the lymphatic tissues

Lupus erythematosus – chronic inflammatory disease of connective tissue, affecting the skin and various internal organs

Lymphoedema – abnormal swelling of body tissues due to an accumulation of tissue fluids

Module 11: The Endocrine System

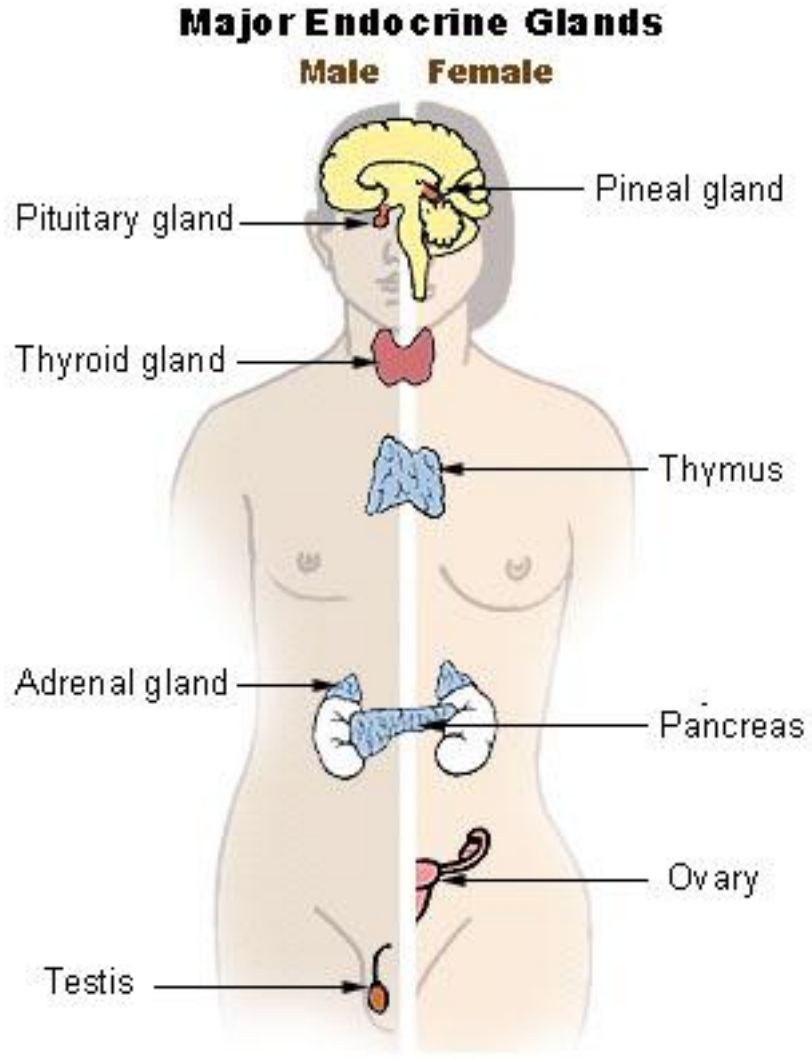
Part 1: Types of Hormones

Learning objectives

In this module, you will learn:

- The function of the endocrine system.
- The definition of a hormone.
- The principal hormone secretions from the main endocrine glands and their effects on the body.

Endocrine system



The endocrine system consists of hormones secreted by glands travelling through the blood to target tissues.

When you think of the endocrine system, you should think of hormones. Hormones are secreted by glands and travel via the bloodstream to what are called target tissues. Substances secreted by glands that don't travel via the bloodstream are called exocrine substances.

We know that glands secrete hormones, but how do the hormones know where to go? They look for special receptors on the target tissue. Hormones work by virtue of their shape. They just fit certain receptors. This diagram showing important endocrine glands.

Types of hormones

There are three basic types of hormones: prostaglandins, steroids and non-steroids.

Prostaglandins

Prostaglandins are secreted by cells and have a local effect. This means that they are secreted by cells and only travel to nearby cells. This is known as a paracrine secretion. Once the hormone reaches the target cell, it can use what is known as the second messenger system. Prostaglandins help to control smooth muscle contraction and relaxation. Prostaglandins also help to promote inflammation and pain.

Steroid hormones

Steroid hormones are transported in the blood. They connect with a special transport protein known as a carrier protein. Once reaching the target cell, the hormone splits from the carrier protein.

Remember that lipid-soluble substances can diffuse through a cell membrane. Since steroid hormones are considered lipids, they can diffuse through the cell membrane and enter the cell. Once inside the cell, steroid hormones combine with specialised receptors located within the cytoplasm of the cell. The hormone combines with the receptor and the receptor-hormone complex moves into the nucleus of the cell. There it causes changes in DNA transcription that cause changes in the metabolism and functioning of the cell.

Non-steroid hormones

Non-steroidal hormones enter the cell differently than steroids. Non-steroidal hormones are not lipid soluble. Since they cannot diffuse directly into the cell they must enter via a different process. Non-steroid hormones enter the cell by using what are known as second messengers.

Receptors for non-steroidal hormones are located in the cell walls of the target cells. When the hormone connects with the receptor on the outside of a cell membrane, a protein known as a G-protein activates and moves down the membrane into the cell. The G-protein binds to an enzyme known as adenylate cyclase and activates it. Adenylate cyclase along with ATP forms a molecule called cyclic adenylate monophosphate or cAMP. cAMP is also known as the second messenger.

cAMP works by activating another enzyme called protein kinase. Protein kinase facilitates the phosphorylation of various proteins. Phosphorylation occurs when phosphates are attached to a molecule. The phosphorylated proteins then activate some enzymes and inactivate others inside the cell. This alters the metabolic activity of the cell and the cell responds in accordance with the intended action of the hormone.

Results of second messenger activation include altered membrane permeability, activation of enzymes, protein synthesis, modulation of metabolic pathways, promoting movement of cells and causing secretion of other hormones.

cAmp works with a variety of hormones including those from:

- Hypothalamus
- Anterior pituitary
- Posterior pituitary
- Parathyroid
- Adrenals
- Thyroid
- Pancreas

There are other second messengers besides cAMP. These include:

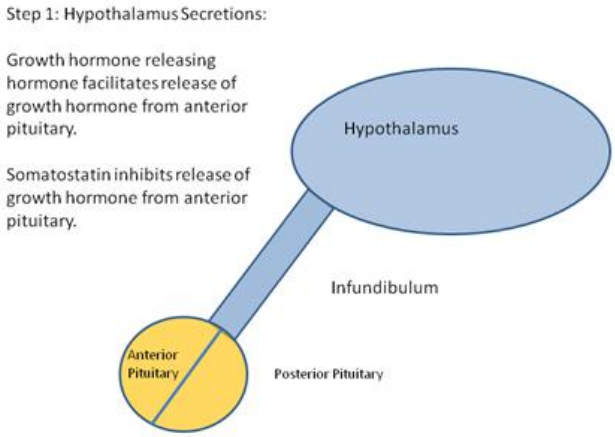
- Diacyglycerol (DAG)
- Inositol triphosphate (IP3)
- Cyclic guanosine monophosphate (cGMP)

Hormones operating via second messengers have a much greater response. Many second messengers can be activated by one hormone.

Second messengers transfer information from the hormone to the cell:

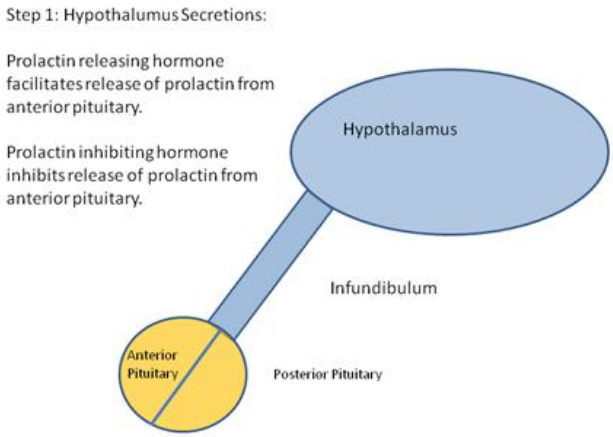
Hormone – G-protein – cAMP – protein kinases
The kinases then alter the cell's function.

Part 2: Overview of Hormones
In order to get the big picture, we will present a brief overview of the important hormones.



Step 2: Pituitary Secretion: Growth Hormone

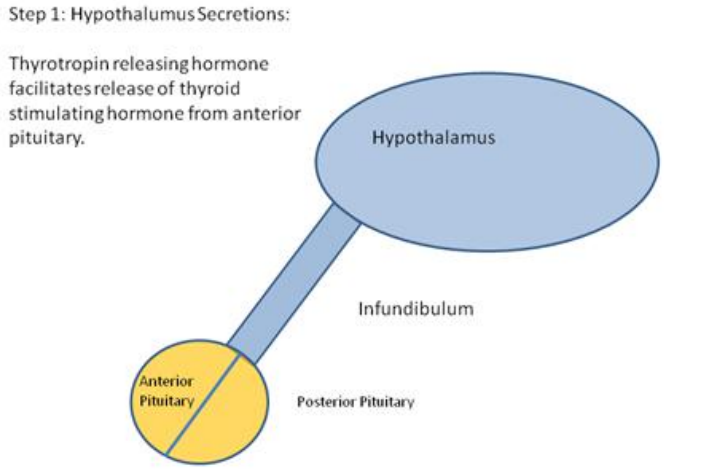
Growth hormone is secreted in response to two secretions by the hypothalamus: Growth hormone releasing hormone (GHRH) and somatostatin (SS). Growth hormone affects cellular metabolism by promoting the movement of amino acids into cells for protein synthesis which affects the overall growth of the organism. Growth hormone releasing hormone secreted by the hypothalamus stimulates the release of growth hormone by the anterior pituitary. Somatostatin inhibits the release of growth hormone.



Step 2: Pituitary Secretion: Prolactin

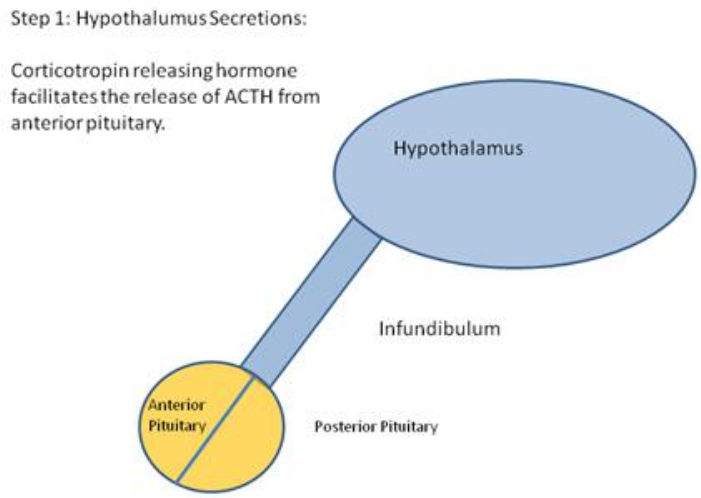
Growth hormone stimulates cells to enlarge and undergo mitosis as well as increasing the rate of protein synthesis and increasing the cellular use of carbohydrates and fats.
Prolactin is secreted in response to two secretions by the hypothalamus. Prolactin-releasing factor (PRF) stimulates secretion of prolactin by the anterior pituitary. Prolactin-inhibiting hormone (PIH) from the hypothalamus inhibits secretion of prolactin by the anterior pituitary.
The function of prolactin is to stimulate milk production in females. In males, prolactin decreases the secretion of luteinizing hormone which facilitates production of the primary

male sex hormones or androgens. Too much prolactin secretion in males can cause infertility.



Step 2: Pituitary Secretion: Thyroid stimulating hormone

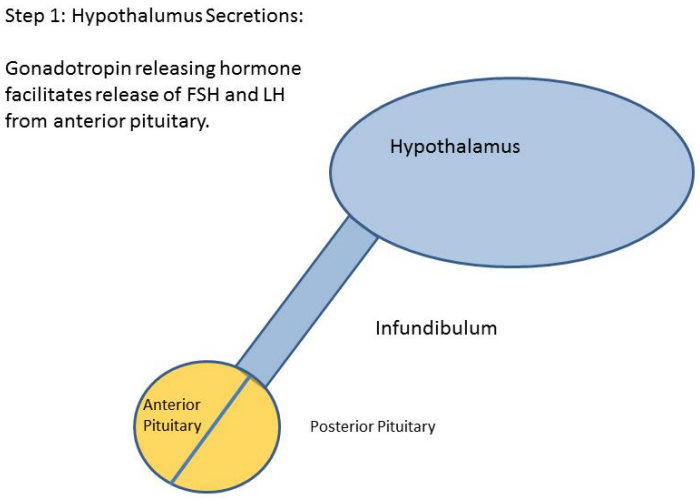
Thyroid stimulating hormone is released by the anterior pituitary in response to the release of thyrotropin releasing hormone from the hypothalamus. Thyroid stimulating hormone causes the thyroid gland to release the thyroid hormones triiodothyronine and tetraiodothyronine (T3 and T4). The blood concentration of thyroid hormones provides a negative feedback mechanism to the hypothalamus to help control the release of thyroid stimulating hormone. Secretion of T3 and T4 is also affected by stress.



Step 2: Pituitary Secretion: Adrenocorticotropic Hormone (ACTH)

Adrenocorticotropic hormone is secreted by the anterior pituitary in response to secretion of corticotropin-releasing hormone (CRH) by the hypothalamus. ACTH is picked up by the adrenal cortex and stimulates secretion of hormones by the adrenal cortex. Adrenal cortex hormones then provide feedback to the hypothalamus and anterior pituitary to help regulate secretion of ACTH. Stress also affects secretion of ACTH.
Follicle stimulating hormone is secreted by the anterior pituitary partly in response to the secretion of a releasing factor known as gonadotropin-releasing hormone (GnRH). In females, FSH stimulates growth and development of egg cell containing follicles in

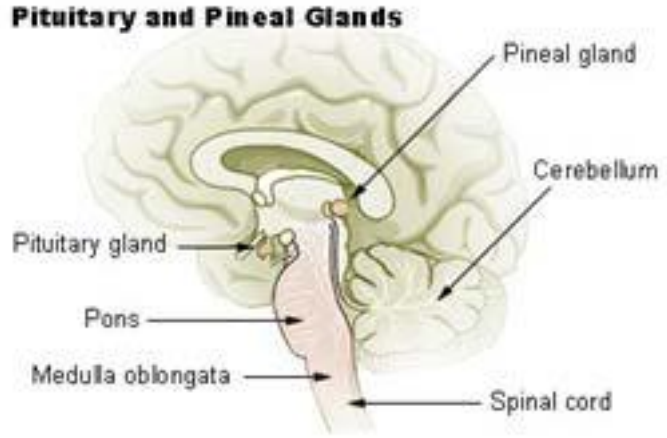
ovaries and stimulates follicular cells to produce oestrogen. In males, FSH stimulates the production of sperm cells in the testes when the male reaches puberty.



Step 2: Pituitary Secretions: Follicle stimulating hormone (FSH) and Luteinizing hormone (LH).

Luteinizing hormone secretion is also partly controlled by the release of the gonadotropin-releasing hormone by the hypothalamus. Luteinizing hormone stimulates the glands of the reproductive system to produce sex hormones.

Hypothalamus and Pituitary Gland



The pituitary gland can be divided into two parts. The anterior pituitary or adenohypophysis and the posterior pituitary or neurohypophysis.

The anterior pituitary has a different connection to the hypothalamus than the posterior pituitary. The anterior pituitary connects to the hypothalamus by way of a capillary network. This allows for a direct communication pathway between hypothalamus and anterior pituitary.

The posterior pituitary has a different connection to the hypothalamus. It connects via special cells called neurosecretory cells. The cell body resides in the hypothalamus and the cell extends into the posterior pituitary.

Anterior Pituitary Gland

There is always a two-step process with regard to secretions of the anterior pituitary:

Step 1: Hypothalamus secretes special hormones called releasing factors that target the anterior pituitary.

Step 2: Anterior pituitary responds by secreting hormones.

We will always see this two-step process when it comes to anterior pituitary secretions. Let's see an example of the 2-step process. We will examine how growth hormone is secreted by the anterior pituitary.

Step 1: Hypothalamus secretes two hormones that control the secretion of growth hormone by the anterior pituitary.

Growth Hormone Releasing Hormone—facilitates secretion of growth hormone from the anterior pituitary.

Somatostatin—inhibits secretion of growth hormone from the anterior pituitary.

Step 2: Growth hormone is either secreted or inhibited depending on which releasing factor is secreted by the hypothalamus.

Posterior Pituitary

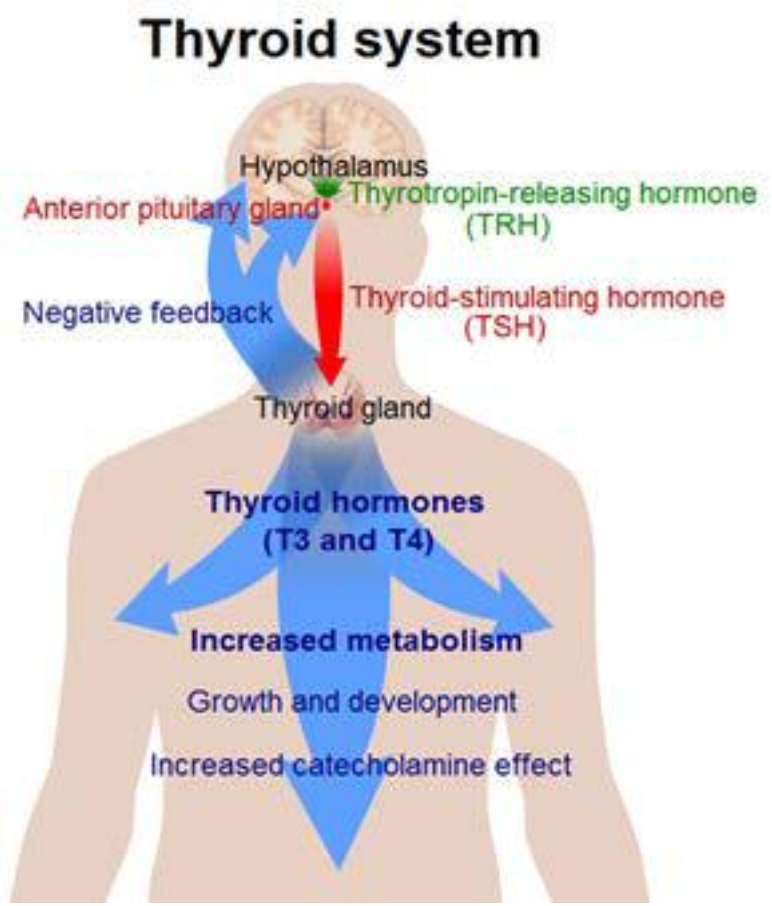
The posterior pituitary secretes only two hormones. These are antidiuretic hormone and oxytocin.

So how is ADH (antidiuretic hormone) regulated? There are osmoreceptors that sense changes in the chemical concentration of the blood in the hypothalamus. When the blood gets too concentrated, the receptors tell the posterior pituitary to release ADH. This causes the body to retain fluid so the blood becomes less concentrated. ADH targets the kidneys to do this. I know you want to know just how this works, but you'll have to be patient and wait until we get to the urinary system to learn just how this works.

The other posterior pituitary hormone is oxytocin. Oxytocin stimulates uterine contractions during labour and delivery and milk ejection. Sometimes doctors give Pitocin (oxytocin) to women in labour to help stimulate the uterine contractions and speed up the birth.

The secretion of oxytocin is one of the few positive feedback mechanisms. If you have ever experienced childbirth, you'll probably remember that the contractions don't get milder over time, they get stronger.

Feedback—Feedback



The thyroid gland is located in your neck just below the Adam's apple (the thyroid cartilage). There are two types of cells in the thyroid. Follicular cells secrete the hormones T3 (triiodothyronine) and T4 (tetraiodothyronine). Parafollicular cells secrete the hormone calcitonin.

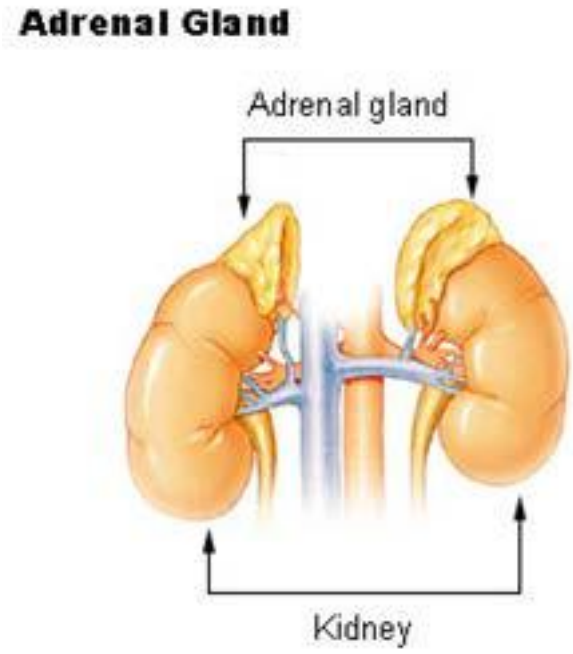
The hypothalamus secretes thyrotropin-releasing hormone (TRH) that travels to the anterior pituitary and tells it to secrete thyroid stimulating hormone (TSH). TSH then targets the thyroid gland causing the secretion of T3 and T4. These hormones then work to stimulate metabolism.

Negative feedback works to control the levels of T3 and T4 in the blood. For example, if the level of T4 gets too high then the secretions of TSH and TRH decrease, which works to bring the level of T4 back into range. And if the level of T4 gets too low, then the secretions of TSH and TRH increase, which raises the level of T4.

Calcitonin is the other thyroid hormone. It works with another hormone from the parathyroid glands called parathyroid hormone (PTH). The parathyroid glands are small masses of tissue located on the back of the thyroid.

Both PTH and calcitonin work to regulate blood calcium levels. PTH does the opposite and raises blood calcium levels. Both are controlled by the actual calcium in the blood. For example, if blood calcium levels are too high, calcitonin is secreted and PTH is inhibited.

Part 3: Hormone Details
Aldosterone



Aldosterone is secreted by the adrenal cortex and promotes sodium retention by the kidneys.
Aldosterone is secreted by the adrenal gland. It is produced by cells of the zona glomerulosa of the adrenal cortex. Aldosterone acts to regulate electrolytes such as magnesium and potassium. These are known as mineral electrolytes, thus aldosterone is known as a mineralocorticoid.
Aldosterone causes the kidney to conserve sodium and secrete potassium. The release of aldosterone is more strongly facilitated by the increase in plasma potassium concentration. The decrease in plasma sodium concentration does not affect the secretion of aldosterone as strongly. However, the decrease in sodium concentration can affect the renin-angiotensin system in the kidneys (see urinary system) and stimulates the release of aldosterone. Both aldosterone and the renin-angiotensin system work together to conserve blood volume and sodium. Aldosterone works by inhibiting the release of sodium by the kidney and the renin-angiotensin system works by causing vasoconstriction.
Aldosterone is also released via stimulation of the adrenal cortex by ACTH.

Cortisol

Cortisol helps to maintain blood glucose levels between meals by facilitating the conversion of fats and proteins to glucose.
Cortisol is also secreted by the adrenal cortex, specifically by the cells of the zona fasciculata.
Cortisol has an effect on glucose metabolism, thus it is called a glucocorticoid. Cortisol secretion increases glucose levels in the blood. It does this by stimulating the liver to convert non-carbohydrates into glucose. This process is called gluconeogenesis. It also stimulates the release of fatty acids for use as an energy source. These processes help to regulate the level of blood glucose between meals.
Cortisol also has an effect on your immune system. Cortisol works to inhibit inflammation and some of the white blood cells that function in immunity. The medication hydrocortisone is essentially cortisol and is used to treat inflammation.

Cortisol is released in response to the release of ACTH by the anterior pituitary gland. Remember that ACTH is released in response to release of CRH by the hypothalamus. This system provides a negative feedback mechanism to help control the level of cortisol in the blood.
Cortisol is also released in response to stress. Long periods of stress can cause an increase in blood glucose as well as inhibition of the immune system.

Norepinephrine and Epinephrine
Norepinephrine and Epinephrine (adrenalin) are secreted by the adrenal medulla and stimulate the sympathetic nervous system.
The adrenal medulla or inner portion of the adrenal gland is closely connected to the sympathetic nervous system. The adrenal medulla contains specialised cells called chromaffin cells that secrete chemicals called catecholamines. The catecholamines that are produced are norepinephrine and epinephrine. Norepinephrine (NE) and epinephrine (E) have both neurotransmitter and hormonal actions.
NE and E are secreted by the adrenal medulla in response to impulses produced by the sympathetic nervous system (SNS). The SNS is connected via nerve fibres to the adrenal medulla. The actions of NE and E from the adrenal medulla are similar to the actions of the (SNS). Thus secretion of NE and E will cause an increase in heart rate, blood pressure, respiration, and a decrease in digestion. The hormonal action of NE and E lasts longer than neurotransmitter action because it takes longer to remove NE and E from the endocrine system. Both the adrenal glands and the SNS work together to provide the sympathetic response.
Glucagon and Insulin
Both Glucagon and Insulin are secreted by the pancreas. Glucagon increases blood glucose while insulin decreases blood glucose.
Glucagon (secreted by alpha cells in the pancreas) works to increase the level of glucose in the blood. It does this by stimulating the liver to convert the storage form of glucose (glycogen) into glucose via a process known as glycogenolysis. Glucagon also stimulates the process of gluconeogenesis, which converts non-carbohydrates substances into glucose in the liver and breaks down fats into fatty acids and glycerol.
Glucagon is secreted when glucose levels are diminished in the blood. Secretion of glucagon is inhibited by high glucose blood levels.
Insulin (secreted by beta cells in the pancreas) works to decrease the levels of glucose in the blood. It does this by reversing the processes stimulated by glucagon. Insulin facilitates the storage of glucose in the liver by stimulating the production of glycogen from glucose. Insulin also inhibits the process of gluconeogenesis, stimulates protein synthesis and increases the storage of lipid in adipose tissue.
Insulin also facilitates the release of glucose into body tissues by stimulating facilitative diffusion of glucose carriers in cell membranes. For example, muscle cells contain insulin receptors. Glucose is transported into the muscle cell when insulin attaches to the insulin receptor. Once inside, glucose is used to produce ATP needed for muscle contraction.
Insulin is secreted when blood glucose levels are high and inhibited when blood glucose levels are low.
Somatostatin (secreted by the delta cells) inhibits both glucagon and insulin secretion. Thus it also works to control glucose levels in the blood.
Melatonin
Melatonin is secreted by the pineal gland and helps to regulate sleep-wake cycles.
Melatonin is secreted by a small pine cone shaped gland located between the cerebral hemispheres called the pineal gland. It attaches to the posterior portion of the thalamus.

The pineal gland secretes melatonin. Melatonin is synthesised from the neurotransmitter serotonin and is involved in the regulation of sleep-wake cycles known as circadian rhythms. Melatonin secretion increases with a decrease in light. Melatonin also helps to regulate the menstrual cycle.

Common pathologies

Addison's disease – hyposecretion of corticosteroid hormones

Cretinism – hyposecretion of thyroxine

Cushing's syndrome – hypersecretion of glucocorticoids

Diabetes – deficiency or absence of insulin. Occurs in three forms:

- **Insulin-dependent diabetes** – due to destruction of islet cells in the pancreas, occurs mainly in children and young adults
- **Diabetes mellitus (T2 diabetes)** – also known as non-insulin-dependent diabetes or late onset diabetes. Insulin output can be above or below normal and can be controlled by diet alone or together with oral drugs
- **Diabetes insipidus (T1 diabetes)** – hyposecretion of the anti-diuretic hormone by the posterior lobe of the pituitary gland, leading to hypoglycaemia

Dwarfism – hyposecretion of the growth hormone in childhood leading to stunted growth

Gigantism – hypersecretion of the growth hormone in childhood leading to rapid growth. Also known as acromegaly

Gynecomastia – hypersecretion of oestrogen and progesterone in men which can lead to muscle atrophy and breast development

Hirsutism – hypersecretion of testosterone and overproduction of androgens in women, leading to male pattern hair growth

Hypoglycaemia – low blood sugar level

Myxoedema – hyposecretion of thyroxine, slow metabolism

Polycystic ovaries syndrome – hyposecretion of oestrogen and progesterone in women leading to ovarian cysts, cessation of periods, obesity, hirsutism and sterility

Seasonal affective disorder (SAD) – hyposecretion of melatonin, with the onset of winter comes depression, excessive sleeping, overeating and general lethargy

Stress – associated with adrenaline in particular, excessive and chronic stress has a damaging effect on almost every part of the body

Thyrotoxicosis – hypersecretion of thyroxine, also known as Grave's disease

Module Twelve: The reproductive system

Part 1: The Male and Female Reproductive Systems

Learning objectives

In this module, you will learn:

- Functions of the reproductive systems.
- Structure and function of the parts of the female and male reproductive systems.
- Common pathologies.

The male and female reproductive systems

Both males and females contain packages of genetic information that are passed on to offspring.

The overall function of both male and female reproductive systems is to pass on genetic information to offspring. The male produces half of the genetic information and packages it in sperm cells. These cells develop and travel through the male to the female.

The female also produces half of the genetic information and packages it in an egg cell called an oocyte. The oocyte is cyclically produced and is either fertilised to complete its

development or is not and subsequently discarded. Hormones work to control and support these processes.

The male

First of all, we can divide both male and female systems functionally into primary and secondary sex organs. The primary sex organs in the male are the testes while the primary organs in the female are the ovaries. All of the other organs are considered secondary.

The testes are located in the scrotum which hangs outside of the body. The scrotum helps to keep the testes at a slightly lower temperature because sperm cells need a cooler temperature for better development. The inside of the testes are structured like a series of tubes (seminiferous tubules). The immature sperm cells are located around the perimeter of the insides of the tubes and move to the middle of the tubes (lumen) when they mature. There are also cells surrounding the tubes that work to support the sperm cells and produce the male hormone testosterone.

The non-sperm cells in the testes include:

Leydig cells—secrete testosterone

Sertoli cells (sustentacular cells)—in the adult these cells secrete a hormone called inhibin and substances that help sperm develop and mature.

Once sperm cells mature, they move to a structure on the surface of the testes called the epididymis. These paired structures each have three portions consisting of a head, body and tail. The epididymis works to help sperm cells mature and they can spend up to three weeks in the tubule system within the epididymis. Sperm move through the epididymis to the vas deferens.

The vas deferens or ductus deferens is a muscular tubular structure that connects with the tail of the epididymis. The muscular layers help to propel sperm cells through the tube. Each vas deferens moves through the inguinal canal and travels through the abdominal cavity and over the top of the bladder to the seminal vesicle. As the vas deferens nears the seminal vesicle, the tube widens into an area called the ampulla.

The seminal vesicles are located between the bladder and rectum. They contain epithelium that secretes an alkaline substance, fructose and prostaglandins.

The prostate is a walnut shaped gland just below the bladder. The prostate gland secretes an alkaline milky fluid that helps to nourish and mobilize sperm. The fluid also contains enzymes (hyaluronidase) and prostate specific antigen (PSA).

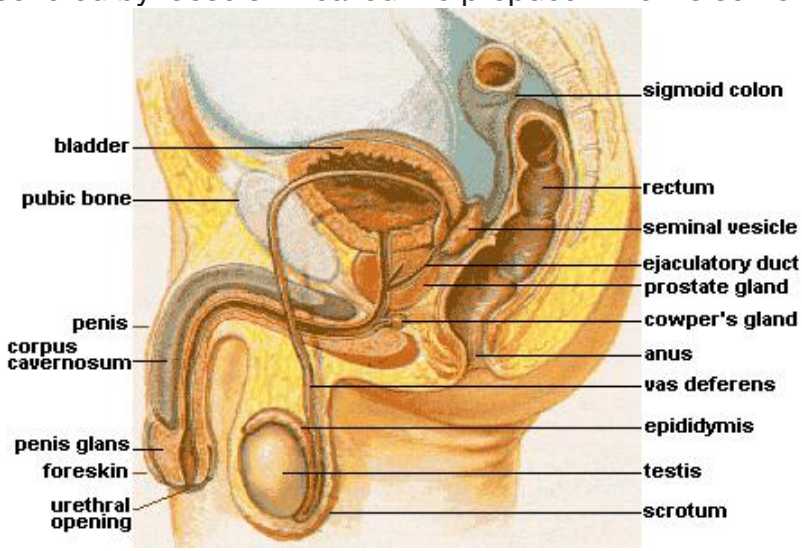
The urethra (prostatic urethra) passes through the prostate gland. The prostate also contains another set of paired ducts that connect the seminal vesicles to the urethra called the ejaculatory ducts.

The paired bulbourethral glands (Cowper's glands) are pea-shaped glands that secrete an alkaline substance and mucous to help protect and transport the sperm.

The urethra begins at the base of the urinary bladder and passes through the prostate gland and through the penis ending at an opening known as the urinary meatus of the penis. The urethra is lined with a mucous membrane. There are three parts to the male urethra. These include the portion travelling through the prostate (prostatic urethra), the portion extending from the base of the prostate gland to the penis (membranous urethra) and the portion running through the centre of the penis (penile urethra).

The penis consists of three columns of tissue called erectile columns surrounded by fibrous coverings surrounded by skin. The two superior columns are called the corpus cavernosum and the lower column is called the corpus spongiosum. Each corpus cavernosum contains a deep artery and is surrounded by a fibrous covering called a tunica albuginea. The corpus spongiosum contains the urethra. The distal portion of the

penis contains a slightly larger structure called the glans penis. The glans penis is covered by loose skin called the prepuce which is sometimes removed by circumcision.



The female

The primary sex organs of the female reproductive system are the ovaries. All of the other structures are considered secondary organs. Ovarian follicles are located inside of the ovaries. The ovarian follicle contains the egg cells known as oocytes. The oocytes are released at about half way through the menstrual cycle in what is known as ovulation.

The fallopian tubes (aka uterine tubes) extend from the uterus and continue to near the ovaries but do not contact them. The vas deferens carries the sperm cells in the male and the fallopian tubes carry the oocytes in the female.

The fallopian tubes have three sections. These include the first third that extends from the isthmus of the uterus, the second third which ends in a widened area called the infundibulum and the final third which ends in finger-like projections called fimbriae.

The fallopian tubes transport the oocyte to the uterus after fertilisation and are the sites for fertilisation by sperm cells. Most fertilised oocytes move to the uterus but occasionally they will deposit somewhere in the pelvic cavity causing what is known as an ectopic pregnancy.

The uterus is a pear-shaped structure about three inches long and two inches in width. The uterus has two divisions including the body and cervix. The body ends anteriorly as a narrow region called the cervix and posteriorly as a rounded structure called the fundus.

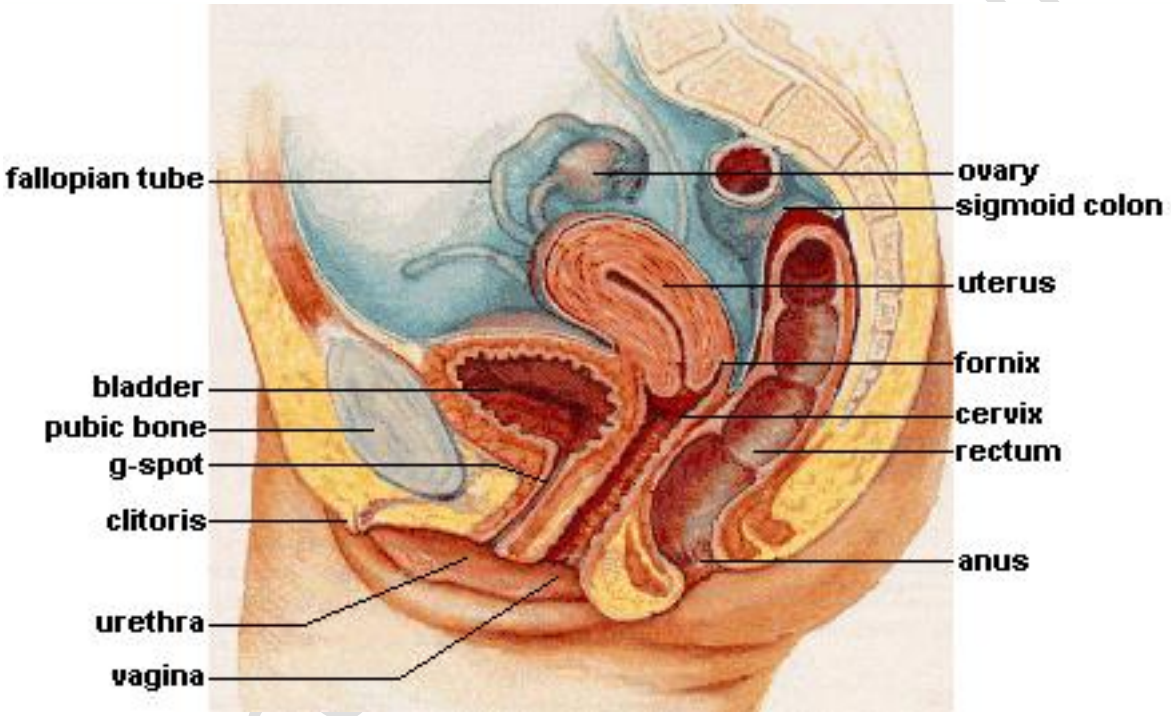
The uterus has three layers. The inner layer is called the endometrium. The endometrium varies in thickness and is thinner just after menstruation and thicker at the end of the cycle. The endometrium has an extensive blood supply and contains mucous secreting cells. The mucous changes its consistency during various times of the menstrual cycle. It is normally thicker during most of the cycle and contains more water near the time of ovulation to help move sperm cells.

The middle layer or myometrium is a thick smooth muscle layer. The smooth muscle is capable of producing very strong contractions during childbirth. The outer layer or perimetrium consists of a serous membrane.

The body of the uterus lies on top of the bladder in what is called an anteflexed position. The cervix of the uterus connects with the vagina at an upward right angle. This connection allows for pockets around the cervix called the anterior and posterior fornix that allow for pooling of semen to increase the chances of fertilisation.

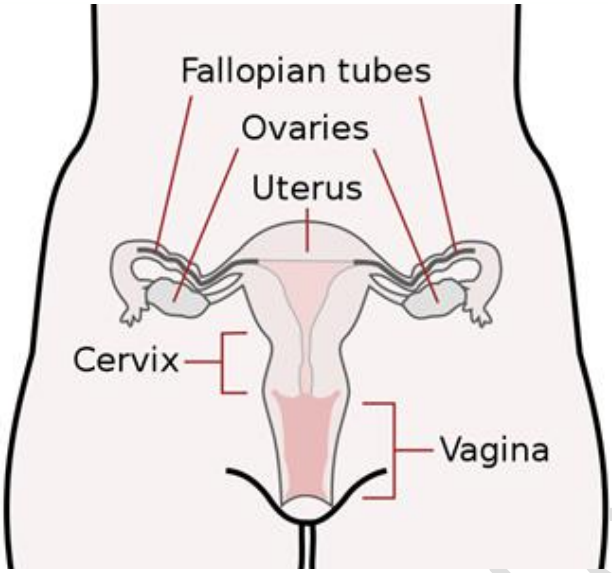
The uterus can lie in retroflexion in which the uterus tilts backwards. Retroflexion can sometimes cause prolapse of the uterus. The uterus is held in place by a series of

ligaments. These include two broad ligaments, two uterosacral ligaments (posterior and anterior), and two round ligaments.
The posterior ligament forms a pouch called the posterior cul de sac or rectouterine pouch (of Douglas). Likewise, the anterior ligament also forms a pouch called the anterior cul de sac or vesicouterine pouch.
The vagina is located between the rectum and urethra. It is a tubular structure about three inches long that opens to the outside and extends superior and posterior to the cervix of the uterus. The vagina is primarily smooth muscle lined with an epithelial mucous membrane. The mucous membrane can form around the opening of the vagina. This structure is called a hymen. In some cases, the opening to the vagina can be completely covered by the hymen (imperforate hymen). An imperforate hymen needs to be medically punctured to allow discharge of the menstrual flow.
The vulva consists of several externally located structures of the female reproductive system. These include the labia majora and minora, mons pubis, clitoris, vestibule, urinary meatus, greater and lesser vestibular glands.



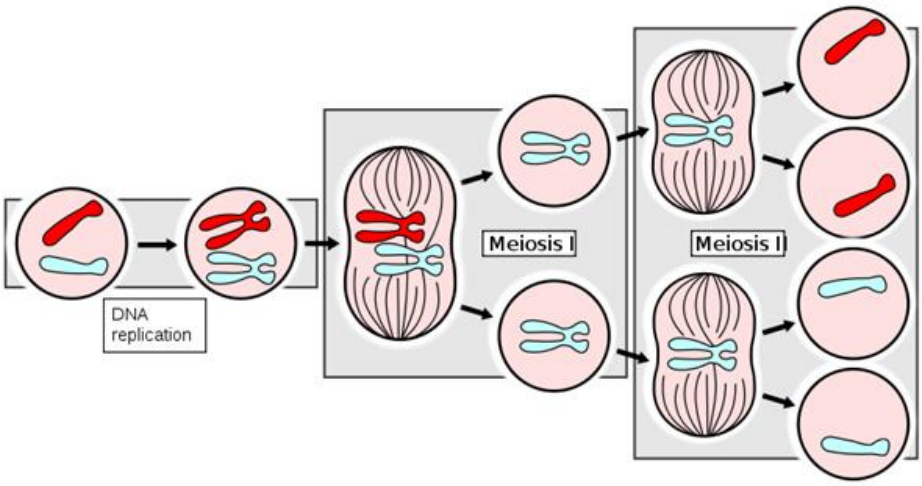
The labia majora are skin covered structures consisting of primarily adipose and connective tissue. The outer surface of the labia majora contains hair while the inner surface does not. They also contain a mucous lining. They are analogous to the scrotum of the male. The labiaminora are hairless structures located medially to the labia majora. The space between both labia minor is known as the vestibule.
The clitoris is an organ consisting of erectile tissue. It is located just superior and behind the labial junction. The clitoris contains two corpuscavernosum but no corpus spongiosum so it is similar in structure to the penis. The superior aspect of the clitoris contains a covering of tissue known as the prepuce.
Between the clitoris and opening to the vagina (vaginal orifice) is the urinary meatus which is the external opening of the urethra. On the sides of the vagina are the greater vestibular glands or Bartholin's glands that open into the area between the labia minor and hymen. The lesser vestibular glands or Skene's glands are located near the urinary meatus.
The perineum is the area between the vagina and anus. The perineum helps to form the muscular floor of the pelvis and can be torn during vaginal childbirth. The perineum

contains the urogenital triangle which is formed by drawing a line between the ischial tuberosities with the anterior point of the triangle just superior to the prepuce.
The mammary glands or breasts are superficial to the pectoral muscles. Internally they consist of a series of lobes separated by connective tissue. The lobes subdivide into lobules containing secretory cells. The cells are arranged in clusters around a central duct. The smaller ducts combine to form larger ducts called lactiferous ducts for each lobe. The lactiferous ducts open to the outside at the nipple. The breasts also contain suspensory ligaments (of Cooper) that help to support them. Each breast contains a circular pigmented area called an areola. The areola contains sebaceous (oil secreting) glands to help protect the nipple.
The breast also contains adipose tissue and lymphatics that drain into the axillary region.

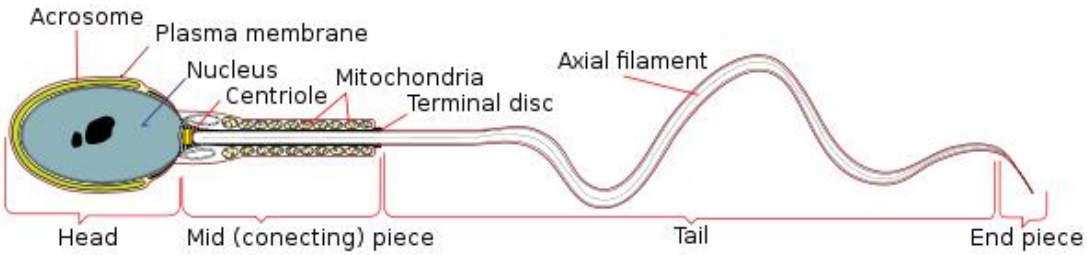


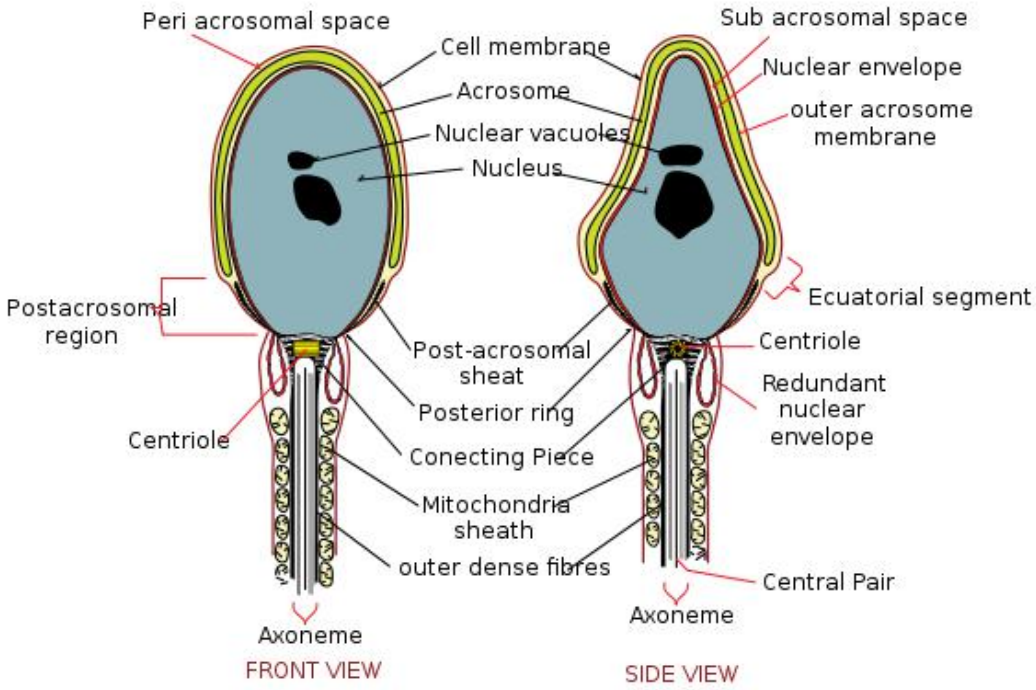
Part 2: Sperm Cells
Making sperm cells is called spermatogenesis. Spermatogenesis begins with the undeveloped sex cells called spermatogonia. Spermatogonia reside in the testes and will begin to mature around the age of puberty. They continue to do so throughout an adult male's life.
The process begins with the secretion of hormones called gonadotropins from the anterior pituitary gland. These include follicle stimulating hormone (FSH) and luteinizing hormone (LH). Both are secreted in response to the releasing factor gonadotropin releasing hormone secreted by the hypothalamus. But aren't these hormones female hormones? Well, not exactly - this is one of those similarities between males and females. These hormones are found in both sexes.
Luteinizing hormone targets the interstitial cells (Leydig cells) of the testes and promotes the secretion of testosterone. Follicle stimulating hormone (FSH) targets the sustentacular cells (Sertoli cells) of the testes and promotes their maturation and response to testosterone. Both FSH and testosterone work to facilitate the maturation of spermatogonia.
Spermatogonia begin to develop while the male is also developing inside of the mother's uterus. They don't completely develop in utero as their maturation is halted until puberty. They will divide and develop into primary spermatocytes. When testosterone increases during puberty, they complete their development.
Once reaching puberty, the primary spermatocytes undergo another type of cell division called meiosis. There are two stages of meiosis including meiosis I and meiosis II. Meiosis

is similar to mitosis with one big difference. In mitosis, you end up with two cells with the same number of chromosomes but in meiosis, you end up with two cells with half the number of chromosomes.
The normal adult human has 46 chromosomes (called the diploid number of chromosomes). Chromosomes form pairs that have the same but not necessarily identical genes. These are called homologous chromosomes. The pairs essentially split into two sections of homologous chromosomes with each new cell having 23 chromosomes (haploid number of chromosomes). The chromosomes may contain different variants of genes. For example, one cell may contain a different variant for the gene for eye colour than the other cell.



Once those sperm cells mature during puberty they are ready to go. Mature sperm cells contain three parts including a head, midpiece and tail. The head contains the genetic material and has an enzyme containing structure called an acrosome on its outer surface. The acrosome contains enzymes such as hyalouronidase that help the sperm cell penetrate the egg cell of the female. The midpiece (engine) contains many mitochondria that produce a good deal of energy in the form of ATP to power the long tail or flagellum. The tail contains the flagellum which is constructed of protein microtubules.





Erection and ejaculation

This is a complicated process involving both sympathetic and parasympathetic nervous systems. The sacral spinal cord sends parasympathetic impulses to the penis during sexual stimulation. The impulses result in the secretion of nitric oxide which causes vasodilation of the deep arteries in the erectile columns of the penis. Blood then fills the erectile columns which in turn close off the return pathway for blood by compression the dorsal vein of the penis. The penis then becomes erect.

Sexual stimulation then results in orgasm, emission and ejaculation. Emission is the movement of sperm and secretions from the seminal vesicle, prostate and bulbourethral gland into the urethra. Emission is under sympathetic control from the sacral spinal cord which results in smooth muscle contractions throughout the reproductive tract. Skeletal muscles at the base of the penis contract to cause ejaculation which is the forceful expelling of semen from the urethra. Following ejaculation, sympathetic impulses cause vasoconstriction of the arteries of the penis, the penis again becomes flaccid.

Part 3: Testosterone

Besides facilitating spermatogenesis, testosterone has other important functions in the male reproductive system. Testosterone is one of a group of hormones called androgens (male hormones).

Testosterone levels are higher during foetal development to help the initial development of the male reproductive system and descent of the testes. Testosterone levels then fall during childhood until puberty where they again rise to essentially finish the job of maturation of the male reproductive system.
The actions of testosterone during puberty include the following:

- Enlargement of the vocal cords and deepening of the voice
- Increased muscular growth
- Increased body hair on face, axilla and pubic areas
- Strengthening of bones
- Increased metabolism
- Maturation of the sex organs

Testosterone is regulated by a feedback mechanism involving hormones from the hypothalamus and anterior pituitary gland. We saw that testosterone is secreted in response to LH secreted by the anterior pituitary gland. LH is secreted in response to gonadotropin-releasing hormone from the hypothalamus. Blood concentration of testosterone is monitored by the hypothalamus which responds through negative feedback to control the secretion of gonadotropin releasing hormone. The testes also secrete a hormone called inhibin which feeds back to the hypothalamus, exhibiting the same effect as testosterone.

Egg cells

Oogenesis

Each ovary contains millions of sex cells called oocytes. The oocytes are encased in packages called follicles. At the premature stage, the follicles are known as primordial follicles and each contains a primary oocyte. The primary oocytes begin meiosis but do not complete it until puberty. The development of oocytes is known as oogenesis.
As oogenesis continues at puberty, the primary oocytes finish meiosis I, which results in two cells each containing the haploid number of chromosomes (23). When the oocytes finish meiosis, they are called secondary oocytes. Unlike spermatogenesis in the male, the resultant cells consist of one secondary oocyte and a polar body. The polar body is not a viable cell but helps the secondary oocyte conserve resources to help make it as viable as possible. Development stops at this point unless fertilisation occurs. Once the secondary oocyte is fertilised, it completes meiosis and produces a second polar body. The fertilised cell is now called a zygote and has the diploid number of chromosomes (46).
The follicle plays an important role in oogenesis as well. The follicle matures under the influence of FSH. It first becomes a primary follicle and contains a region known as the zona pellucida. The zona pellucida contains glycoprotein that gradually separates the oocyte from the inner walls of the follicle. The follicle continues to mature into a secondary follicle which is characterised by the presence of a cavity called the antrum. The oocyte is pushed against the inner wall of the follicle at this stage. Finally, the follicle reaches the end of maturation as it becomes a mature or Graffian follicle. The antrum is filled with fluid and the follicle moves to the surface of the ovary. Maturation of the follicle occurs in half of the menstrual cycle.
At about midway through the menstrual cycle, the follicle pushes the oocyte out in what is called ovulation. This occurs in response to a surge of LH from the anterior pituitary gland. The oocyte moves toward the fallopian tube. If it becomes fertilised, it will eventually move to the uterus for implantation. If it is not fertilised, it will degenerate.

Female sex hormones

During foetal development, the hormones gonadotropin-releasing hormone (GnRH), FSH and LH cause the initial development of the reproductive system as well as the descent of

the ovaries to their normal position in the pelvic cavity. Secretion of GnRH then decreases until puberty which occurs at about age 10. During puberty, the levels of these hormones increase causing the secretion of oestrogens and progesterone.
Oestrogens are a group of molecules with oestradiol as the most abundant. Oestrogens are secreted by the ovaries as well as the adrenal glands, adipose tissue and the placenta (during pregnancy). Oestrogens promote the development of the secondary sex organs of the female.
Actions of oestrogen include:

- Development of the breasts.
- An increase in adipose tissue under the skin in specific areas of the body (thighs, buttocks, breasts).

There are also changes associated with the secretion of androgens during puberty including increased hair in the genital and axillary regions.
Oestrogens provide negative feedback to the hypothalamus and anterior pituitary gland. For example, a rise in oestrogen levels works to inhibit the secretion of GnRH which, in turn, inhibits the secretion of FSH and LH.

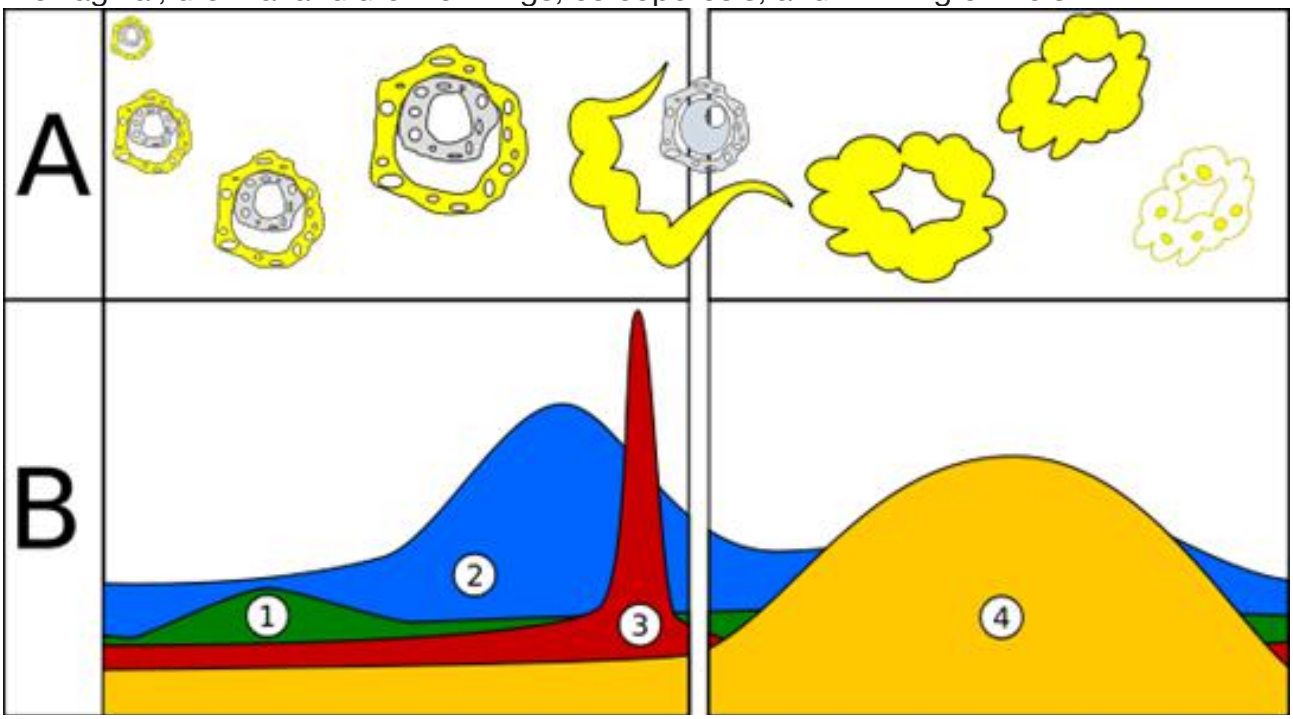
Menstrual cycle

The menstrual cycle consists of three phases:

- Proliferative phase—uterus thickens
- Ovulation—luteinizing hormone causes egg to be released
- Luteal phase—inner layer of uterus sloughs off

The female menstrual cycle begins during puberty (between the ages of 10-13 years). It is characterised by changes in the endometrium of the uterus. The first menstrual cycle is called menarche. GnRH is secreted by the hypothalamus causing the secretion of FSH and LH. FSH causes maturation of the ovarian follicle and secretion of oestrogens by the granulosa cells. LH also helps the follicle to mature and stimulates the production of oestrogens.
Oestrogens cause an increase in the thickening of the endometrium during the first phase of the menstrual cycle (proliferative phase).
During the proliferative phase, the follicle secretes oestrogen that works to inhibit the release of LH. Instead of being released by the anterior pituitary, LH is stored. At about the 14th day, LH is released (LH surge) causing the follicle to release the oocyte in what is called ovulation. The follicle then moves toward the fallopian tube and is either fertilised or not.
Following ovulation, the follicle becomes what is known as a corpus luteum. The corpus luteum secretes large amounts of progesterone and oestrogens during this second half of the cycle.
The oestrogens and progesterone inhibit the release of LH and FSH from the anterior pituitary which, in turn, keeps other follicles from maturing. Progesterone also facilitates increased vascularisation and thickening of the endometrium. If the oocyte is not fertilised, the corpus luteum begins to degenerate near the end of the cycle at around the 24th day. What is left of the degenerated corpus luteum is called a corpus albicans. When the follicle goes from the corpus luteum to the corpus albicans stage, the secretions of oestrogen and progesterone diminish. This causes the thickened endometrium to slough off. The endometrium and accompanying blood constitute the menstrual flow which continues for about 3-5 days.
Menstruation continues throughout the female lifespan until the late 40s or early 50s where it begins to become irregular and eventually stops completely. This process marks the period of menopause. During this time, the few remaining follicles no longer respond to FSH and LH. Since the follicles don't mature, there is a subsequent drop in oestrogens

and progesterone. The consequences of low levels of these hormones include thinning of the vaginal, urethral and uterine linings, osteoporosis, and thinning of the skin.



1. Follicle -Stimulating Hormone 2. Oestrogens 3. Luteinizing Hormone 4. Progesterone A. Maturing follicle & corpus luteum B. Hormone levels

Part 4: Fertilisation

Sperm cells that reach the oocyte attempt to penetrate it with the help of the enzymes located in the acrosome. Once a sperm cell penetrates the oocyte, it sheds its tail and the oocyte becomes unresponsive to other sperm. The nucleus of the sperm cell enters the oocyte and the oocyte undergoes meiosis II, creating a second polar body. The genetic material from sperm and oocyte combine and the resultant cell is called a zygote. The zygote continues mitotic divisions to form a group of cells that migrates to the uterus. The fallopian tube helps the migration along with its ciliated epithelial lining and smooth muscle contractions. The cells eventually implant in the wall of the uterus.

The layer surrounding the embryo secretes a hormone called human chorionic gonadotropin which helps to maintain the corpus luteum throughout the pregnancy. This results in high levels of oestrogens and progesterone. After the first trimester, the placenta takes over the job of secreting these hormones.

Breast milk production

The hormone prolactin works to stimulate milk production after birth. The first milk to appear is called colostrum which contains some nutrients including proteins and antibodies. When the baby suckles the breast, the sensory impulses travel to the hypothalamus which, in turn, causes the release of oxytocin from the posterior pituitary gland. Oxytocin causes milk ejection by stimulating contraction of the myoepithelial cells of the breasts.

Common pathologies

Female

Amenorrhea – absence or stopping of menstrual periods

Cancer of the breast – usually detected by breast or axillary lump

Cancer of the cervix – few symptoms in the early stages. Regular check-ups advised

Cancer of the ovaries – difficult to diagnose, symptoms often vague and associated with gastrointestinal problems
Dysmenorrhea – painful and difficult menstrual periods
Ectopic pregnancy – development of a foetus at a site other than the uterus
Endometriosis – inflammation of the endometrium
Fibroid – abnormal growth of fibrous and muscular tissue developing in the wall of the uterus
Polycystic ovaries syndrome – also known as Stein-Leventhal syndrome. For symptoms, see The Endocrine System
Pre-menstrual syndrome – term for a variety of physical and psychological symptoms experienced 3-14 days before the onset of a menstrual period
Infertility – inability to conceive or to induce conception
Male
Cancer of the testis–first symptom is usually slight enlargement of the testis
Cancer of the prostate – usually no symptoms apart from frequent urge to pass water, blood in urine or ejaculate
Prostatitis – inflammation of the prostate gland
Infertility – low sperm count, absence of sperm, low motility of sperm or stress are most common reasons

Module Thirteen: The Urinary system

Part 1: The Kidneys

Learning objectives

In this module, you will learn:

- The functions of the urinary system.
- Individual parts of the urinary system and their functions: kidneys, ureters, urinary bladder and urethra.
- Common pathologies.

The kidneys

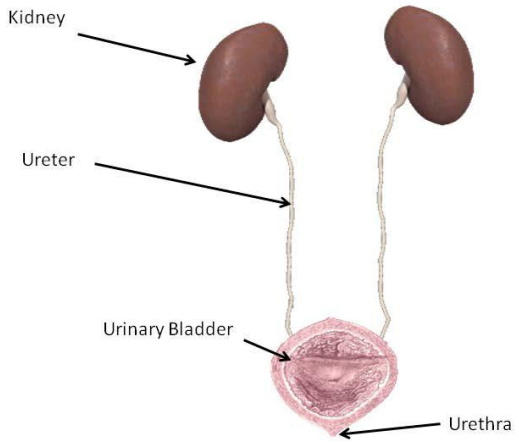
The kidneys are bean-shaped organs located behind the abdominal cavity. They are retroperitoneal. The peritoneum is the membrane that lines the abdominal cavity so they are behind the abdominal cavity.

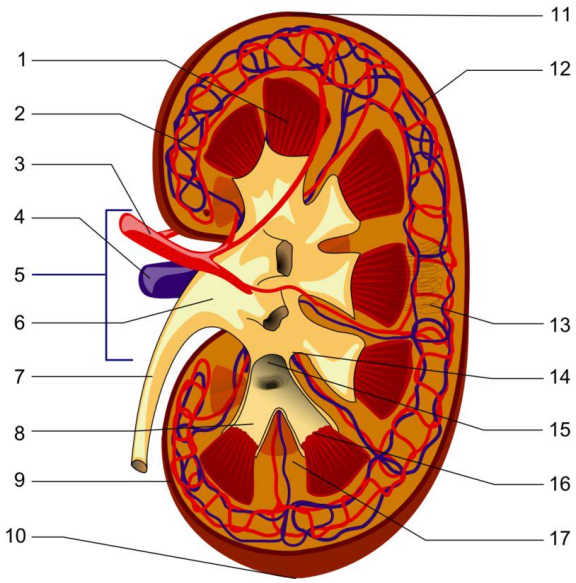
They are located on the sides of the low back around the twelfth rib and extend to about the third lumbar vertebra. The kidneys are surrounded by fat (perirenal fat) and a tough fibrous membrane called a renal capsule.

Inside, there are two major divisions. The outer portion is called the renal cortex and the inner portion is called the medulla. Some cortical tissue extends into the medulla (renal columns). The medulla contains triangular structures called renal pyramids. At the tip of each pyramid is a structure called the renal papilla. Urine drains from the renal papilla to the minor and major calyces to the renal pelvis and finally to the ureter.

Blood enters the kidney at a dent called the renal hilus. The renal artery brings blood in and the renal vein brings it out. The renal artery branches upon entering the kidney. The branches include:

Renal artery—segmental—interlobar—arcuate—interlobular





1. Renal pyramid 2. Interlobular artery 3. Renal artery 4. Renal vein 5. Renal hilum 6. Renal pelvis 7. Ureter 8. Minor calyx 9. Renal capsule 10. Inferior border 11. Superior border 12. Interlobar vein 13. Nephron 14. Renal sinus 15. Major calyx 16. Renal papilla 17. Renal column

Getting down to the microscopic structures we see one all-important structure in the kidney. This is the nephron which is the structure that makes urine. There are around one million nephrons in one kidney and they do a great job making urine. Some nephrons lie near the medulla and are called juxtamedullary nephrons. These nephrons extend deep into the medulla. Other nephrons reside in the cortex and only minimally extend into the medulla. These are known as cortical nephrons.

The afferent arteriole brings blood to the nephron and the efferent arteriole brings blood out. Between the afferent and efferent arterioles is a tuft of capillaries called the glomerulus. The glomerulus is surrounded by a fibrous capsule called the glomerular capsule (Bowman's capsule). The glomerular capsule connects with the proximal convoluted tubule which connects with the nephron loop (loop of Henle). The nephron loop connects with the distal convoluted tubule which, in turn, connects with the collecting duct which transports urine to the renal papilla.

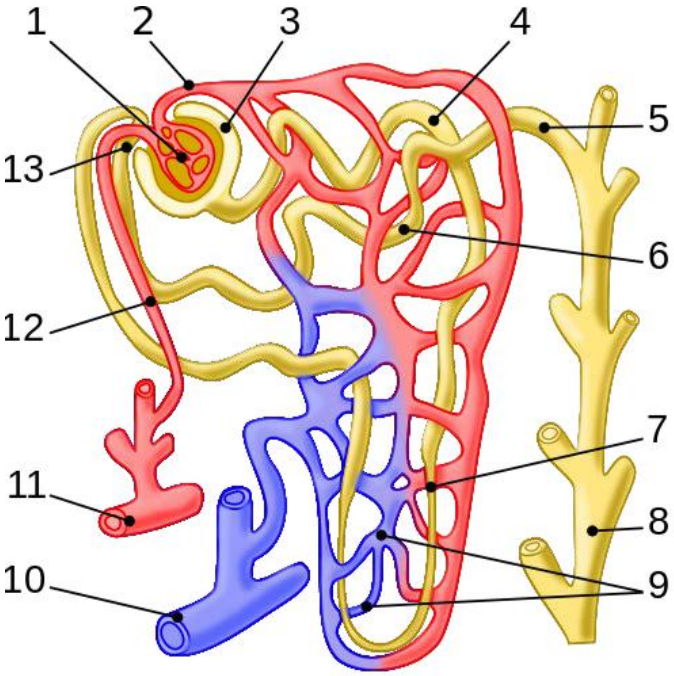
The ureters carry the urine from the kidney to the bladder. The ureters have a smooth muscle layer that is capable of producing peristaltic contractions that occur once every two to three minutes. The parasympathetic nervous system increases these contractions and the sympathetic nervous system inhibits them.

The urinary bladder is a hollow organ that resides in the pelvic cavity. The area on the inside of the bladder between the two ureter connections and the urethra is called the trigone.

The urinary bladder and ureters are internally lined with transitional epithelium. The bladder also has a thick smooth muscle layer sometimes called the detrusor muscle. Contraction of the detrusor muscle increases the internal pressure of the bladder and causes urine to be expelled.

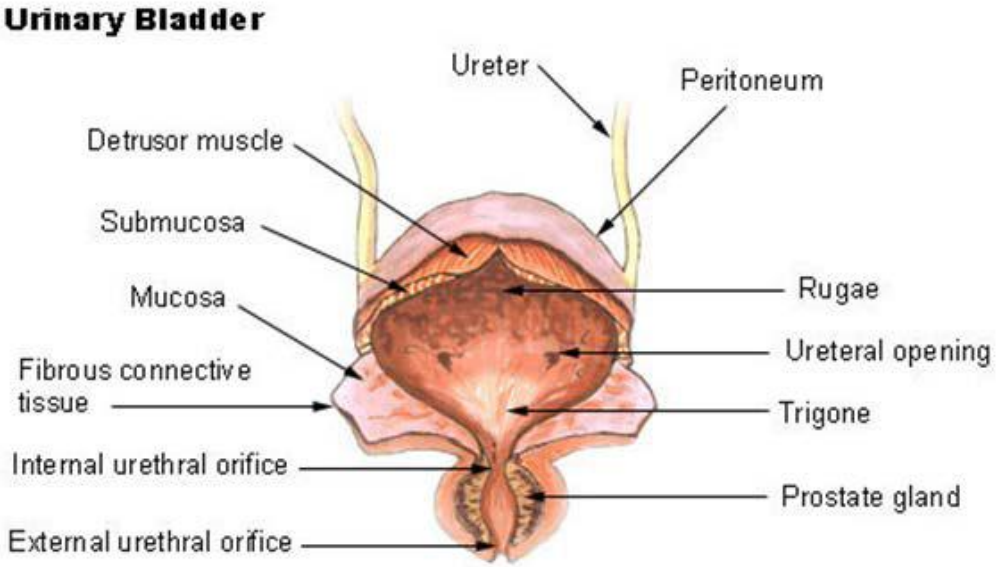
Male bladders contain an area of smooth muscle and elastic tissue called the internal urinary sphincter. This area is not present in females. The function of this structure is to keep semen from entering the urinary bladder during intercourse. Both males and females have an external urinary sphincter located in the urethra that controls the flow of urine.

The male urethra consists of three parts. The prostatic urethra exits the bladder and extends to the inferior prostate gland. It then becomes the membranous urethra until it enters the penis where it becomes the penile urethra.



1. Glomerulus, 2. Efferent arteriole, 3. Bowman's capsule, 4. Proximal tube, 5. Cortical collecting tube 6. Distal tube, 7. Loop of Henle, 8. Collecting duct, 9. Peritubular capillaries, 10. Arcuate vein, 11. Arcuate artery, 12. Afferent arteriole, 13. Juxtaglomerular apparatus.

Part 2: Urinary Physiology



There are 3 primary processes of urine formation:

- Filtration
- Tubular reabsorption (move fluid from kidney to blood)
- Tubular secretion (move fluid from blood to kidney)

We can gain insight into how the kidneys work by examining the inputs and outputs. Blood flows into the kidney and urine and blood flows out. So the kidneys must somehow make urine from the blood. The blood enters via the renal artery and exits via the renal vein. The urine exits by way of the ureters and flows to the bladder, urethra, and out of the body.

One of the simplest ways to make urine from blood is to filter the blood. This is actually the first stage of urine formation (filtration). Filters work by the movement of substances

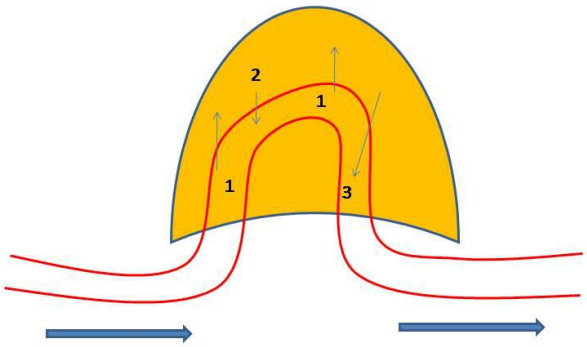
from areas of higher to lower pressure across a filtration membrane. The filtration membrane sorts substances based on size. You could think of it as being filled with holes. Smaller substances pass through the holes while larger substances do not. Smaller substances that are filtered include water, electrolytes and glucose.
There would be a problem if filtration was the only mechanism of urine formation. Our bodies need many of the filtered substances and they would be lost in the urine. So there must be another mechanism that helps to maintain the balance. These include tubular reabsorption and secretion.
Tubular reabsorption and secretion work together to reclaim substances like water, glucose and electrolytes after they have been filtered. Tubular reabsorption employs a number of mechanisms in order to move filtered substances back into the blood. Tubular secretion also uses a number of mechanisms to move substances from the blood to the urine. Besides reclaiming filtered substances, both of these processes finetune electrolyte, water and pH balance.
Besides maintaining fluid, electrolyte and pH balance, the kidneys monitor blood oxygen levels. They secrete the hormone erythropoietin in response to low oxygen levels. The hormone travels to the bone marrow to stimulate the production of red blood cells. The kidneys also work to control vitamin D synthesis.

Urine formation process 1:

Filtration

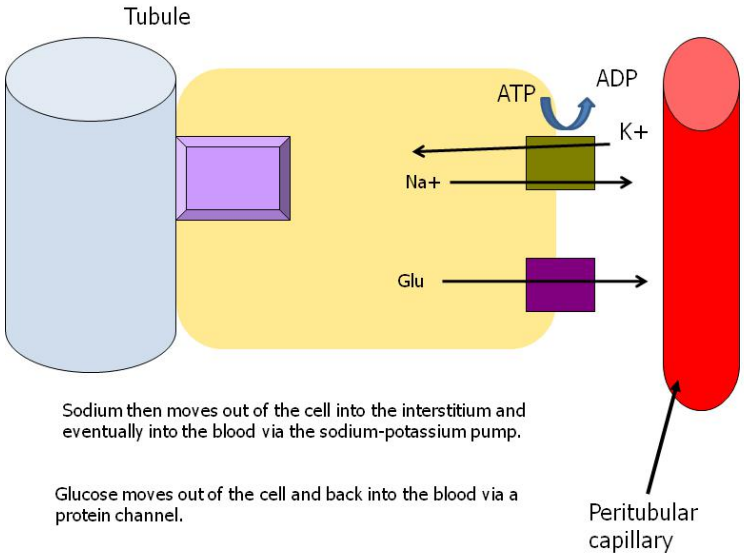
The kidneys make a lot of filtrate each day. They typically produce about 123 ml of filtrate per minute which adds up to about 180 litres per day. If all of this filtrate ended up as urine you would spend your days in the bathroom and drinking water! Fortunately, most of that filtrate is reabsorbed leaving around one to two litres of urine per day (which allows you some time away from the bathroom).
In order to move substances through the filter, there must be a pressure gradient. Substances must move from an area of higher pressure to lower pressure. The pressure gradient is called filtration pressure or net filtration pressure. Net filtration pressure is directly proportional to the glomerular filtration rate. So if for some reason net filtration increases or decreases, so does glomerular filtration rate, and so does the amount of filtrate produced.
Net filtration pressure is the combination of a series of pressures that exist in the renal corpuscle. These include glomerular capillary hydrostatic pressure, glomerular capsular hydrostatic pressure and colloid osmotic pressure.
Glomerular capillary hydrostatic pressure is the blood pressure inside the capillaries. It is usually about 50 mmHg and must be greater that the pressure inside the glomerular capsule known as glomerular capsular hydrostatic pressure. This one is the main pressure and must be greater than the total of the other pressures in order for the filter to work.
The glomerular capillary hydrostatic pressure is controlled in part by the diameter of the afferent and efferent arterioles. The efferent arterioles have a smaller diameter than the afferent arterioles. The smaller diameter works to decrease blood flow through the efferent arterioles increasing the pressure inside the glomerular capillaries. Changing the diameter of the afferent and efferent arterioles changes the glomerular capillary hydrostatic pressure. For example, increasing the diameter of the afferent arteriole or decreasing the diameter of the efferent arteriole increases the capillary pressure.
The pressure inside the glomerular capsule is called the glomerular capsular hydrostatic pressure.This pressure is created by fluid inside the capsule as well as downstream in the tubules. It is usually about 10 mmHg. The glomerular capsular hydrostatic pressure works against filtration.

Colloid osmotic pressure is produced by the presence of plasma proteins in the blood called colloids. The colloids produce a pulling force causing water to move back into the glomerular capillaries. This pressure is usually about 30 mmHg.
We can calculate the net filtration pressure by the following:
The kidneys are constantly working to keep the amount of filtrate relatively constant despite changes in mean arterial pressure. For example, as systemic blood pressure increases, the afferent arterioles to vasoconstrict keeping the glomerular capillary hydrostatic pressure constant. Likewise, when blood pressure decreases, the afferent arteriole dilates.
The sympathetic nervous system affects the afferent arteriole by causing it to vasoconstrict under intense sympathetic activity such as when exercising strenuously or when in shock.



Glomerular filtration: 1. Glomerular capillary hydrostatic pressure. 2. Glomerular capsular hydrostatic pressure. 3. Colloid osmotic pressure

Urine formation process 2:
Tubular reabsorption
During filtration, substances were just sorted based on size. This means that lots of stuff move through the filter that our bodies need, like glucose and water, for example. There must be some other process that works to reclaim these important substances. There is and it's called tubular reabsorption.
One important thing to remember is that in tubular reabsorption substances move from the tubule to the blood.
Substances move by various ways in tubular reabsorption and we will cover a few.
Symporters
Some cells lining the kidney tubules contain special transport proteins called symporters. This is how the sodium glucose symporter works: Sodium provides the energy in the form of a gradient. There's lots of sodium coming out of the filter and moving into the tubules compared to inside the cells lining the tubules. So sodium moves through the transport protein and glucose goes along with it.



So, what would happen if lots and lots of glucose was produced by the filter and moved into the tubules? Well, the amount of glucose would exceed the number of symporters. This would cause glucose to flow into the urine and out of the body in a condition called glucosuria. This happens in diabetes.
Other substances are transported back into tubular cells via symporters. These include amino acids and vitamins.

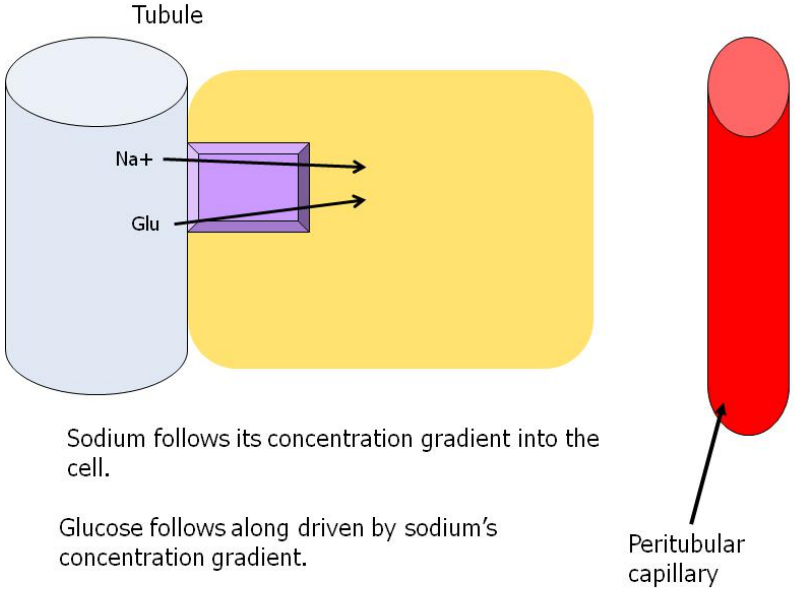
Passive movement of substances

Other substances move passively from the tubules to the blood. Sodium is again one of these as well as calcium, magnesium, potassium. Since so much sodium moves into the interstitium surrounding the tubules water also follows sodium via osmosis. This is how much of the water is reabsorbed.

Part 3: Urine Formation

Urine formation process 3:

Tubular secretion



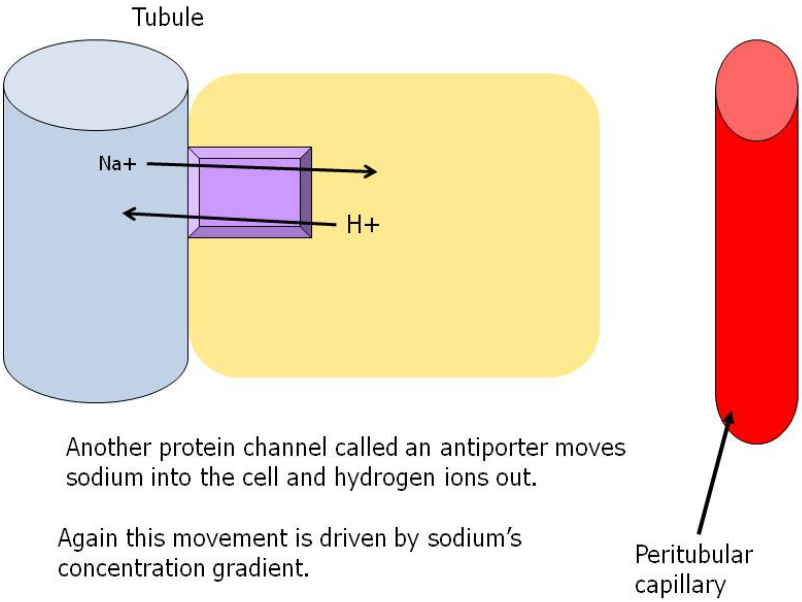
Tubular secretion involves moving substances from the blood to the tubules. Unlike tubular reabsorption that moves substances in order to maintain fluid and electrolyte

balance, tubular secretion primarily works to eliminate toxic substances or by-products of metabolism.

Antiporters

Tubular secretion can involve active or passive transport. An example of passive transport is the sodium-hydrogen antiporter. This transport protein uses the sodium gradient to move sodium from the tubule to inside the cell while at the same time moving excess hydrogen ions out of the cell and into the tubule.

In describing the antiporter, I like to use the analogy of the revolving door. Let's say that I am staying in one of those fancy hotels with a big revolving door. I enter the door and push on the glass to move the door. At the same time, someone is exiting the hotel and moves through the door going in the opposite direction and not pushing at all. I am providing the energy while the other person moves in the opposite direction getting a free ride. In the case of the antiporter, sodium provides the energy in the form of a gradient while hydrogen comes with it.



Aldosterone

Certain tubule cells are "leaky" to sodium and potassium. In other words, when aldosterone attaches to receptors on these cells, it increases their permeability to sodium and potassium. So, aldosterone causes more sodium to be reabsorbed, while at the same time causing potassium to be secreted.

Atrial Natriuretic Hormone (ANH)

Atrial Natriuretic Hormone (ANH) is secreted by the wall of the right atrium in the heart in response to atrial stretch. ANH has the opposite action of aldosterone and inhibits sodium and water reabsorption in the kidney tubules.

Bicarbonate reabsorption

Bicarbonate ions do move from the kidney tubules to the blood. However, there are a few steps along the way that make it seem complicated.

Hydrogen is secreted into the tubule by way of the sodium-hydrogen antiporter. Hydrogen runs into bicarbonate ions to form carbonic acid. The carbonic acid dissociates into carbon dioxide and water. The carbon dioxide then diffuses into cells lining the lumen of the tubule and combines with water in the presence of carbonic anhydrase to form carbonic acid. The carbonic acid once again dissociates into hydrogen and bicarbonate ions. The hydrogen gets antiported back out to keep the process looping while the bicarbonate moves out of the cell and into the blood.

Urea

Urea flows through the nephron loop, distal convoluted tubule and collecting duct. The collecting duct is permeable to urea so some flows back into the medulla. Some urea makes its way back to the descending limb of the nephron loop which is also permeable to urea allowing urea to flow in. This creates a cycle that helps to maintain the high medullary concentration gradient.

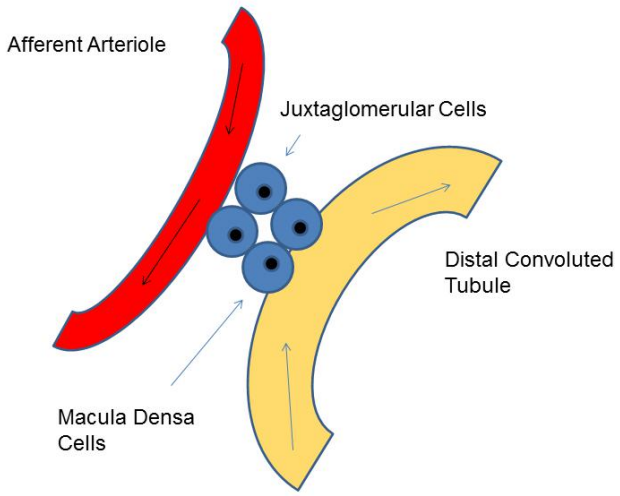
Juxtaglomerular apparatus (JG apparatus)

The JG apparatus helps to control blood pressure and the amount of urine produced. The juxtaglomerular apparatus is a group of cells residing at the junction of the afferent arteriole and distal ascending limb of the nephron loop. The juxtaglomerular apparatus consists of two different types of cells. Juxtaglomerular cells are located on the afferent arteriole side.

The juxtaglomerular cells monitor blood pressure. When blood pressure decreases, the cells secrete rennin which will increase it. Renin then triggers the renin-angiotensin system. The end result is the formation of a substance called angiotensin II.

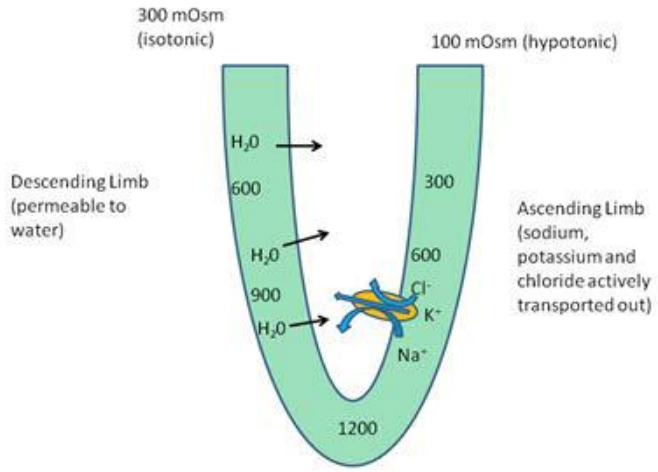
Angiotensin II promotes vasoconstriction (which raises blood pressure) and secretion of the adrenal cortex hormone aldosterone. Aldosterone promotes sodium reabsorption and since water follows salt (osmosis again) we get fluid retention which also raises blood pressure.

The other cells in the juxtaglomerular apparatus are the macula densa cells. These babies monitor the filtrate in the kidney tubule. Usually, they keep the afferent arteriole open by secreting nitric oxide synthetase secretion which promotes nitric oxide secretion (a vasodilator), but if too much filtrate is produced nitric oxide synthetase secretion is inhibited. The cells also secrete adenosine which promotes vasoconstriction of the afferent arteriole. The vasoconstriction of the afferent arteriole causes a subsequent decrease in the production of filtrate.



Juxtaglomerular apparatus. The juxtaglomerular cells secrete renin while the macula densa cells secrete nitric oxide.

The Nephron loop



The nephron loop contains two parts. These are the descending and ascending limbs. In the descending limb, water moves out but salt stays in (concentration increases).
In the ascending limb, salt is pumped out and water stays in (concentration decreases).
The nephron loop consists of two segments including a descending and ascending limb each with different characteristics.
The descending limb contains a thin layer of epithelium that is more permeable to water than the thick portion of the ascending limb. An isotonic fluid enters the descending limb. As it progresses down the limb, water diffuses into the interstitium causing the concentration to dramatically increase.
The thick segment of the ascending limb inhibits the passage of water by diffusion and contains a series of active transport proteins that selectively move substances. Sodium and chloride are moved out of the ascending limb and into the interstitium by way of these active transport proteins. As fluid moves up the ascending limb, the concentration decreases. A hypotonic solution exits the ascending limb and enters the distal convoluted tubule.
The countercurrent consists of the “current” of water moving in one direction and the “current” of sodium chloride moving in the opposite direction. The high “salt” gradient is maintained by the active transport of sodium and chloride in the ascending limb. Urea also diffuses into the descending limb adding to the increased concentration.

Antidiuretic Hormone (ADH)

ADH causes water retention by increasing permeability in the distal convoluted tubule. ADH is secreted by the posterior pituitary gland in response to an increase in blood solute concentration as sensed by osmoreceptors in the hypothalamus. ADH targets the kidney, particularly the distal convoluted tubule.
ADH affects the distal convoluted tubule by making it more permeable to water by increasing the appearance of aquaporins (water channels). Remember that the fluid exiting the nephron loop is hypotonic. The hypotonic fluid enters the distal convoluted tubule that is surrounded by the interstitium and peritubular capillaries which are isotonic. If the tubule is impermeable to water, then dilute urine is produced. If the tubule is made more permeable to water, then water moves to the more highly concentrated interstitium and blood. ADH then plays an important role in maintaining fluid balance.

Urine composition

Adults produce about one to two litres of urine daily. Pathologies such as diabetes or some medications can produce a larger urine output known as polyuria. A urine output of

less than 500 ml/day is known as oliguria and an output less than 100 ml is known as anuria.
Urine is the final product of the kidney. It is mostly water (95%) with a few other solutes including nitrogenous wastes, electrolytes, pigments, and toxins. It can also contain abnormal substances including glucose, albumin, bile and acetone.
Urine is usually clear or straw coloured. An abnormal colour may indicate the presence of blood, bile, bacteria, drugs, food pigments, or high solute concentration. Urine will become cloudy after standing due to a build-up of bacteria. Pus from problems such as kidney infections will also make urine cloudy.
Urine has a slight odour. It will develop an ammonia odour after standing due the breakdown of urea. An acetone odour may indicate diabetes. The pH of urine varies between 4.6 and 8.0. The specific gravity is between 1.001 and 1.035.

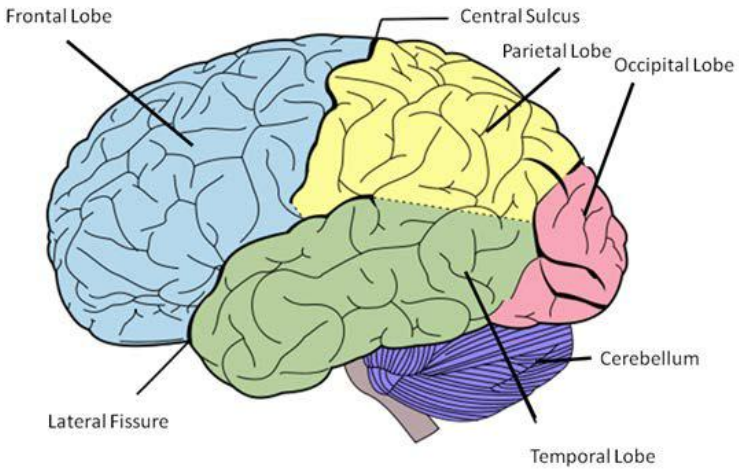
Micturition
Urine continuously flows from the kidney to the bladder. The bladder acts as a storage reservoir for urine and can store up to one litre. At about 300 ml, the urge to urinate becomes evident. Once the wall is stretched, the micturition reflex is stimulated. Stretch of the bladder sends impulses to sensory neurones in the pelvic nerves to the sacral segments of the spinal cord. Micturition is under parasympathetic control and parasympathetic impulses cause the bladder to contract. The motor impulses for micturition originate in a micturition centre in the pons. The centre also receives input from the cerebral cortex (so you can decide whether or not to micturate). Contraction of the bladder increases the internal pressure pushing urine into the urethra.
The micturition reflex is an involuntary reflex in infants. Voluntary control of the reflex does not occur until around age 2-3 years.
Renal clearance
Renal clearance represents how much blood has to pass through the kidney to completely remove a substance.
Renal clearance is used to determine kidney function. Renal clearance is the volume of blood plasma from which a substance is completely removed in one minute. Renal clearance reflects the three processes of urine formation which include glomerular filtration, tubular reabsorption and tubular secretion.
Common pathologies
Cancer of the bladder – early symptom is usually blood in the urine
Cystitis – inflammation of the urinary bladder
Incontinence – inability to control urination voluntarily
Kidney stones – deposits forming solid stones in the renal pelvis of the kidney, ureter or bladder
Nephritis – non-specific term for inflammation of the kidney
Pyelonephritis – bacterial infection of the kidney
Urinary tract infection – bacterial infection of the urinary system

Module Fourteen: The Nervous System

Part 1: The Brain
Learning objectives
In this module, you will learn:

- Function and organisation of the nervous system.
- Characteristics of nervous tissue.
- Structure and function of different types of neurons.
- Transmission of nerve impulses.
- Common pathologies.

The brain
The brain consists of four major structures. These include the cerebrum, diencephalon, brainstem and cerebellum.
The cerebrum
The cerebrum is the largest portion of the nervous system. The cerebrum consists of two hemispheres, right and left, connected by a white matter bridge called the corpus callosum. On the surface of the cerebrum are folds called gyri and grooves called sulci. Deep grooves are known as fissures. Each hemisphere is divided into lobes. The lobes are the frontal, parietal, temporal and occipital.



The frontal lobe processes information involving motor movements, concentration, planning and problem solving as well as the sense of smell and emotions. The parietal lobes process sensory information with the exception of hearing, smell and vision. The temporal lobes process information related to hearing, smell and memory as well as abstract thought and making judgments. The occipital lobe processes visual information.
The frontal lobe processes information involving motor movements, concentration, planning and problem solving as well as the sense of smell and emotions. The parietal lobes process sensory information with the exception of hearing, smell and vision. The temporal lobes process information related to hearing, smell and memory as well as abstract thought and making judgments. The occipital lobe processes visual information.
Some lobes are divided by fissures. Along the superior aspect of the cerebrum lies the longitudinal fissure that divides the parietal lobes. The lateral fissure (Sylvian fissure) is located on the side and separates the temporal from parietal lobes. One sulcus called the central sulcus is located midway on the side of the cerebrum and separates the frontal

from parietal lobes. Deep in the lateral fissure is the insula which is often referred to as a fifth lobe of the cerebrum.
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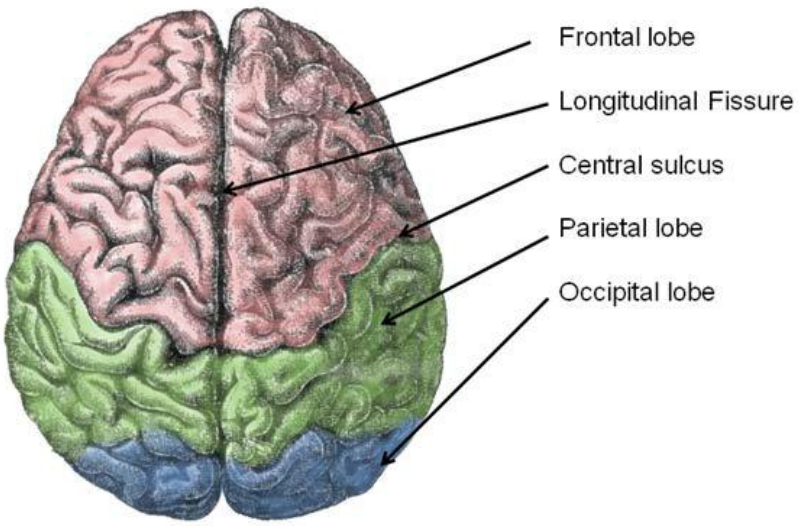


The diencephalon
The diencephalon consists of the thalamus and hypothalamus.
Thalamus
The thalamus is the largest part of the diencephalon. It consists of two lateral portions connected by a stalk called the interthalamic adhesion which is sometimes referred to as

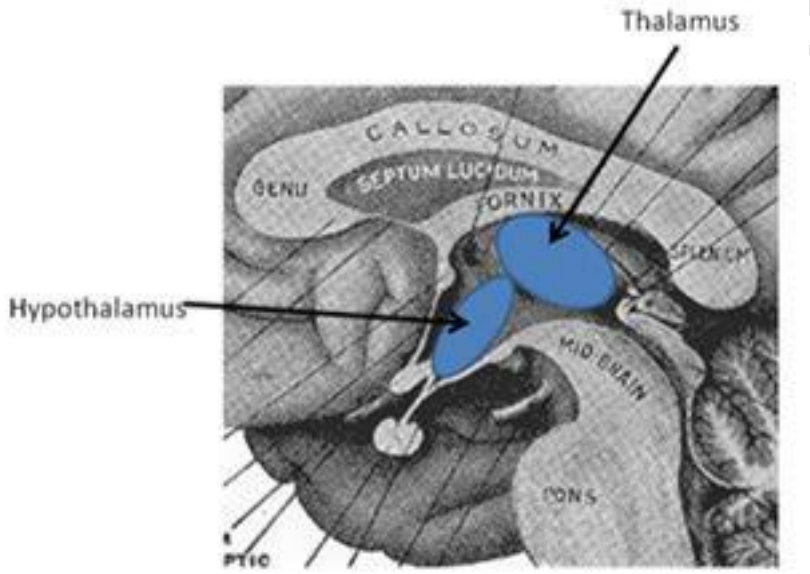
the intermediate mass. The thalamus carries all sensory information to the cerebral cortex with the exception of the sense of smell which is carried directly to the frontal lobe of the cerebral cortex by the olfactory nerves. The thalamus is sometimes referred to as a relay station for sensory information. The thalamus is also intimately involved in emotions due to its connections to the limbic system.

Hypothalamus

The hypothalamus lies inferior and anterior to the thalamus. It contains the mamillary bodies on its anterior surface. The mamillary bodies process information associated with the sense of smell and emotions. A stalk-like projection called the infundibulum projects anterior and inferior and connects to the pituitary gland. The hypothalamus is intimately connected with the endocrine system and helps to regulate hormones. The hypothalamus also regulates body temperature, thirst, hunger and sexual drive and is involved in processing emotions, mood, and sleep along with the reticular activating system.

The epithalamus is located posterior and superior to the thalamus. It is a small area that works to process the sense of smell and emotional responses. The pineal body (gland) is also located in this area. It is a pine shaped structure that helps to regulate sleep-wake cycles by secreting the hormone melatonin.

The subthalamus is located inferior to the thalamus. It contains nuclei that are involved in controlling motor information.



The brainstem

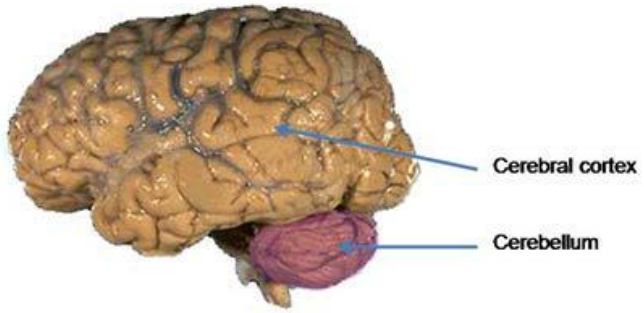
The brainstem has three parts: the midbrain, pons and medulla oblongata.

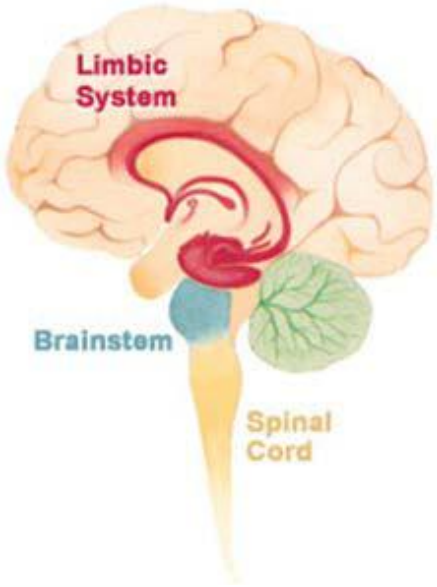
The brainstem lies between the cerebral cortex and the spinal cord. It consists of the midbrain, pons and medulla oblongata. The medulla oblongata is the most inferior portion of the brainstem and contains a number of centres for controlling heart rate, respiration, swallowing, vomiting and blood vessel diameter. These centres consist of nuclei which are clusters of neurone cell bodies. The spinal tracts also continue through the medulla connecting the spinal cord with the brain. The medulla contains two rounded structures called olives (not the martini kind) which consist of nuclei that help to control balance, coordination and sound information. On the anterior surface of the medulla lie two enlargements called pyramids. The pyramids consist of the descending spinal cord tracts. The pons is the middle section of the brainstem. The pons also contains spinal cord tracts as well as nuclei that help to control respiration and sleep.

The midbrain is the most superior portion of the brainstem. There is a roof (tectum) that contains four bumps (nuclei) called the corpora quadrigemina. The two superior nuclei (bumps on the top) are called the superior colliculi while the inferior are called the inferior colliculi (bumps on the bottom).
The superior colliculi help to control the movement of the head toward stimuli including visual, auditory, or touch. The inferior colliculi help to process hearing and also receive input from the skin and cerebrum. The floor of the midbrain is called the tegmentum. It contains two reddish coloured structures called the red nuclei that process information for unconscious motor movements. The midbrain also contains the cerebral peduncles that carry motor information from the cerebrum to the spinal cord. The substantia nigra resides in the midbrain and processes information relating to tone and coordination of muscles.
The reticular formation is located throughout the brainstem and is primarily concerned with regulating sleep-wake cycles.

The cerebellum

The cerebellum processes information for balance, coordination, fine motor movements, and joint position.
The cerebellum is like a small version of the brain. It is located in the back of and below the cerebrum. It is connected to the brainstem via three cerebellar peduncles (superior, middle and inferior peduncles). The cerebellum contains both grey and white matter. The white matter branches much like a tree and is called the arbor vitae.
The cerebellum contains a number of different types of neurones but one in particular; the Purkinje cell is the largest cell in the brain. These cells can synapse with as many as 200,000 other fibres. Purkinje cells are inhibitory cells and function in processing motor information. The cerebellum can be divided into three parts. The flocculonodular lobe is the inferior portion. The vermis constitutes the middle portion and the two lateral hemispheres make up the remaining portion.
The cerebellum functions in processing information related to complex movements, coordination and unconscious proprioception.





Limbic system

The limbic system processes emotions.

Often called the seat of emotions, the limbic system consists of portions of both the cerebrum and diencephalon. The limbic system is also involved in reproduction and memory (emotions go with memory and reproduction). The limbic system contains the cingulate gyrus located just superior to the corpus callosum and the parahippocampal gyrus located on the medial aspect of the temporal lobe.

The cerebral spinal fluid system

Fluid circulates inside and outside of your brain and spinal cord.

CSF is produced by the choroid plexus and flows between the two lateral ventricles (in the cerebral hemispheres) through the interventricular foramen to the 3rd ventricle (near the thalamus) through the cerebral aqueduct to the 4th ventricle (between the brainstem and cerebellum) and on to the spinal cord.

Did you know there are large hollow chambers inside of your brain? These chambers are called ventricles and contain a fluid known as cerebral spinal fluid or CSF.

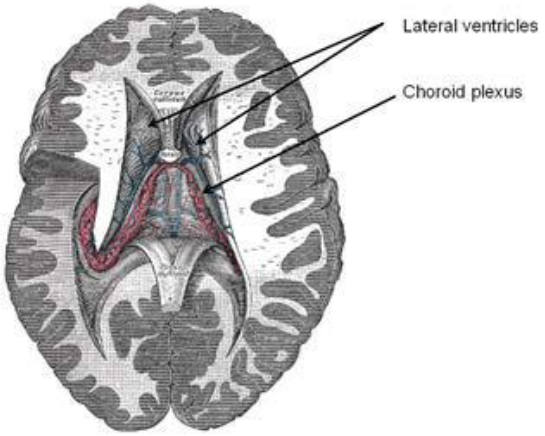
Cerebral spinal fluid (CSF) has to come from somewhere, and it comes from blood. It acts as a shock absorber and cushions the brain and spinal cord. CSF is produced by small vascular structures called choroid plexus.

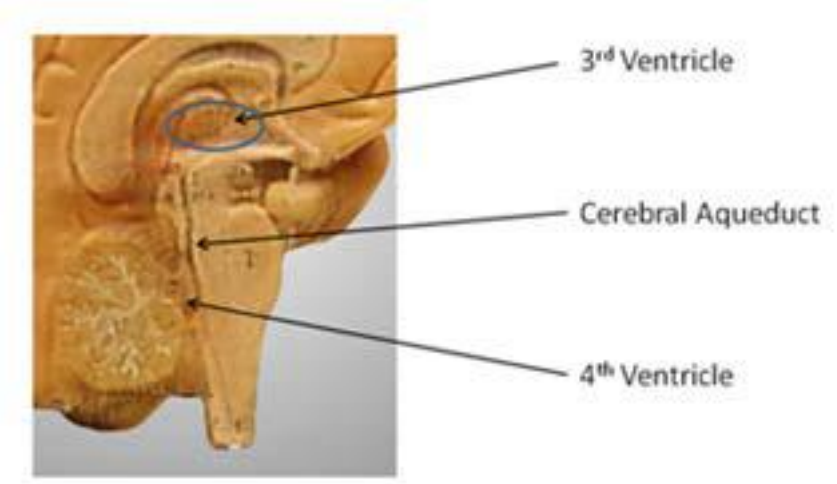
The blood vessels in a choroid plexus form a blood-brain barrier between the blood and CSF. The capillaries inside of the brain also form a blood-brain barrier. Examples of substances that can pass through the blood-brain barrier include lipid soluble drugs and alcohol. Water soluble substances can also enter the brain via transport proteins.

CSF not only circulates in the subarachnoid space but also within the hollow ventricles. There are four total ventricles in the nervous system. There are two lateral ventricles separated by a fibrous membrane called the septum pellucidum, a third and fourth ventricle. The lateral ventricles are located within the cerebral hemispheres. The third ventricle lies between the two halves of the thalamus in the diencephalon. The fourth ventricle lies between the brainstem and the cerebellum.

The ventricles are connected via foramen (holes) or tubular passages. The lateral ventricles connect to the third ventricle via the interventricular foramen. The third ventricle connects to the fourth via a tube passing through the midbrain called the cerebral aqueduct (aqueduct of Sylvius). The fourth ventricle connects with the central canal of the spinal cord. The fourth ventricle also connects with the subarachnoid space via lateral and medial apertures (holes). The median aperture is called the foramen of Magendie and the two lateral apertures are called the foramen of Luschka.

CSF is produced by the choroid plexus that make about 500 ml/day. However, some of the CSF is absorbed so there are only about 140 ml in the system at any one time. This is due to the CSF being absorbed by arachnoid granulations. Arachnoid granulations are masses of arachnoid tissue located in the dural venous sinuses. CSF can move into the blood at these locations.





Meninges

Cerebral spinal fluid also circulates around the outside of the brain. This is where the arachnoid granulations that absorb cerebral spinal fluid are located.

The tissue surrounding the brain is collectively known as the meninges. The meninges consist of three layers. These are the dura mater, arachnoid mater and pia mater.

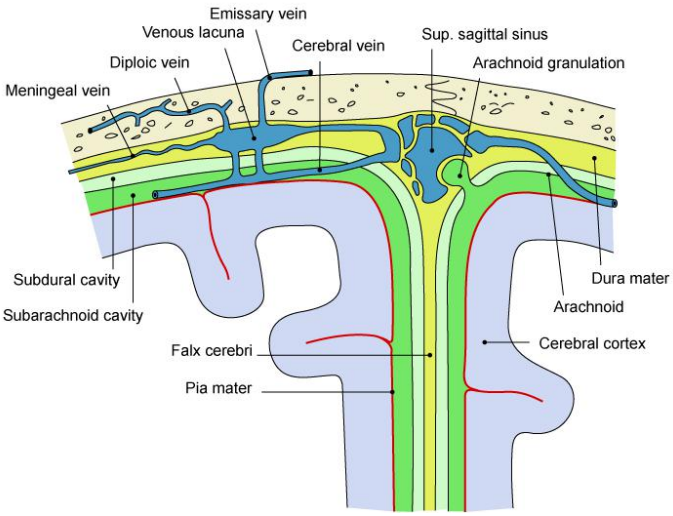
Dura mater—tough durable outer covering.

Arachnoid mater—middle covering. This one looks like a spider web.

Pia mater—thin, inner covering. The word “pia” is the smallest word of the three and is the thinnest and innermost layer.

Between the arachnoid and pia mater layers is a space called the subarachnoid space. This is where the cerebral spinal fluid is located.

The arachnoid granulations are located in the arachnoid mater. They connect with the venous circulation via the venous sinuses surrounding the brain.



Part 2: The Spinal Cord and Peripheral Nervous System

The other large central nervous system structure is the spinal cord.

Spinal cord structure

The spinal cord consists of a core of grey matter surrounded by white matter surrounded by the meninges.

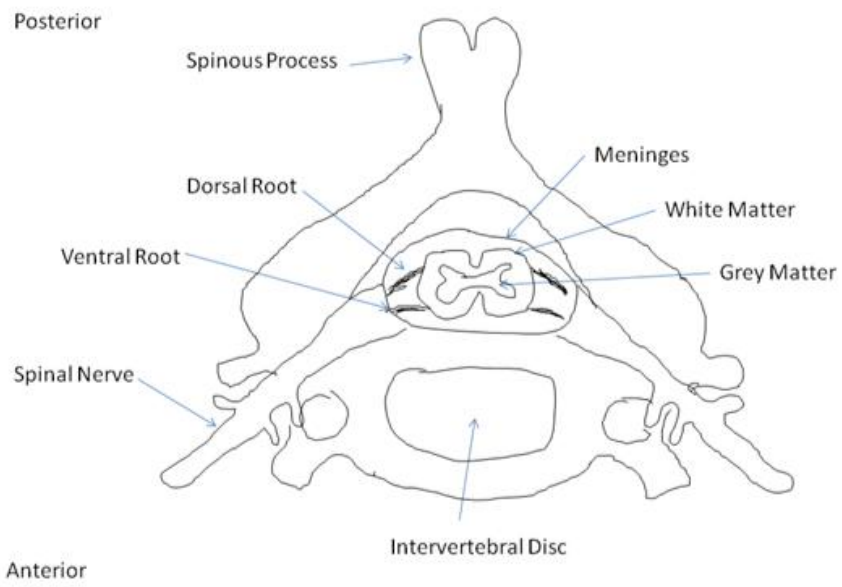
The cord begins at the foramen magnum of the occipital bone and ends at about the second lumbar vertebra in a cone-shaped process called the conus medullaris. The remaining nerves come off the end of the cord as the cauda equina (also called a horse's tail).

The basic structure is a core of grey matter surrounded by white matter surrounded by meninges. There are also two nerve "roots" exiting the cord on each side. One root comes out of the front and is called the ventral root while the other exits the back and is called the dorsal root.

You might also notice that the spinal cord is symmetrical (like the body). The right and left sides are connected by a bridge of grey matter called the grey commissure. Each grey matter area is further divided into what are called horns. There are anterior, posterior and lateral horns.

The white matter is also divided into areas called funiculi. There are anterior, posterior and lateral funiculi.The difference between grey and white matter is that white matter looks lighter in colour than grey matter because it contains a fatty substance called myelin.

There are two spaces that are important as well. These are the subarachnoid space, which, as we stated, before is between the arachnoid and pia mater, and the epidural space, which is between the dura mater and the bony walls of the spine.



Spinal cord tracts

Sensory information goes up. It follows ascending spinal tracts. Motor information goes down. It follows descending spinal tracts.

One major function of the spinal cord is to carry information to and from the brain. This information is carried by areas in the white matter called spinal tracts. Tracts are like pathways that carry various types of information. Sensory information is carried to the brain by ascending tracts and motor information is carried from the brain by descending spinal tracts. Some tracts cross over (decussate) to the other side. The right side of the brain processes sensory information and sends motor information to the left side of the body and vice versa.

Important ascending tracts

Some important ascending tracts include the **fasciculus gracilis, fasciculus cunneatus, spinothalamic and spinocerebellar**. There are generally three neurons that carry information from the stimulus to the brain. The first order neuron (first neuron in the series) carries information from a sensory receptor to the spinal cord. The second order neuron carries the information to an area in the brain called the thalamus and the third order neuron carries the information to the cortex of the brain.

The **fasciculus gracilis** is located in the posterior funiculus. This tract carries information related to discriminative touch, visceral pain: example = organ pain from a heart attack, vibration, and proprioception (position of joints in space). The tract carries this information from the middle thoracic and lower areas of the body.

The fasciculus gracilis is part of the posterior spinal cord called the dorsal column. At the middle thoracic region, (about T6) it combines with the **fasciculus cunneatus.** It contains first order neurons that travel up the same side of the cord and cross over at the brainstem in an area known as the medulla oblongata (specifically in the gracile nucleus).

The fasciculus cunneatus is also located in the posterior funiculus. It carries the same type of information as the fasciculus gracilis from the middle to upper areas of the body (T6 and above). It is also part of the dorsal column and its fibres cross over in the medulla (cunneate nucleus) as well.

The second order fibres of the fasciculus gracilis and cunneatus combine to form an area known as the medial lemniscus from the medulla oblongata to the thalamus.

The **spinothalamic** tract consists of two portions. The **anterior and lateral spinothalamics** are located in the anterior and lateral funiculi. The spinothalamics are sometimes referred to as the anterolateral system.

The **anterior spinothalamic** tract carries information related to light touch and pain. Light touch is clinically defined as perceived sensation from stroking an area of the skin without hair. The fibres from the anterior spinothalamic tract cross at one to two segments above their entry point in the spine.

The **lateral spinothalamic** tract is an important clinical tract because it carries information related to pain and temperature. Its fibres also cross in a way similar to the anterior spinothalamic tract. Lesions of the lateral spinothalamic tract will result in loss of pain and temperature. For example, in a Brown-Sequard lesion (sometimes called a hemisection of the spinal cord) there is a contralateral loss of pain and temperature below the level of the lesion as well as a bilateral loss of pain and temperature at the segmental level of the lesion.

The **spinocerebellar** tract also consists of two portions. The **anterior and posterior spinocerebellar** tracts are both located in the lateral funiculus. The fibres in the posterior tracts do not cross while the anterior fibres cross at the medulla oblongata. The spinocerebellar tracts carry information related to coordination of muscles from the lower limbs and trunk to the cerebellum.

Important descending tracts

Motor tracts carry information from the brain to the effectors. These consist of the **corticospinal, rubrospinal and reticulospinal**.

The **corticospinal** tract consists of anterior and lateral portions located in the anterior and lateral funiculi. These tracts are sometimes referred to as the pyramidal tracts. Fibres in the lateral tract cross over at the medulla oblongata. Fibres in the anterior portion cross at various levels in the spinal cord. Both tracts convey motor information to skeletal muscles.

The **rubrospinal** tracts are located in the lateral funiculi. The fibres from these tracts cross over in the brain and descend through the lateral funiculi. The rubrospinal tracts also carry motor information to skeletal muscles. They also carry information about posture and coordination.

The **reticulospinal** tracts consist of anterior and lateral tracts. They are located in the anterior and lateral funiculi. Some of the fibres cross while others do not. These tracts carry information related to muscular tone and activity of sweat glands.

Here is a summary of the tracts:

Fasciculus gracilis/cunneatus—carry touch and pressure information and cross in the medulla oblongata.

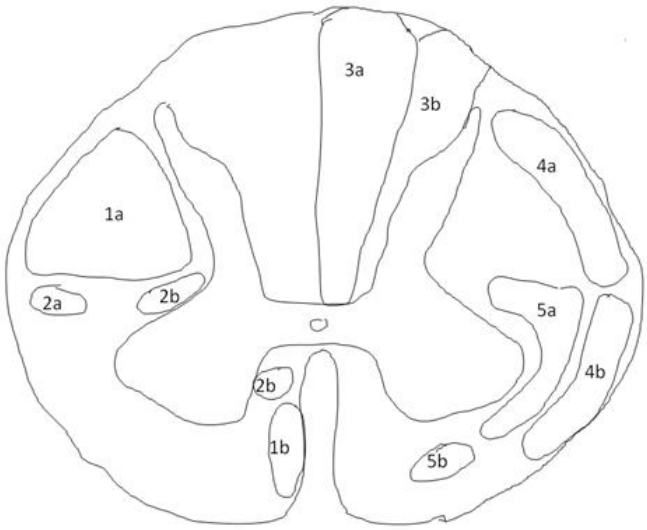
Lateral spinothalamic—carries pain and temperature information and crosses 1-2 segments above where the information enters the cord.

Anterior spinothalamic—carries light touch and pain information and crosses 1-2 segments above where the information enters.

Spinocerebellar—has two parts: anterior and posterior. Carries information for coordination and the fibres do not cross.

Corticospinal—carries motor information to muscles.

Rubrospinal—carries motor information to muscles.



Reticulospinal—carries motor information for muscle tone and sweat glands.
1a. Lateral Corticospinal 1b. Anterior Corticospinal 2a. Rubrospinal2b. Reticulospinal3a. Fasciculus Gracilis3b. Fasciculus Cunneatus4a. Posterior Spinocerebellar 4b. Anterior Spinocerebellar 5a. Lateral Spinothalamic 5b. Anterior Spinothalamic

Peripheral nervous system

The peripheral nervous system consists of all of the nervous system structures located outside of the brain and spinal cord. Some of the peripheral nervous system structures we will cover include the spinal nerves, cranial nerves, and the autonomic nervous system.

Spinal nerves

The dorsal and ventral roots coming off of the spinal cord combine to form spinal nerves. There are 31 pairs of spinal nerves. They are named after their attachment point in the spine. For example, cervical nerves are named C1-C8, thoracic T1-T12, lumbar L1-5, and sacral S1-S5. All spinal nerves are mixed nerves and carry both sensory and motor information. Once they exit the cord, the spinal nerves branch. There are three branches:

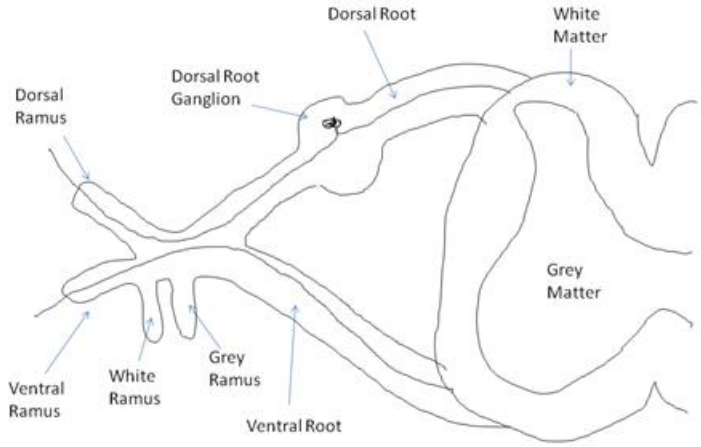
- **Anterior**. The ventral branch (ramus) innervates the sides and anterior trunk.
- **Posterior**. The posterior branch (sometimes called a ramus) innervates the back. It carries sensory information from the central region of the back as well as motor information to the muscles of the spine.
- **Visceral**. The visceral branch becomes part of the autonomic nervous system.

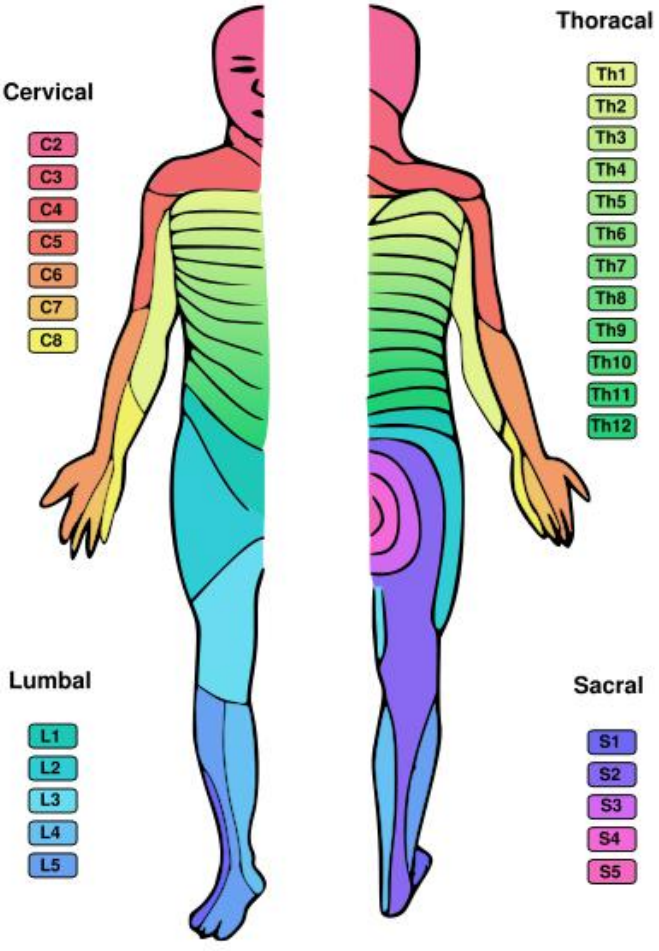
There is also a meningeal branch that courses back into the spinal canal and innervates the vertebrae, meninges, and spinal ligaments. Spinal nerves carry sensory information from the surface of the body and motor information to the muscles. Each nerve carries sensation from a specific area of the body called a dermatome.

Some spinal nerves combine to form complex networks called plexi. There are four major plexi in the human body. The cervical plexus (C1-C4) innervates the posterior head and skin of the neck. The brachial plexus (C5-T1) consists of the ventral rami (branches) from spinal nerves C5-T1. The rami form three trunks and the trunks become six divisions which again join to form three cords. Five branches emerge from the three cords which constitute the major nerves of the upper extremity. These include the axillary, radial, musculocutaneous, ulnar and median nerves.

The lumbar plexus consists of the ventral rami from spinal nerves L1-L4. The sacral plexus consists of the ventral rami from spinal nerves L4-S4. Sometimes both plexi are

referred to as the lumbosacral plexus. The major nerves exiting the lumbosacral plexus include the obturator, femoral, and sciatic.





The cranial nerves

Cranial nerves carry sensory and motor information mostly from the head.

There are twelve pairs of cranial nerves. Eleven of these originate in the diencephalon or brainstem while one pair originates in the frontal lobe of the brain. The cranial nerves can carry sensory information, motor information or both. The sensory information consists of touch, pain, taste, hearing and vision. Motor information controls skeletal muscles, organs

and glands. Some cranial nerves also carry information for the parasympathetic nervous system. The cranial nerves are usually designated as Roman numerals (I—XII).

I (Olfactory)
II (Optic)
III (Oculomotor)
IV (Trochlear)
V (Trigeminal)
VI (Abducens)
VII (Facial)
VIII (Auditory)
IX (Glossopharyngeal)
X (Vagus)
XI (Accessory)
XII (Hypoglossal)

Type of cranial nerves:

I (Sensory)
II (Sensory)
III (primarily Motor)
IV (primarily Motor)
V (Both)
VI (primarily Motor)
VII (Both)
VIII (Sensory)
IX (Both)
X (Both)
XI (primarily Motor)
XII (primarily Motor)

Here is an overview of the function of the cranial nerves:

1. **Olfactory**: Carries information for sense of smell to frontal lobe.
2. **Optic**: Carries information for sense of sight to occipital lobe.
3. **Oculomotor**: Innervates eye muscles.
4. **Trochlear**: Innervates superior oblique muscles of eye.
5. **Trigeminal**: Carries sensory information from face. Motor to masseter and temporalis muscles (chewing muscles).
6. **Abducens**: Innervates lateral rectus muscles of eye.
7. **Facial**: Carries sensory information from anterior 2/3 of tongue. Motor to muscles of facial expression.
8. **Auditory** (Vestibulocochlear): Carries information for sound, static and dynamic equilibrium from inner ear.
9. **Glossopharyngeal:** Carries sensory information for taste from posterior 1/3 of tongue. Motor to swallowing muscles.
10. **Vagus**: Sensory information from oesophagus, respiratory and abdominal viscera. Motor to heart, stomach, intestines and gallbladder. Also helps to coordinate swallowing.
11. **Spinal Accessory**: Motor to trapezius and sternocleidomastoid muscles.
12. **Hypoglossal**: Motor to tongue.

Autonomic nervous system

The autonomic nervous system has two parts. The sympathetic division prepares your body for action (fight or flight) while the parasympathetic division calms you down.

The autonomic nervous system can be thought of as an “automatic” system because it works to maintain homeostasis in the body even when it is in an unconscious state. The autonomic nervous system (ANS) can control respiratory, cardiovascular, urinary, digestive and reproductive functions. It works to maintain the balance of fluids, electrolytes, blood pressure, nutrients, and blood gasses. The ANS does this by sending motor impulses to viscera, cardiac and smooth muscle. Since it sends motor impulses to viscera, the ANS is also known as a visceral motor system.
The ANS is divided into two subdivisions. The sympathetic is often referred to as the “fight or flight” system. The sympathetic division emerges from the thoracic spine. The parasympathetic division begins in the cervical and lower thoracic spine and sends fibres to the same organs as the sympathetic. The sympathetic and parasympathetic divisions typically have the opposite effect on organs and thus work to maintain balance based on the body’s needs.
For example, the sympathetic system can increase heart rate while the parasympathetic system decreases it.

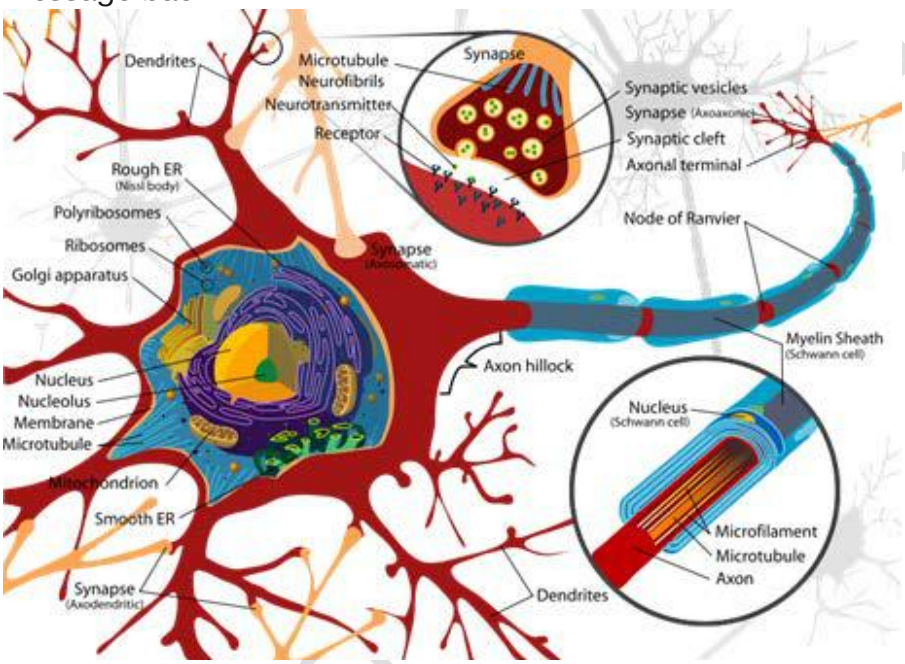
Part 3: Cells of the Nervous System
We will now take a look at the small structures of the nervous system, namely the neurons.
The cells of the nervous system are called neurons.

Neurons
Neurons are nervous system cells that talk to each other.
The neuron is the carrier of information in the nervous system. The neuron has a number of parts but there are three basic parts you should learn:
Cell body—sometimes called the perikaryon, it contains many of the cell organelles we described in Module 1. These include mitochondria, microtubules, Golgi apparatus, and a granular cytoplasm. The cell body also contains Nissl Bodies which are membranous packets of chromatophilic substance consisting of rough endoplasmic reticulum (this makes proteins).
Dendrites—extensions of the cell body that typically receive information from other neurons.
Axon—a long process that transmits information to other neurons. Some axons contain a wrapping called the myelin sheath. The axon connects to the cell body via a structure called the axon hillock. The axon ends in a structure called the axon terminal. The axon terminal releases chemicals called neurotransmitters that carry messages to other neurons.
There are a number of different types of neurones but the one we will be learning about is called the multipolar neuron.
Neuroglia
The nervous system also contains cells that support neurons called neuroglia. There are a few different types of neuroglia that have a number of important functions.
Astrocytes provide structural support and may also help in regulating electrolytes. They are star-shaped and can be found between neurons and blood vessels. Astrocytes help to maintain the blood-brain barrier and help to repair damaged areas in the central nervous system by forming scar tissue.
Oligodendrocytes produce the myelin that surrounds white matter axons in the brain and spinal cord.

Ependymal cells form the lining of the central canal and ventricles in the spinal cord and brain. They are also found in the choroid plexus of the brain. They help to produce CSF by providing a porous membrane for blood plasma to pass through.
Microglia are very small cells that are located throughout the central nervous system. They provide support and help to clean up debris through phagocytosis.

Connecting neurons

There are literally billions and billions of connections in your nervous system. One neuron can have up to 10,000 connections with other neurons. The axon of one neuron can connect with the dendrites of another neuron. The connection is called a synapse.
The first neuron in a 2-neuron system is called the pre-synaptic neuron and will secrete a neurotransmitter that floats across what is called the synaptic cleft to the second neuron called the post-synaptic neuron. The neurotransmitter is then picked up by the dendrites of the postsynaptic neuron.
It is important to know that neurons can only send one of two different messages: Either a neuron can send a message to move the message forward or to hold the message back.



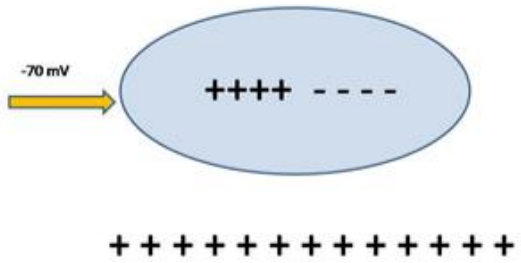
Part 4: How Neurons Work

Neurons talk to each other by generating electrical messages called action potentials that result in sending messages called neurotransmitters to one another.

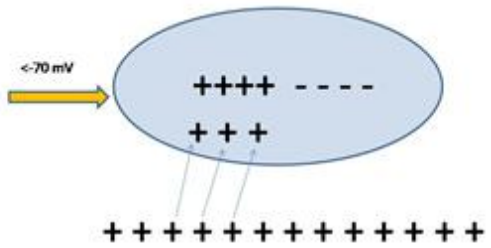
The resting membrane potential

This can be a difficult concept to learn completely, but remember in the big picture approach: it is necessary to see the big picture first before seeing all of the details.
Let's begin by saying that neurons don't like to exist in an electrically balanced state. They get unbalanced because their membranes are permeable to some substances but not to others. It just so happens that some of those substances can move out of the cell while others are trapped in. Since these substances have charges, the cell is left with a negative charge on the inside of its membrane.
The substances we are talking about are mostly sodium (Na+) and potassium (K+). This brings us to two important rules in human physiology:
There is always more sodium outside the cell than inside.
There is always more potassium inside the cell than outside.

Now let's say there are some negative ions trapped inside the cell. And let's say that potassium can move out of the cell (remember there's more potassium inside than out). Both of these conditions work to provide more positive charges outside the cell than inside.



What happens next is that something stimulates the cell so that sodium gates open. Following our rule that there is more sodium outside the cell than inside; sodium rushes into the cell as it moves down its concentration gradient. This produces the condition in this diagram:



Positively charged sodium ions move into the cell causing the cell to become less negative.
This process is called depolarization. It is best to associate sodium with depolarization.
Why is it called depolarization? When the cell exists in its unbalanced state it is said to be polarized.
The movement of sodium into the cell tends to reduce this difference in charge from outside to inside. We say the cell is becoming less polar or depolarizing.
The cell will continue to depolarize all the way to + 30 millivolts.
Next, the sodium gates close and potassium gates take over causing potassium to move out of the cell (actually the potassium gates were open all of the time but the net effect of potassium moving out was negligible as compared to sodium moving in).
The cell is repolarising. The cell repolarises all the way back to -70mV.
So where is the action potential?
As the cell depolarises from -70mV, it becomes less negative. At some point, it will reach -55mV.
This is an important number because something special happens at -55mV.
-55mV is called the Threshold.

The something special that happens at the threshold is that a large number of sodium gates open causing the cell to rapidly depolarize all the way to +30 mV. Once the cell depolarizes to - 55mV, it can't be stopped.

The action potential is the rapid change in voltage from -55mV to +30 mV.

What happens if the cell depolarizes but doesn't reach the threshold?

Nothing. The cell just repolarizes back to -70mV.

Where are all these sodium gates that open when the threshold is reached? They are located in the axon hillock—where the axon connects to the cell body.

What happens if potassium gates are opened when the cell is at resting membrane potential?

The cell goes into what is called hyperpolarization and no action potential is produced.

What causes the cell to depolarize or hyperpolarize in the first place?

Neurons respond to substances known as neurotransmitters. Keep in mind our physiology rule:

Neurotransmitters can do one of two things. They either move the message forward or hold the message back.

In other words, there are excitatory and inhibitory neurotransmitters. Excitatory neurotransmitters move the message forward by depolarizing the neuron and producing an action potential. Inhibitory neurotransmitters hold the message back by hyperpolarizing the neuron and keeping it from producing an action potential. Remember that depolarization has to do with opening sodium gates and hyperpolarization has to do with opening potassium gates.

How the action potential moves down the axon

There are two different types of axons. Some consist of grey matter while others have a fatty substance called myelin surrounding them (white matter). You could think of the difference as being similar to bare wires as compared to insulated wires.

In the grey matter axons (bare wire), the action potential moves down in a wave-like motion. Sections of the axon depolarise causing subsequent sections to depolarize. We say the action potential propagates down the axon.

In the white matter axons (insulated wire), action potentials move in a different way but before we can discuss this, we need to look at some other differences of white matter axons. The myelin substance in white matter axons is produced by special cells called Schwann cells. Since there are a number of Schwann cells that make up the myelin sheath, there are gaps in the myelin. These gaps are very special and even have a special name. They are called "Nodes of Ranvier".

Not only do these nodes have a special name, they also have a special structure. There are large numbers of sodium gates located at these nodes and they open in response to an action potential. When the action potential reaches a node, the sodium gates open, causing sodium to rush into the axon. The end result is the impulse appears to jump from node to node. This also has a special name. This type of movement of an action potential along a myelinated axon is called saltatory conduction.

What is the purpose of myelinated axons?

It turns out that saltatory conduction in myelinated axons is much faster than unmyelinated axons. Nerve impulses have to travel a long distance in some neurons. Think of an impulse going from the spinal cord to your big toe. That's a lot of distance to cover. Myelinated axons are more numerous in areas that require this fast conduction. When the myelin becomes damaged (demyelination), the impulse does not conduct as rapidly. This can result in numbness, tingling, pain and even loss of muscle function. One example of this problem is seen with carpal tunnel syndrome.

Release of the neurotransmitter

Once the impulse reaches the end of the axon, it enters a structure called the axon terminal. This is where the neurotransmitter is located that will carry the message to the next neuron. Upon reaching the axon terminal, the action potential causes another ion gate to open. This time the ion is calcium. Since these calcium gates respond to the action potential, they are often referred to as voltage gated calcium channels.
Once these calcium channels open, calcium rushes into the axon terminal causing the release of the neurotransmitter from a package called a synaptic vesicle. The neurotransmitter then moves across the synaptic cleft to the next neurotransmitter.

Examples of neurotransmitters

Here are a few examples of neurotransmitters.

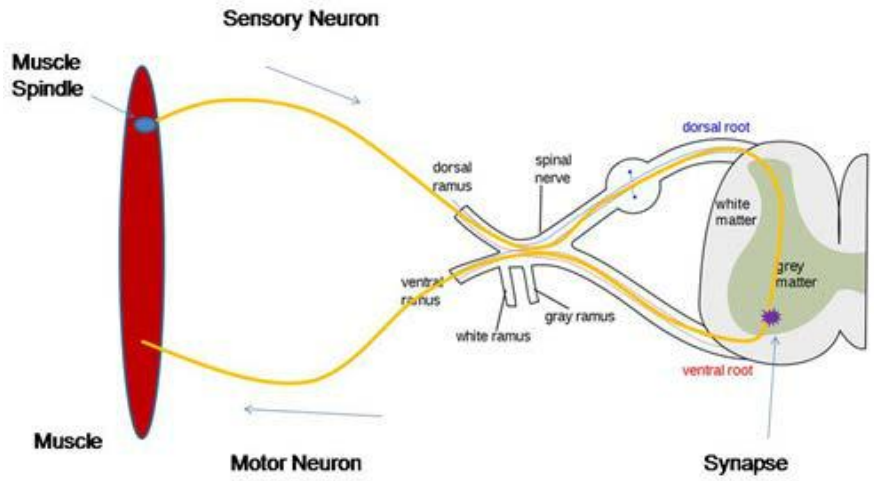
Acetylcholine: Decreases heart rate, increases secretions of sweat and saliva and facilitates muscle contractions.

Norepinephrine: Increases heart rate, decreases circulation of blood.

Dopamine: Increases happiness and alertness.

GABA: Decreases anxiety, alertness, muscle tension and memory.

Serotonin: Increases well-being and happiness, decreases pain.



The Autonomic Nervous System

The autonomic nervous system controls internal organs. It is the part of the nervous system which directs involuntary muscles, such as smooth and cardiac muscle and glands. You will remember from Topic 3 in Module 1 on the muscular system that smooth and cardiac muscles are responsible for such processes as digestion and respiration and the heart beating. This system is also called the **involuntary nervous system.**

The autonomic nervous system is what keeps our heart beating, our lungs breathing and our digestive system moving food through the body. You cannot control these action and they take place without even knowing about them. Autonomic motor nerves travel to cardiac muscle, smooth muscle and to glands.

The autonomic nervous system can also be divided into two parts:

- **the sympathetic system** – which is concerned with mobilising body's energy during times of stress. It is involved in the fight or flight response.
- **the parasympathetic system** – concerned with the conservation of the body's energy. It slows down or relaxes the body and regulates the involuntary activity of glands, smooth muscle and cardiac muscle.

These two subsystems work together but in opposition to each other. The sympathetic nervous system prepares the body for sudden stress.

The 'fight or flight' response is what happens when a person is scared for their safety. Have you ever been really frightened by something and noticed what happens to your body? The things you might have noticed are that your heart beats faster, your blood pressure increases, your digestion slows down and you breathe more heavily.

What you don't know is happening is that the **sympathetic nervous system** sends an instant message to release the hormone adrenalin which causes the body to be ready to either have a fight with someone or run away- fight or flight!

This response goes back to when stone-age man lived in caves and chased animals for food. When he met a woolly mammoth when out hunting, the cave man would be very frightened and had to decide very quickly whether to try to kill the animal for food or to run away to avoid being killed himself!

The **parasympathetic nervous system** does the exact opposite. It prepares the body for rest and regulates the involuntary essential body functions.

Luckily we no longer have to fight animals for food but we still have the same response when we get very scared. Here is a table which shows how the sympathetic system works and how the parasympathetic system works in opposition.

Sympathetic and Parasympathetic Effects		
Structure	**Sympathetic**	**Parasympathetic**
Eye (pupil)	Dilation	Constriction
Nasal Mucosa	Mucus reduction	Mucus increased
Salivary Gland	Saliva reduction	Saliva increased
Heart	Rate increased	Rate decreased
Arteries	Constriction	Dilation
Lung	Bronchial muscle relaxation	Bronchial muscle contraction
Gastrointestinal Tract	Decreased motility	Increased motility
Liver	Conversion of glycogen to glucose increased	Glycogen synthesis
Kidney	Decreased urine	Increased urine
Bladder	Contraction of sphincter	Relaxation of sphincter
Sweat Glands	↑Sweating	No change

This has been a lot to take in – the human nervous system is not simple! Please answer the questions in the next Activity to see how much you have understood about the peripheral nervous system.

Part 5: Reflexes

Reflexes are involuntary responses to sensory stimuli.

One of the simplest communication structures in the nervous system is the 2-neuron reflex arc. Think of going to the doctor and having her tap your leg just below your knee. Your usual response is to briefly straighten your leg in a jerking motion. Sometimes this is referred to as a monosynaptic (one synapse) reflex.

In this reflex, we have only two neurons. There is a sensory neuron that carries the message that the muscle length has changed to the spinal cord. There is also a motor neuron that carries the message from the cord back to the muscle.

When you strike the tendon of a muscle (say the patellar tendon just below the knee), it causes a brief lengthening of the muscle. This is sensed by a special receptor in the muscle called a muscle spindle. The receptor takes the information about stretch to the spinal cord where it relays it to another neuron. This neuron is a motor neuron that carries the message to contract the muscle (to take up the slack) back to the muscle. The result is the familiar knee jerk.

Memory

There are basically two types of memory. Short-term memory allows you to remember small bits of information for brief periods. Long-term memory allows for storing lots of information for long periods of time.

The brain is capable of storing vast amounts of information in its memory. There are two basic types of memory. Short-term memory stores 6-8 pieces of information for brief periods. For example, a telephone number is 7 pieces of information long and can be stored for a short amount of time until the person is asked to remember something else. Long-term memory, as its name implies, allows for storage of information for much longer periods of time (as long as a lifetime). Types of long-term memory include declarative and procedural. Declarative is sometimes referred to as explicit and procedural is referred to as implicit.

Declarative memory occurs in part of the temporal lobes and the hippocampus and amygdala. The hippocampus is involved in retrieving stored memories whereby the amygdala stores emotions associated with memories. Declarative memory is also stored in various parts of the cerebrum. Memories are grouped together as well. For example, faces may be stored in a different location than names. Retrieving a memory involves accessing various components and assembling them. Over time, memories decay and can lead to false memories.

Procedural memory involves storing skills such as playing an instrument or driving a car. Procedural memories are stored in the premotor area of the cerebrum and cerebellum.

Information to be remembered moves from short-term to long-term memory. Neurons in long-term memory actually change in response to storing information. The phenomenon of long-term potentiation occurs when memories are stored. This involves changes in neurotransmitter storage and release as well as protein synthesis. New connections are made and maintained between neurons. This flexible and adaptive characteristic of the brain is known as neural plasticity.

Common pathologies

Anxiety – fear of the unknown can vary from mild to severe. Panic attacks and phobias.

Bell's palsy – disorder of the seventh cranial nerve resulting in paralysis on one side of the face

Cerebral palsy – damage to the central nervous system in a baby before, during or just after birth
Depression – although still often referred to as a chemical imbalance, more and more evidence points to a link between mood/depression and the gut microbiota
Epilepsy – neurological disorder with recurrent and temporary seizures
Headache – affects the head but excluding the face. From simple to chronic, migraine to cranial it can arise from stress to neurological disorders
Meningitis – inflammation of the meninges from bacterial or viral infection
Motor neurone disease – progressive degenerative disease of the motor neurons of the nervous system
Multiple sclerosis – disease of the central nervous system
Myalgic encephalomyelitis – also known as chronic fatigue syndrome, characterised by extreme disabling fatigue
Neuralgia – pain along the entire course or branch of a peripheral sensory nerve
Neuritis – inflammation or disease of a single or several nerves
Parkinson's disease – damage to the grey matter of the brain, also known as basal ganglia
Sciatica – lower back pain which can affect the buttock and thigh
Stress – anxiety, depression, irritability, headaches, back pain, excessive tiredness

Module Fifteen: The Sensory System

Part 1: Somatic Sensory System

All sensors do the same thing. They take information in many forms and convert it into electrochemical impulses so it can be sent to the nervous system.

Here is a list of some of the types of sensory receptors:

- **Chemoreceptors** sense changes in chemical concentration.
- **Pain receptors** (nociceptors) sense tissue damage.
- **Thermoreceptors** sense changes in temperature.
- **Mechanoreceptors** sense mechanical deformation of tissue.
- **Proprioceptors** sense changes in position of joints.
- **Stretch receptors** sense changes in tissue length.
- **Photoreceptors** sense changes in light intensity.

Somatic sensory system

We can divide the sensory system into the senses that sense the skin, muscles, joints and organs and the special senses (vision, hearing, taste, and smell). The somatic senses include touch, pressure, temperature, pain, and stretch.

Specific receptors:

- **Free nerve endings** sense touch and pressure and produce pain.
- **Merkel's discs** sense fine touch and pressure.
- **Pacinian corpuscles** sense heavy pressure.
- **Ruffini corpuscles** sense skin movement and pressure.

Two important receptors in muscles

There are two important sensory receptors located in muscles. These are the muscle spindles and Golgi Tendon Organs.

Muscle spindles are located more centrally in muscles. These are the receptors involved in the reflexes we described in the nervous system chapter. Muscle spindles sense stretch (change in muscle length).

Golgi tendon organs (GTOs) are located at the ends of the muscle near the origins and insertions. These act as a protective mechanism to help keep muscles from pulling off the bone with extreme forces. For example, think of helping a friend move to a new house. You are holding an empty box while your friend fills it full of heavy objects. Eventually, the box becomes so heavy that it triggers the GTOs and your arm muscles relax, with the result that the box drops to the floor.

The special senses

The special senses include taste, smell, hearing and vision.

As we mentioned previously, the special senses include taste, smell, hearing and vision. Taste and smell are very similar in that they are both sensed by chemoreceptors. This is why taste and smell are so closely related. Have you ever had a bad cold or sinus infection where you couldn't taste food? Smell actually accounts for a large portion of taste. Your sense of smell can distinguish between 2000-4000 different smells.

The sense of smell is also closely related to the limbic system (the seat of emotions). This is why certain smells can trigger memories (remember grandma's apple pie and how content you were after eating it?).

The organs for taste are called tastebuds and reside on the tongue. There are also taste buds on the walls of the cheek and the throat. You have about 3000 taste buds.

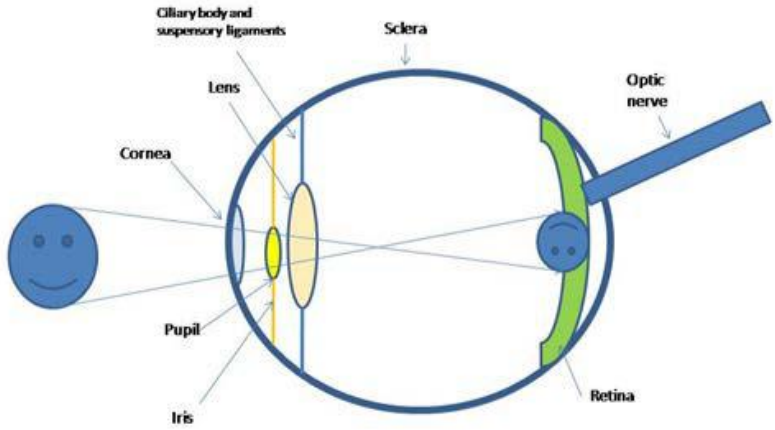
There are five primary taste sensations. Tastes are combinations of these primary sensations.

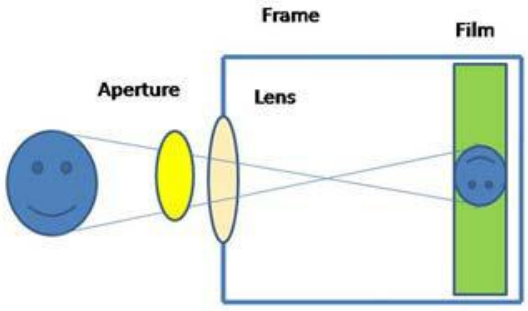
- **Sweet**
- **Sour**

- **Salty**
- **Bitter**
- **Umami**

The 5th taste sensation is called umami. This one is a hearty, meaty taste produced by L-glutamate.
Taste receptors are more sensitive to unpleasant stimuli. For example, we are about a thousand times more sensitive to acids than sweet tastes.

Part 2: Vision
The eye
The eye is put together in three layers called tunics. There is an outer, inner and middle tunic in each eye. In order to understand how the eye is put together, let's look at a camera.
Here is a very basic camera. There is a frame to hold things together, a lens, an aperture and a piece of film. Light rays from the subject pass through the aperture, lens and a space in the frame to reach the film. The aperture can change its diameter to let in more or less light. Notice that the image is upside down on the film.

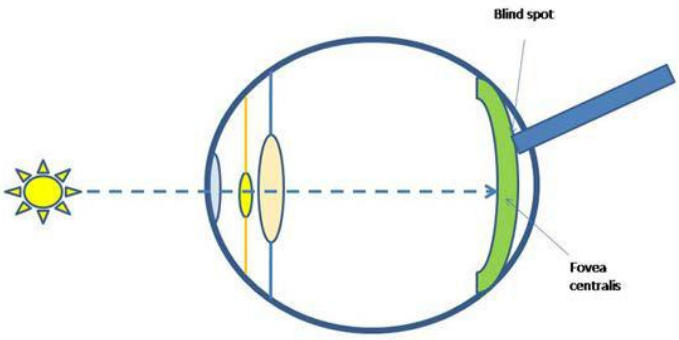


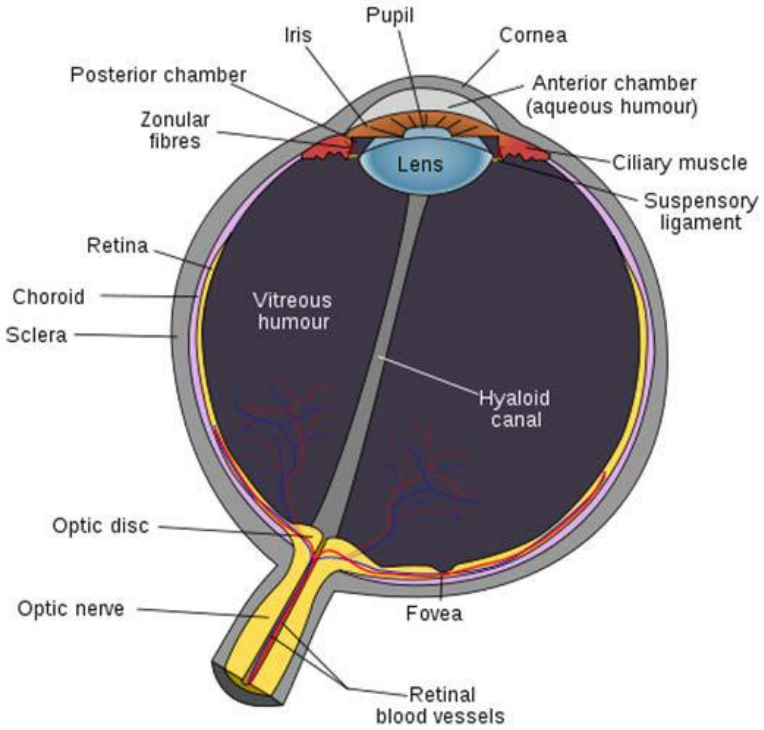


Notice the similarities between the camera and the eye. The “frame” of the eye is the sclera (white portion of the eye). Cameras are usually painted black on the inside. This provides a good contrast for the image on the film. The eye has a similar structure called the choroid coat. It is in the middle layer of the eye and is a dark coloured membrane. The aperture is the pupil, the lens is still the lens, and the film is now the retina. There are some additional structures such as the cornea which is a transparent portion of the outer tunic to allow light into the eye, the iris or coloured part of the eye, and the ciliary body that holds the lens in place.

The large space between the lens and the retina is filled with a jelly-like fluid called vitreous humor. The ciliary body also secretes a watery fluid called aqueous humor which is in the front part of the eye. The optic nerve carries the visual information from the retina to the brain.

The fovea centralis is the area of sharpest vision. The blind spot is where the optic nerve connects to the back of the eyeball.





Light rays that enter the eye and follow a straight path to the back of the eye reach an area called the fovea centralis. This is also known as the area of sharpest vision and is conveniently located in this straight path. This area has the largest concentration of photoreceptors. A bit off to the side is the blind spot where the optic nerve connects to the eyeball. There are no photoreceptors here and the brain "fills in" the area so you don't even realise it.

Moving the eye

The eye can perform complex movements. Just try to follow a ping pong game. It can do this because there are six muscles on each eye. Remember that these muscles are controlled by the cranial nerves. Think of holding a beach ball. Your arms are the eye muscles:

- Stand behind the ball. Hold the ball with one hand on top and the other on the bottom. These are the superior and inferior rectus muscles. Bending either arm will simulate the action of the muscle.
- Stand behind the ball. Hold the ball with one hand on each side. Bending either arm will simulate the action of the medial and lateral rectus muscles.
- Instead of standing behind the ball stand to the side of it. Reach across your body and place on hand on top and the other on the bottom of the ball. This simulates the action of the superior and inferior oblique muscles.

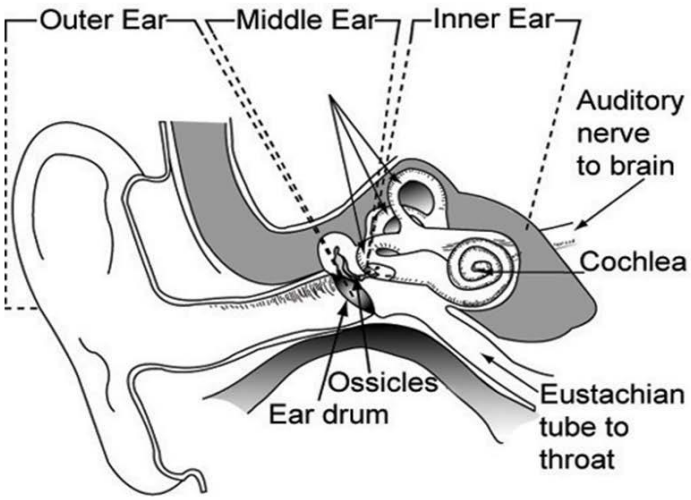
Rods and cones

There are two different types of photoreceptors in the eye. One is for colour and the other for black and white vision. The photoreceptors for colour are called cones. The others are the rods for black and white vision. Cones work better in daylight and rods work better at night. Cones are also more concentrated in the central area of the retina (fovea centralis) while rods are more concentrated in the periphery of the retina (peripheral vision).

These receptors work by virtue of chemical reactions. In the rods, the key substance is rhodopsin. Rhodopsin consists of two parts which include opsin (a protein) and retinal. Rhodopsin is embedded in the rod's cell membrane. Rhodopsin breaks down in light

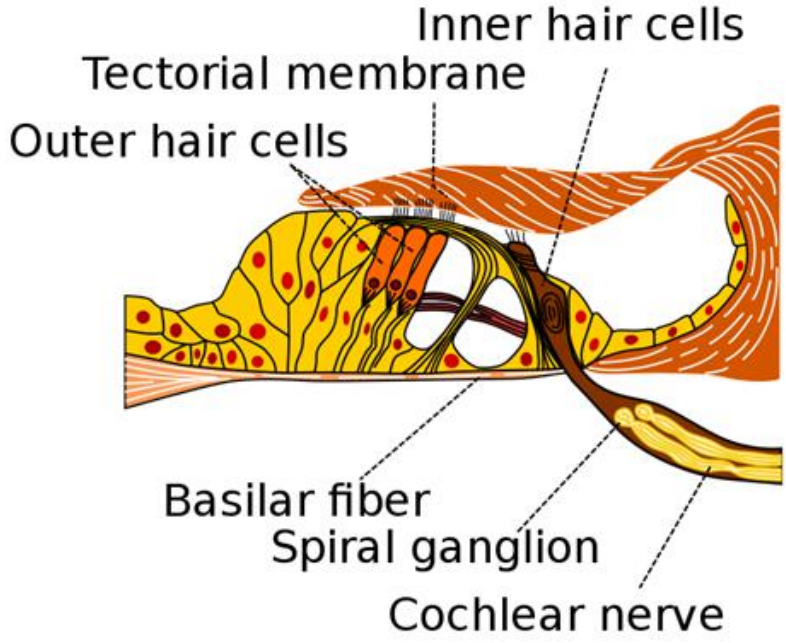
causing the retina to separate from it. The separation of retinal causes changes in the membrane potential that travels to the nervous system.
One important thing about retinal is that it contains vitamin A. It was actually found that soldiers in World War II who did not get enough vitamin A developed night blindness.
Cones require a higher intensity of light in order to trigger action potentials. Cones use different opsins corresponding to the primary colours they absorb (blue, green, red). The reaction of retinal and opsins is essentially the same as in rods. The end result is a change in membrane potential.
If you don't have the right cones or a small amount of a certain type of cone, you will be colour blind. The most common type is red-green colour blindness in which red and green are seen as the same colour. Up to 8-10% of the male population may have some degree of colour blindness.

Part 3: The Ear
The ear consists of 3 parts: outer, middle and inner ear.
The eye had three layer or tunics and the ear has three divisions. These are the outer, middle and inner ear. The structures aren't too complex until you get to the inner ear. So we will summarise the structures with a diagram and brief explanation so you get the big picture.

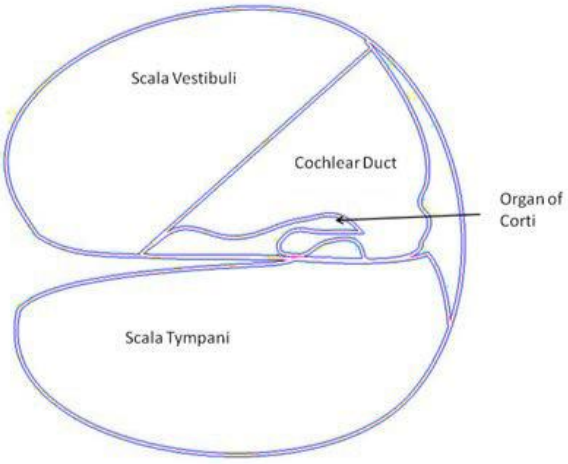


Outer ear
Auricle (or pinna)—the outer portion of the ear.
External auditory meatus—a tube-like structure that runs in the temporal bone.
Middle ear
Tympanic membrane—eardrum.
Malleus, Incus and Stapes—tiny bones called ossicles. Think of a hammer, anvil and stirrup.
Eustachian tube—passageway between the middle ear and upper nasal passages to equalise pressure.
Inner ear
Cochlea—looks like a snail's shell. This is where sound is sensed.
Semicircular canals—look like loops. This is where dynamic equilibrium is sensed.
Vestibule—area between the cochlea and semicircular canals. This is where static equilibrium is sensed.

Oval window—where the stapes connects to the inner ear.
Round window—membrane that helps to equalise fluid pressure.
Vestibulocochlear nerve- cranial nerve VIII.



Inner ear structures
The inner ear is a bit more complex. Not only does it sense hearing but also static equilibrium (if you're sitting, standing or bending over) and dynamic equilibrium (are you sitting in a chair or riding a bicycle?).
Inside the cochlea
The cochlea looks like a snail's shell, and if we were to "unroll" it, we would see a tube-like structure that looks something like a windsock. If we were to slice the tube we would get something like this:



Inside the cochlea, we see three chambers filled with fluid. There are the scala vestibuli, scala tympani and scala media or cochlear duct. The cochlear duct contains the organ that senses hearing called the organ of Corti.
If you look closely at the organ of Corti, you will see little hairs coming out of the top of it. These are the hair cells. Also, notice that the organ of Corti is anchored to a membrane called the basilar membrane (basilar fibre in the diagram). The hair cells stick up and

connect to another membrane called the tectorial membrane. These will be important when we explain how hearing is sensed by the ear.

Ear physiology

It all starts with sound waves. Sound is nothing more than changes in air pressure (or fluid pressure if you're underwater). In other words, there must be a medium to carry sound. So in space, where there is a vacuum, there is no sound. Literally, no one can hear you scream and spacecraft would be silent.

These sound waves reach the ear and are collected by the pinna and the external auditory meatus much like taking a piece of paper and rolling it into a cone with both ends open then sticking the narrow end into your ear.

The sound waves reach the tympanic membrane and cause it to move in and out. This movement of the tympanic membrane is carried via vibrations of the auditory ossicles (malleus, incus and stapes) to the inner ear (at the oval window). The vibrations are then carried to the fluid-filled chambers of the inner ear.

Think of striking a tuning fork and dipping the vibrating end into a bucket of water. You could see the waves produced by the vibrations. The sound waves have been converted to mechanical fluid waves.

The fluid waves reach the organ of Corti and cause the membranes (basilar and tectorial) to resonate and move. The movement is picked up by the hair cells and converted to action potentials carried by cranial nerve VIII (vestibulocochlear nerve). The impulses basically end up in the temporal lobe where sound is perceived.

The tympanic reflex

There are a couple of tiny muscles attached to the ossicles in the middle ear that help to either transmit vibrations from the tympanic membrane or to dampen (inhibit) them. These are the tensor tympani and stapedius muscles.

Static equilibrium

The ear also lets your brain know whether you are reclining on your sofa or standing up. In other words, it senses changes in position. This is called static equilibrium.

Static equilibrium is sensed in the vestibule. Inside the vestibule are two structures called the utricle and saccule, containing hair cells.The hair cells are located in structures called macula and connect to a membrane called the otolithic membrane.

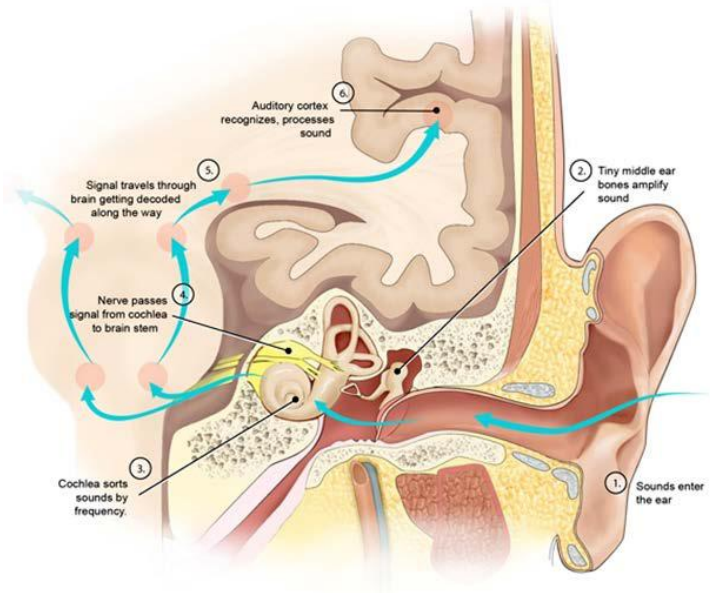
The membrane contains small stone-like structures called otoliths embedded in a membrane that has rocks on it. When you change position the rocks pull on the membrane and bend the hair cells. This motion is converted to action potentials and sent off to the brain.

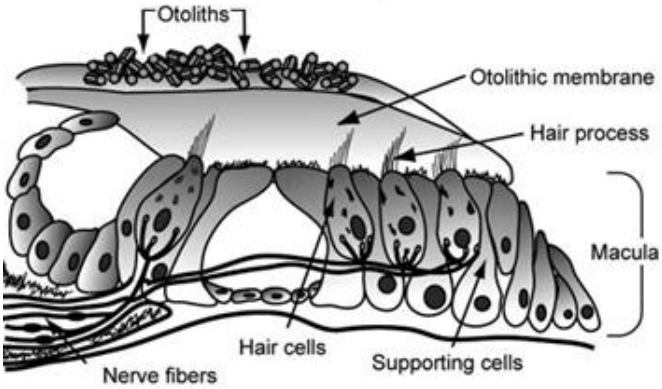
Once in a while, the rocks get out of position causing a condition called benign positional vertigo. Not to worry though because they can be put back into position with a relatively simple manoeuvre called otolithic repositioning.

Dynamic equilibrium

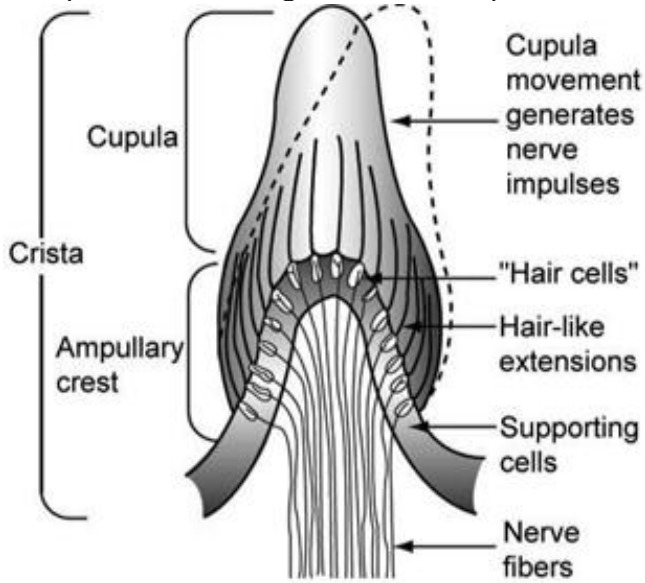
Semicircular canals are filled with fluid. At the base of each semicircular canal is a bulge called the ampulla. Inside the ampulla is a structure called the crista ampullaris. Inside each are hair cells.

Each semicircular canal is filled with fluid. The fluid moves when you move causing the hair cells to bend. The bending is once again translated to action potentials and sent off to the brain. Sometimes the fluid keeps moving even when you are stopped. Think of spinning someone in a rotating chair. When you abruptly stop the chair, the fluid will continue to move causing a sensation of dizziness.





A change in the body's position results in the otoliths pulling on the otolithic membrane. The causes bending of hair cells and transmission of impulses to the brain that are interpreted as changes in static equilibrium.



The crista ampullaris is located inside a semicircular canal. It contains a cupula that bends in response to fluid movement inside of the canals.

Common pathologies

The eye

Achromatopsia –Congenital deficiency in colour perception; also called colour blindness

Astigmatism - Defective curvature of the cornea and lens, which causes light rays to focus unevenly over the retina rather than being focused on a single point, resulting in a distorted image
Cataracts - Degenerative disease in which the lens of the eye becomes progressively cloudy, causing decreased vision
Conjunctivitis - Inflammation of the conjuctiva which can be caused by bacteria, allergy, irritation, or a foreign body
Glaucoma - Condition in which aqueous humor fails to drain properly and accumulates in the anterior chamber of the eye, causing elevated intraocular pressure
Hordeolum - Small, purulent inflammatory infection of a sebaceous gland of the eyelid; also called sty
Macular degeneration - Breakdown of the tissues in the macula, resulting in loss of central vision
Retinal detachment - Separation of the retina from the choroid, which disrupts vision and results in blindness if not repaired
Strabismus - Muscular eye disorder in which the eyes turn from the normal position so that they deviate in different directions
Ear
Acoustic neuroma - Benign tumour that develops from the eighth cranial (vestibulocochlear) nerve and grows within the auditory canal
Anacusis – total deafness
Conductive - Hearing loss due to an impairment in the transmission of sound because of an obstruction of the ear canal or damage to the eardrum or ossicles
Meniere's disease- Rare disorder of unknown origin within the labyrinth of the inner ear that can lead to a progressive loss of hearing
Otitis media - Inflammation of the middle ear, which is commonly the result of an upper respiratory infection
Serous otitis media – Non-infectious inflammation of the middle ear with accumulation of serum (clear fluid)
Suppurative otitis media - Inflammation of the middle ear with pus formation
Otosclerosis - Progressive deafness due to ossification in the bony labyrinth of the inner ear
Presbycusis - Impairment of hearing that results from the ageing process
Tinnitus - Ringing or tinkling noise heard constantly or intermittently in one or both ears, even in a quiet environment
Vertigo - Sensation of moving around in space or a feeling of spinning or dizziness

Conclusion

Well, that's it!

I hope you've enjoyed learning more about your body, mind and senses and that somewhere along the line you've discovered something new and interesting.

There are obviously much, much more to discover in A&P, and we have just scratched the surface.

Having said that, you now have a lot more understanding and knowledge than the majority of people.

Perhaps the most significant discovery is that everything is connected to everything else and when you consider one, you must consider the whole.

I hope you have found at least one system or area that fascinates you more than the others and that you will continue to learn more about the functions of your chosen subject.

All that remains now is for you to dive into the final assessment – and to help you through, I recommend a time of reflection!

I wish you luck.