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SCHOOL OF BIO & CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERING

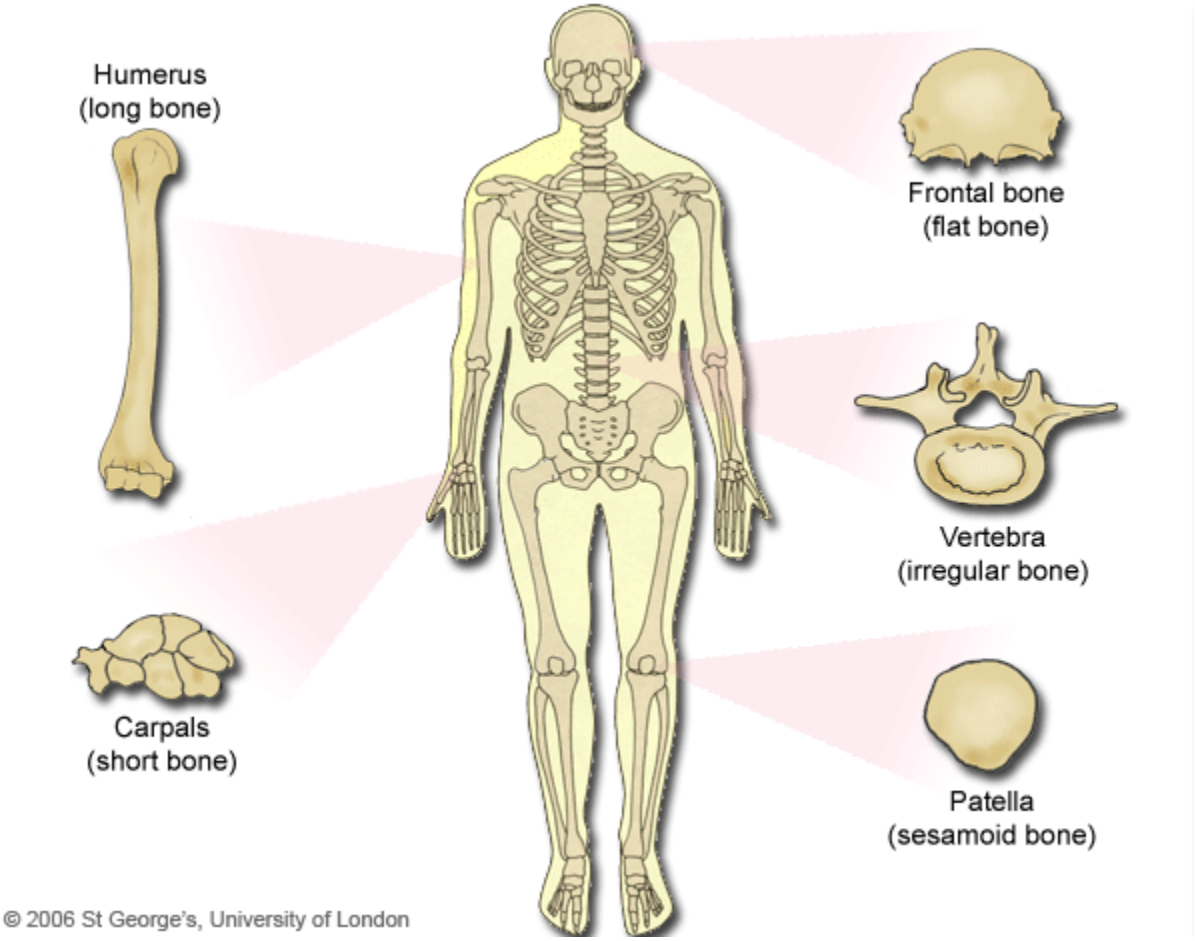
UNIT – I – HUMAN ANATOMY & PHYSIOLOGY – SBMA1303

UNIT I - BONES AND MUSCLE PHYSIOLOGY

A bone is a rigid organ that constitutes part of the vertebral skeleton. Bones support and protect the various organs of the body, produce red and white blood cells, store minerals and also enable mobility as well as support for the body. Bone tissue is a type of dense connective tissue.

TYPES OF BONES

There are 5 types of bones in the human body. These are long bones, short bones, flat bones, irregular bones and sesmoid bones.



Long Bones

Long bones are some of the longest bones in the body, such as the Femur, Humerus and Tibia but are also some of the smallest including the Metacarpals, Metatarsals and Phalanges.

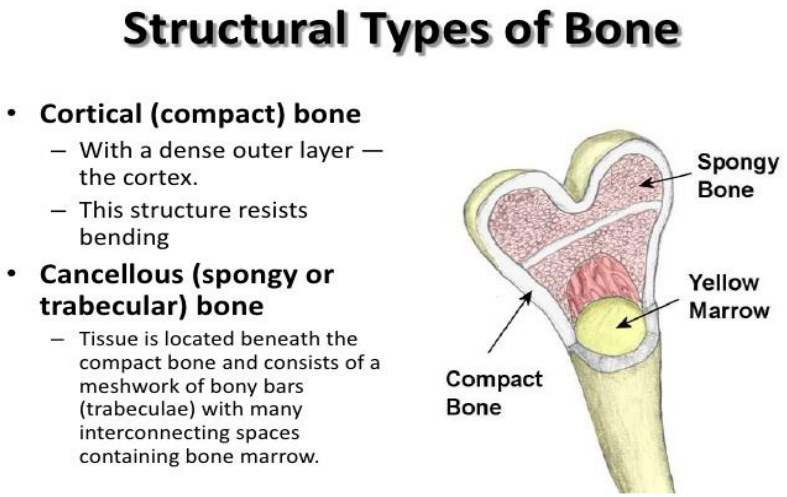
The classification of a long bone includes having a body which is longer than it is wide, with growth plates (epiphysis) at either end, having a hard outer surface of compact bone and a spongy inner known an cancellous bone containing bone marrow. Both ends of the bone are covered in hyaline cartilage to help protect the bone and aid shock absorbtion.

Short bones are defined as being approximately as wide as they are long and have a primary function of providing support and stability with little movement. Examples of short bones are the Carpals and Tarsals - the wrist and foot bones. They consist of only a thin layer of compact, hard bone with cancellous bone on the inside along with relatively large amounts of bone marrow.

Flat bones are as they sound, strong, flat plates of bone with the main function of providing protection to the bodies vital organs and being a base for muscular attachment. The classic example of a flat bone is the Scapula (shoulder blade). The Sternum (breast bone), Cranium (skull), os coxae (hip bone) Pelvis and Ribs are also classified as flat bones. Anterior and posterior surfaces are formed of compact bone to provide strength for protection with the centre consisiting of cancellous (spongy) bone and varying amounts of bone marrow. In adults, the highest number of red blood cells are formed in flat bones.

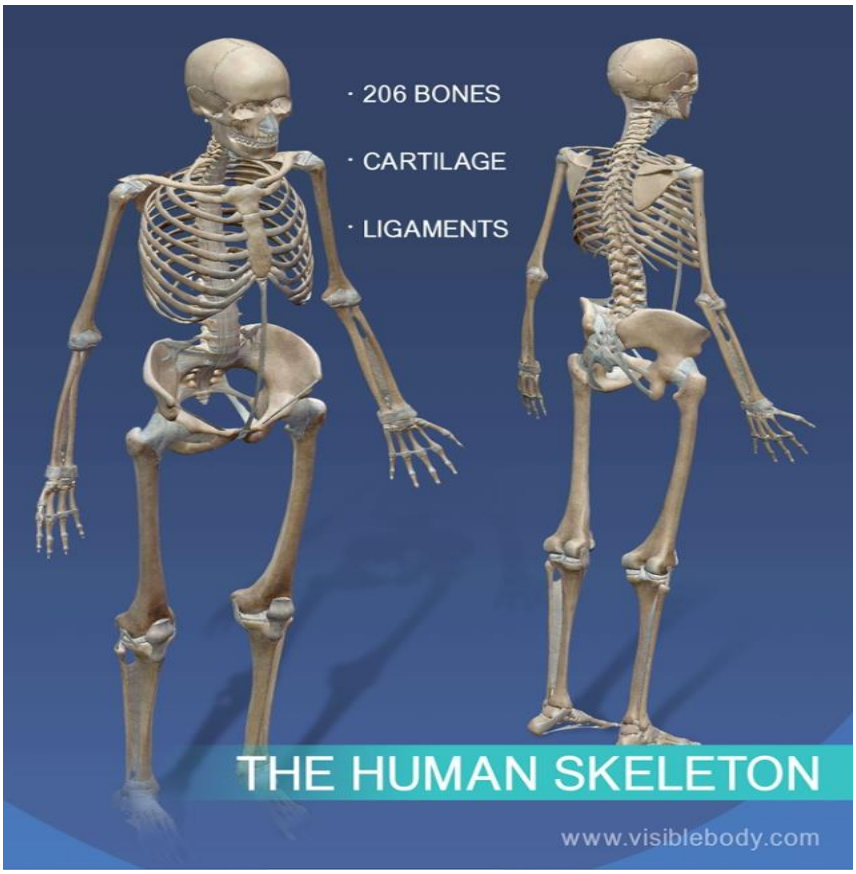
These are bones in the body which do not fall into any other category, due to their non-uniform shape. Good examples of these are the Vertebrae, Sacrum and Mandible (lower jaw). They primarily consist of cancellous bone, with a thin outer layer of compact bone.

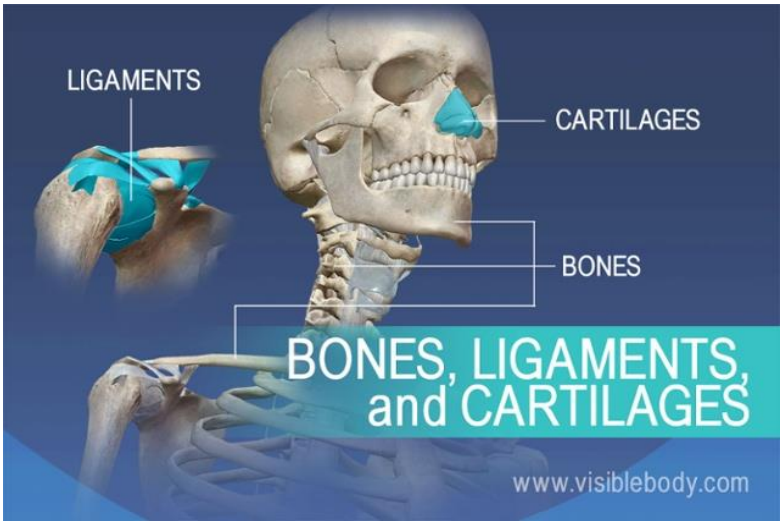
Sesamoid bones are usually short or irregular bones, embedded in a tendon. The most obvious example of this is the Patella (knee cap) which sits within the Patella or Quadriceps tendon. Other sesamoid bones are the Pisiform (smallest of the Carpals) and the two small bones at the base of the 1st Metatarsal. Sesamoid bones are usually present in a tendon where it passes over a joint which serves to protect the tendon.



The human skeleton consists of 206 bones and 32 teeth. The human skeleton also includes ligaments and cartilage. Ligaments are bands of dense and fibrous connective tissue that are key to the function of joints. Cartilage is more flexible than bone but stiffer than muscle. Cartilage

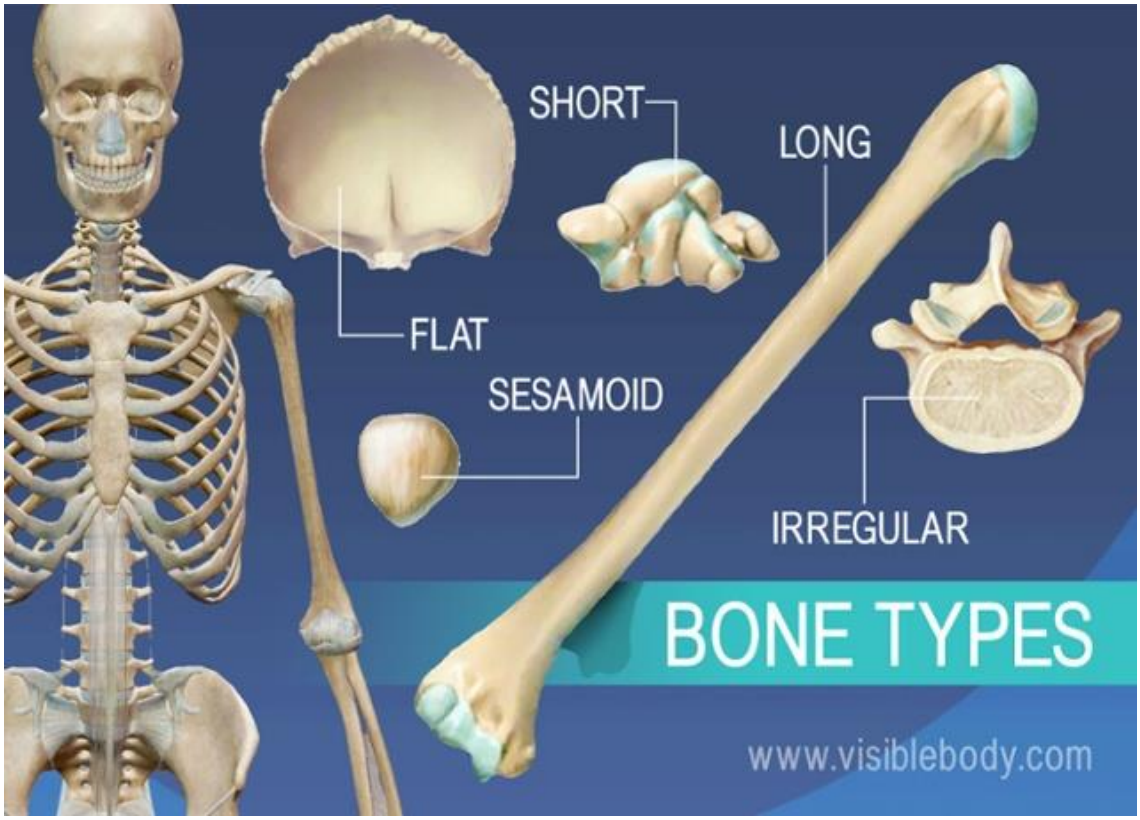
helps give structure to the larynx and nose. It is also found between the vertebrae and at the ends of bones like the femur.





The bones provide structure and protection and facilitate motion. Bones articulate to form structures. The skull protects the brain and gives shape to the face. The thoracic cage surrounds the heart and lungs. The vertebral column, commonly called the spine, is formed by over 30 small bones. Then there are the limbs (upper and lower) and the girdles that attach the four limbs to the vertebral column.

Bones of the human skeletal system are categorized by their shape and function into five types. The femur is an example of a long bone. The frontal bone is a flat bone. The patella, also called the knee cap, is a sesamoid bone. Carpals (in the hand) and tarsals (in the feet) are examples of short bones.



Functions of Bone

1. Support

The skeletal system provides structural support and a framework for attachment of soft tissues and organs.

2. Storage of Minerals

Bones maintain a large reserve of calcium and phosphate ions.

3. Blood Cell Production

The hollow spaces in some bones contains red marrow where blood cells are produced.

4. Protection

In many places bone protects soft tissues and organs.

5. Leverage

The articulation of bones creates levers that change the magnitude and direction of the forces exerted by muscles.

Classification of Bones

There are two basic types of **Bone tissue**

Compact bone is dense and homogeneous and forms the walls of bone.

Spongy bone is composed of slender intertwined pieces of bone enclosing a space filled

with non-bone tissue. It is found in the interior of normal bone.

Bones in their entirety can also be classified according to **shape:**

Long bones are longer than they are wide. All bones of the limbs except for the wrist and ankle bones are long bones.

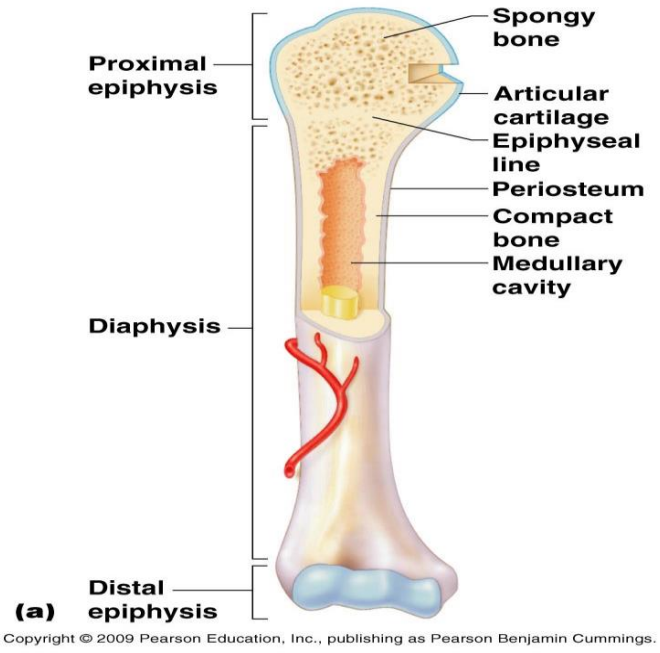
Short bones are cube-shaped and are found in the wrist and ankle of the limbs.

Flat bones are thin and flat and often curved. These bones include some bones of the skull, the ribs and the sternum.

Irregular bones as their name suggests do not fit conveniently into any category according to their shape.

Structure of a Long Bone

The middle long shaft of a long bone is the **diaphysis.** Either end of the long bone where it articulates with another bone it is expanded and the ends are called **epiphyses (sing. epiphysis).**



Except where the bone has a moveable articulation with another bone the bone is covered by a sheath of dense connective tissue called the periosteum. The surface of a moveable articulation is covered by articular cartilage that provides a smooth, slippery surface that decreases friction.

The hollow space within bone is called bone marrow. Bone marrow is filled either with adipose tissue and is then called yellow marrow or blood-forming tissue in which case it is called red marrow. Within the middle of the diaphysis of the long bone there is a large cavity called the marrow or medullary cavity.

Bone Remodeling

Although bone appears solid, it is actually a very dynamic tissue. Bone remodels itself in

response to two factors:

1. Calcium levels in the blood.
2. Pull of gravity and muscles on the bone.

When the body needs calcium, bone-destroying cells called **osteoclasts** break down bone tissue to release its reserves of calcium. **Osteoporosis** is a disease that results from the removal of too much bone tissue by osteoclasts. It results as the result of inactivity (e.g. space flight) and the hormonal changes that are associated with aging particularly in the female.

In response to growth and the stresses that may be placed upon bone, bone tissue is formed by bone-forming cells called **osteoblasts.** Both osteoblasts and osteoclasts work together to model bone during growth and the changing stress that is placed on bone.

Axial Skeleton

The axial skeleton forms the longitudinal axis of the body and can be divided into the **skull, vertebral column** and the **thorax.**

Skull

The skull is formed by two sets of bones, the **cranium** and the **facial bones.**

Cranium

The cranium encloses and protects the brain. It is composed of **8** bones of which include two pairs, the **temporals** and **parietals.** All the cranial bones are joined to one another by tight, interlocking joints called **sutures.**

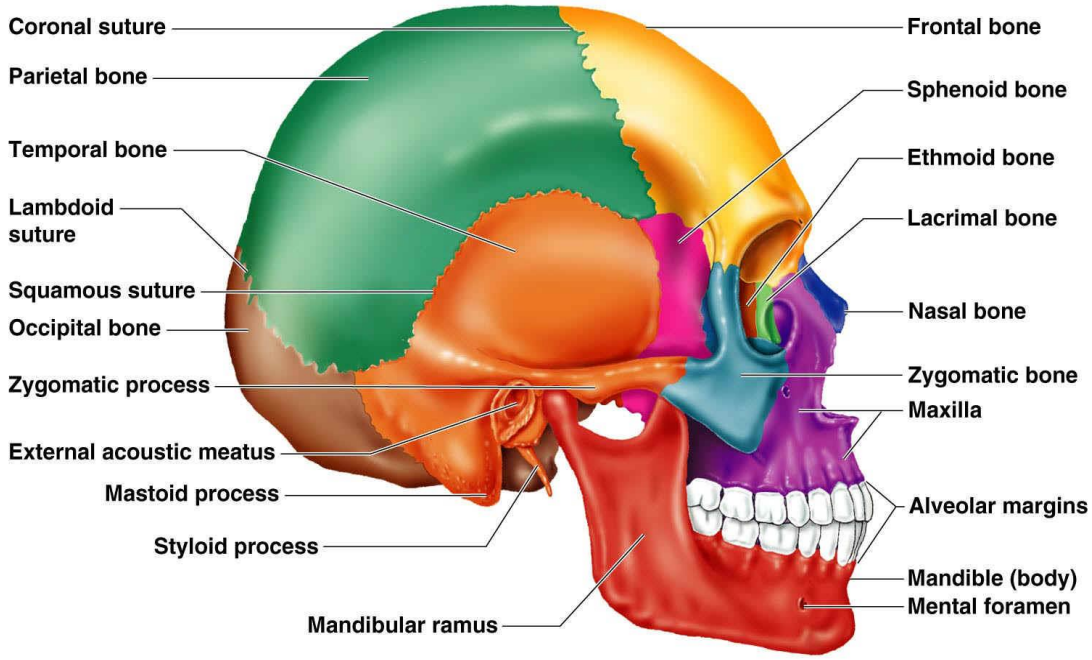
The bones of the cranium are:

Frontal bone

The frontal bone forms the forehead and forms the superior part of the eye's orbit supporting the eyebrows.

Parietal bones

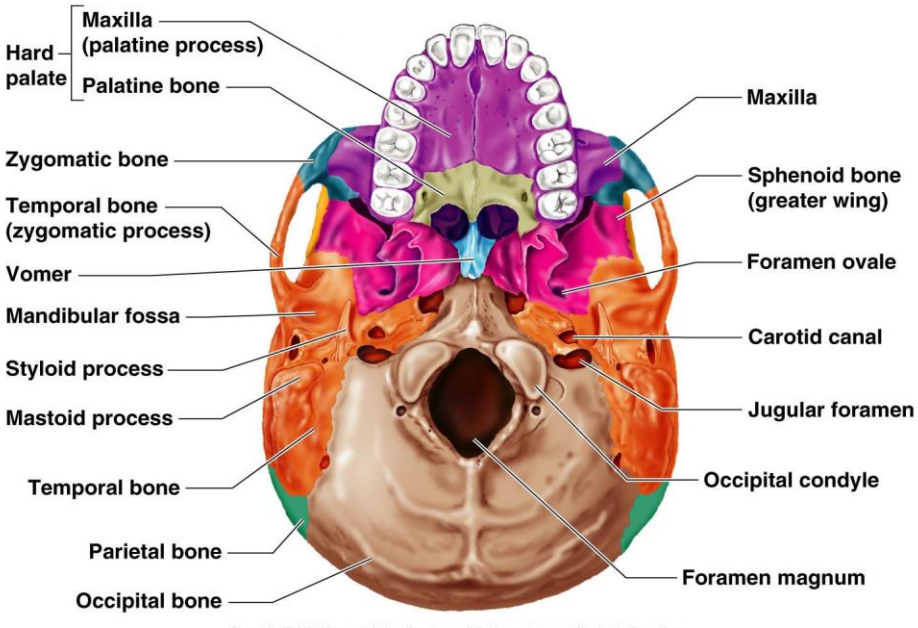
The parietal bones are paired and form the superior and lateral walls of the cranium. Where they meet on the midline they form the **sagittal suture** and where they meet with the frontal bones they form the **coronal suture.**



Temporal bones

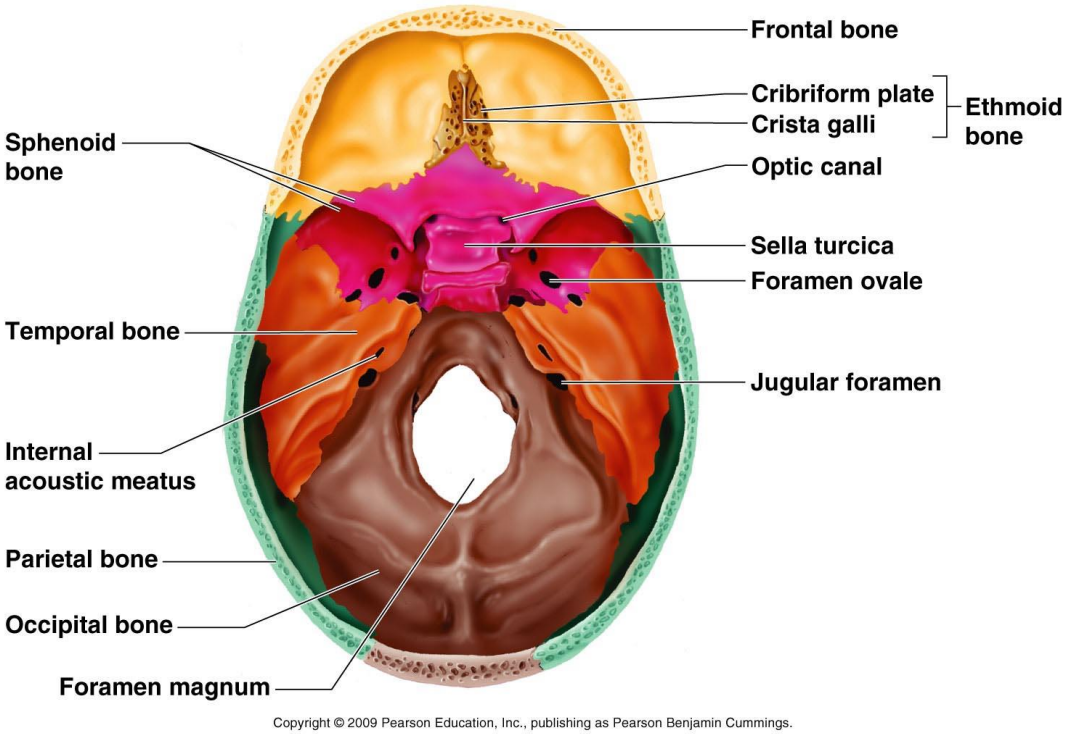
The temporal bones lie inferior to the parietal bones and where they meet with the parietal bones form the **squamosal sutures.** The temporal bones are irregular in shape.

Occipital bones



Occipital bone

The occipital bone forms the floor and the back wall of the skull. Where it joints the parietal bones anteriorly it forms the **lambdoid suture.** At the base of the occipital bone there is a large opening called the **foramen magnum** where the brain joins the spinal cord. The occipital bone articulates with the first vertebra by means of the **occipital condyles.**



Sphenoid Bone

This bone forms part of the floor of the skull and spans the width of the skull. It is very irregular but somewhat butterfly-like in shape. In the midline it contains a depression called the **sella turcica** (Turkish saddle) which contains the pituitary gland.

Ethmoid Bone

The ethmoid bone is another irregularly shaped bone that lies anterior to the sphenoid bone in the floor of the skull. It forms the anterior roof of the nasal cavity.

Facial Bones

The facial bones consist of 14 bones of which only two the **mandible** and the **vomer** are unpaired. These bones include:

Maxillae

These bones form the upper jaw. This bone contributes to the hard palate and holds the upper teeth. This bone also contains a paranasal sinus that can be infected during a cold.

Palatine bones

These bones form the posterior part of the hard palate.

Zygomatic bones

The zygomatic bones are commonly referred to as the cheek bones.

Lacrimal bones

These small bones contribute to the medial wall of the orbit and have a groove that accommodates a passage that allows tears to drain into the nasal cavity.

APPENDICULAR SKELETON

The appendicular skeleton is divided into six major regions: Pectoral girdles (4 bones) - Left and right clavicle (2) and scapula (2). Arms and forearms (6 bones) - Left and right humerus (2) (arm), ulna (2) and radius (2) (forearm).

Bones of the Appendicular skeleton:

- 4 bones in the shoulder girdle (clavicle and scapula each side)
- 6 bones in the arm and forearm (humerus, ulna and radius)
- 58 bones in the hands (carpals 16, metacarpals 10, phalanges 28 and sesamoid 4)
- 2 pelvis bones
- 8 bones in the legs (femur, tibia, patella and fibula)
- 56 bones in the feet (tarsals, metatarsals , phalanges and sesamoid

The Pectoral Girdle

The pectoral girdle bones, providing the points of attachment of the upper limbs to the axial skeleton, consists of the clavicle (or collarbone) in the anterior, as well as the scapula (or shoulder blades) in the posterior. The clavicles, S-shaped bones that position the arms on the body, lie horizontally across the front of the thorax (chest) just above the first rib.

The scapulae are flat, triangular bones that are located at the back of the pectoral girdle. They support the muscles crossing the shoulder joint. The spine runs across the back of the scapula; it is a good example of a bony protrusion that facilitates a broad area of attachment for muscles to bone.

The Upper Limbs

The upper limbs contain 30 bones in three regions: the arm (shoulder to elbow), the forearm (ulna and radius), and the wrist and hand. The humerus is the largest and longest bone of the upper limb and the only bone of the arm. It articulates (joins) with the scapula at the shoulder and with the forearm at the elbow. The forearm, extending from the elbow to the wrist, consists of two bones: the ulna and the radius. The radius, located along the lateral (thumb) side of the forearm, articulates with the humerus at the elbow. The ulna, located on the medial aspect (pinky-finger side) of the forearm, is longer than the radius. It articulates with the humerus at the elbow. The radius and ulna also articulate with the carpal bones and with each other, which in vertebrates enables a variable degree of rotation of the carpus with respect to the long axis of the limb. The hand includes the eight bones of the carpus (wrist), the five bones of the metacarpus

(palm), and the 14 bones of the phalanges (digits). Each digit consists of three phalanges, except for the thumb, which, when present, has only two.

The Pelvic Girdle

The pelvic girdle attaches to the lower limbs of the axial skeleton and is responsible for bearing the weight of the body and for locomotion. It is securely attached to the axial skeleton by strong ligaments. It also has deep sockets with robust ligaments to securely attach the femur to the body. The pelvic girdle is further strengthened by two large hip bones. In adults, the hip bones are formed by the fusion of three pairs of bones: the ilium, ischium, and pubis. The pelvis joins together in the anterior of the body the pubic symphysis joint and with the bones of the sacrum at the posterior of the body.

The Lower Limbs

The lower limbs consist of the thigh, the leg, and the foot. The bones of the lower limb are the femur (thigh bone), patella (kneecap), tibia and fibula (bones of the leg), tarsals (bones of the ankle), and metatarsals and phalanges (bones of the foot). The bones of the lower limbs are thicker and stronger than the bones of the upper limbs because of the need to support the entire weight of the body along with the resulting forces from locomotion.

The femur, or thighbone, is the longest, heaviest, and strongest bone in the body. The femur and pelvis form the hip joint at the proximal end. At the distal end, the femur, tibia, and patella form the knee joint. The patella, or kneecap, is a triangular bone that lies anterior to the knee joint; it is embedded in the tendon of the femoral extensors (quadriceps). It improves knee extension by reducing friction. The tibia, or shinbone, is a large bone of the leg that is located directly below the knee. The tibia articulates with the femur at its proximal end, with the fibula and the tarsal bones at its distal end. As the second largest bone in the human body it is responsible for transmitting the weight of the body from the femur to the foot. The fibula, or calf bone, parallels and articulates with the tibia. It is not weight-bearing, but acts as a site for muscle attachment while forming the lateral part of the ankle joint.

The tarsals are the seven bones of the ankle, which transmits the weight of the body from the tibia and the fibula to the foot. The metatarsals are the five bones of the foot, while the phalanges are the 14 bones of the toes.

Joints

A **joint** or **articulation** (or **articular surface**) is the connection made between bones in the body. They are constructed to allow for different degrees and types of movement. Sutures between the bones of the skull permit very little movement. The connection between a tooth and the jawbone is also called a joint, and is described as a fibrous joint known as a gomphosis. Joints are classified both structurally and functionally.

Structural classification (binding tissue)

Structural classification names and divides joints according to the type of binding tissue that connects the bones to each other. There are three structural classifications of joints

- fibrous joint – joined by dense regular connective tissue that is rich in collagen fibers [7]
- cartilaginous joint – joined by cartilage
- synovial joint – not directly joined – the bones have a synovial cavity and are united by the dense irregular connective tissue that forms the articular capsule that is normally associated with accessory ligaments.

Functional classification (movement)

Joints can also be classified functionally according to the type and degree of movement they allow:

- synarthrosis – permits little or no mobility. Most synarthrosis joints are fibrous joints (e.g., skull sutures).
- amphiarthrosis – permits slight mobility. Most amphiarthrosis joints are cartilaginous joints (e.g., intervertebral discs).
- synovial joint (also known as a *diarthrosis*) – freely movable. Synovial joints can in turn be classified into six groups according to the type of movement they allow: plane joint, ball and socket joint, hinge joint, pivot joint, condyloid joint and saddle joint.

Joints can also be classified, according to the number of axes of movement they allow, into nonaxial (gliding, as between the proximal ends of the ulna and radius), monoaxial (uniaxial), biaxial and multiaxial. Another classification is according to the degrees of freedom allowed, and distinguished between joints with one, two or three degrees of freedom. A further classification is according to the number and shapes of the articular surfaces: flat, concave and convex surfaces.

Biomechanical classification

Joints can also be classified based on their anatomy or on their biomechanical properties. According to the anatomic classification, joints are subdivided into *simple* and *compound*, depending on the number of bones involved, and into *complex* and *combination* joints:

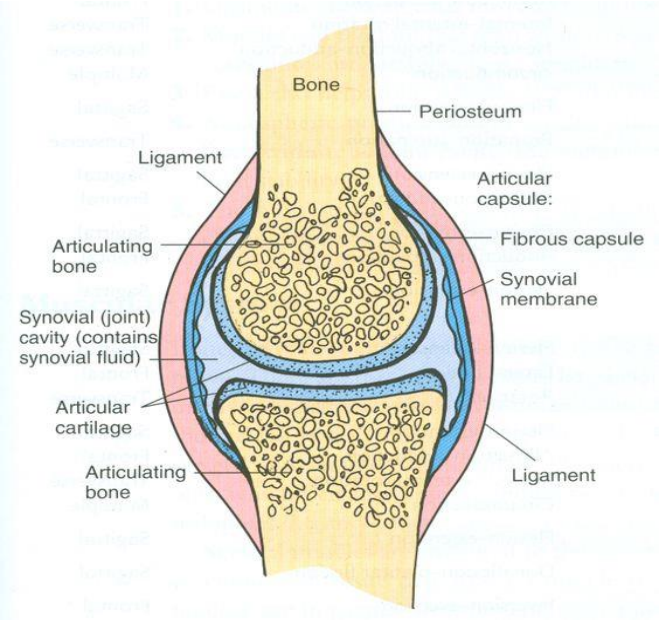
1. Simple joint: two articulation surfaces (e.g. shoulder joint, hip joint)
2. Compound joint: three or more articulation surfaces (e.g. radiocarpal joint)
3. Complex joint: two or more articulation surfaces and an articular disc or meniscus (e.g. knee joint)

Anatomical

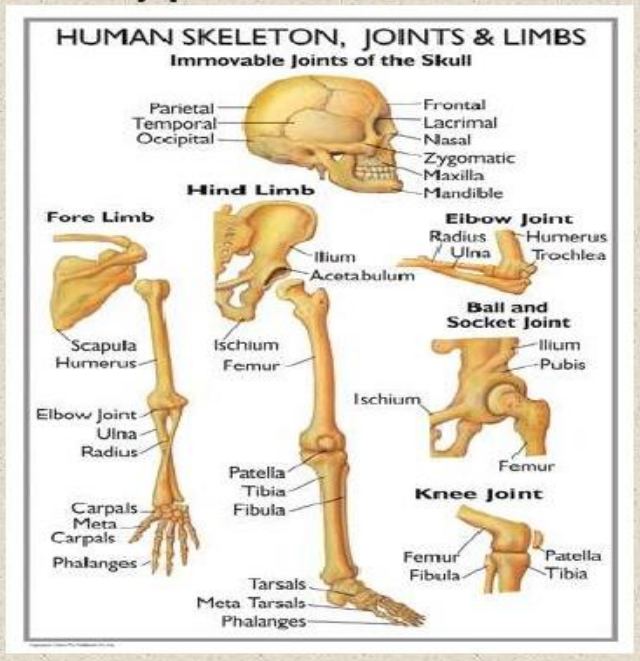
The joints may be classified anatomically into the following groups:

1. Joints of hand
2. Elbow joints
3. Wrist joints
4. Axillary articulations
5. Sternoclavicular joints
6. Vertebral articulations
7. Temporomandibular joints
8. Sacroiliac joints
9. Hip joints
10. Knee joints
11. Articulations of foot

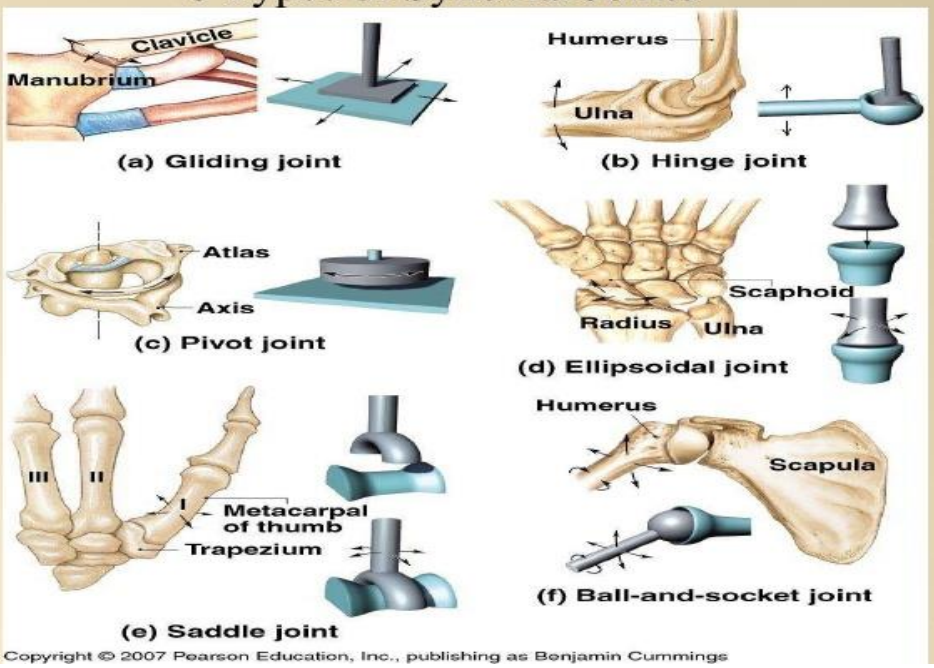
SCHEMATIC DIAGRAM OF SYNOVIAL JOINT



Types of Joints



6 Types of Synovial Joints



A joint is the connection between two bones. The skeletal system is made of different types of joints, including fibrous, cartilagenous and synovial. A ligament holds fibrous joints together. Cartilage joints are bones held together with a connection of cartilage. A synovial capsule surrounds the synovial joints. Synovial joints are the largest number of joint types in the skeletal system. Each joint type has a specific method of movement.

Fibrous Joint

The fibrous (fixed or immovable) joints in the skeletal system include the sutures of the skull. The coronal suture connects the parietal and frontal skull bones. The sagittal suture connects the two parietal bones. The lambdoid suture unites the parietal with the occipital.

Cartilagenous Joint

Cartilagenous joints are partially movable joints consisting of symphyses. Examples of cartilagenous types of joints include the rib cage and the spinal column.

Ball-and-Socket Joint

Mercksource.com, an online medical dictionary, describes a ball-and-socket joint as one in which the rounded surface of a bone fits into and moves within a cup-shaped depression. Examples of this type of synovial joint are the hip and shoulder joints. The ball-and-socket joint allows freedom of movement up, down, right, left and in a full 360-degree rotation.

Saddle Joint

The saddle joint is a biaxial joint that allows movement on two planes--flexion/extension and abduction/adduction. The thumb is the only bone structure in the human body with a saddle joint.

Hinged Joint

Hinged joints include the elbow, fingers, toes and knee. Movement occurs in only one direction or one plane. Innerbody.com states that the hinged joint in the knee is unusual because it allows the knee to swivel, turning the foot from side to side.

Gliding Joint

Gliding joints allow two or more flat or slightly rounded bones to move easily together without friction or grinding. Enotes.com, an online nursing encyclopedia, states the function of a gliding joint is to allow motions such as smooth sliding of bone past bone, bending, stretching and circular motion. Examples of gliding joints include the forearm to wrist joint and the lower leg to ankle joint.

Pivot Joint

A pivot joint is a synovial joint designed with one end fitting like a cylinder inside a ring. Pivot joints at the base of the skull allow the head to rotate. Other pivot points allow the rotation of the palm.

Condyloid Joint

Condyloid joints are biaxial joints that permit up, down and side-to-side motions. Medical-look.com lists the radiocarpal joint in the wrist as an example of a condyloid joint.

TYPES OF MUSCLES

There are three classifications of muscles found throughout the human body. They are Skeletal, Cardiac, and Smooth Muscles.

Skeletal Muscles

Most muscles that make up the human body are under our conscious or voluntary control meaning we can command their movement by messages sent from our brains to the muscles via the nervous system. These muscles are called Skeletal Muscles and are usually connected to the skeletal system by bundles of collagen fibers which are more commonly known as tendons. Skeletal muscles make up around 43% of a man's and 36% of a woman's whole body mass, making it the most abundant tissue in the human body.

Cardiac Muscles

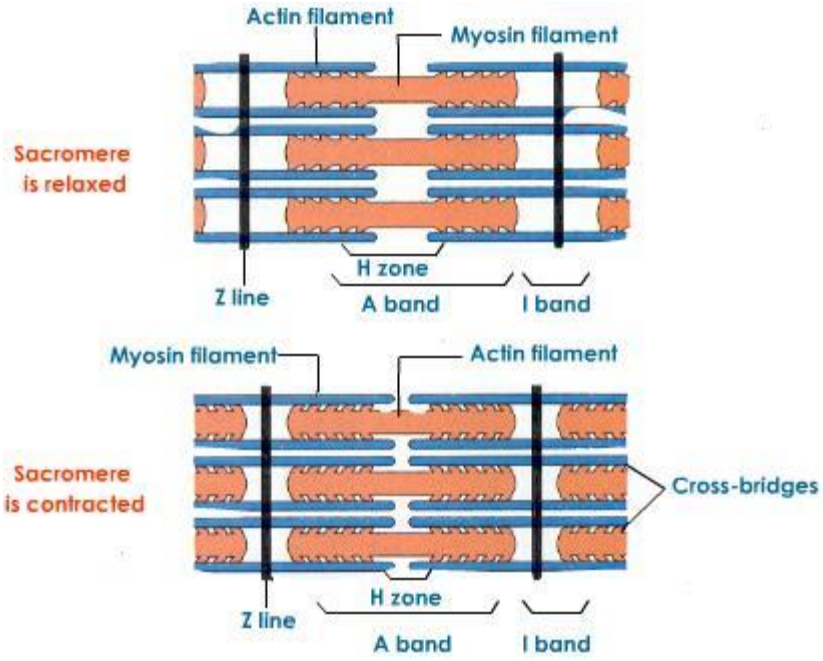
The cardiac muscle is the only muscle of it's kind in the body and it is responsible for our beating heart. The cardiac muscle is an involuntary muscle meaning we have no conscious control of it's motion. The cardiac muscle is responsible for coordinated contractions (heart beats) of cardiac muscle cells in the organ which pumps oxygenated blood throughout the body.

Smooth Muscles

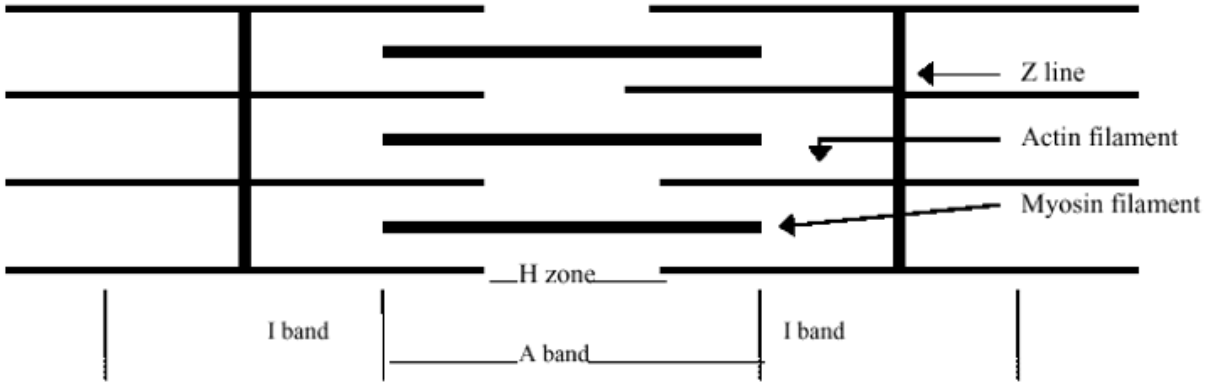
Smooth muscles are also involuntary muscles which are usually found internally in the human body. These Smooth muscles surround or are part of internal organs such as the lungs, intestines, bladder, the reproductive tracts, the iris of the eyes as well as within the walls of blood vessels. These smooth muscles play a huge importance to the day to day functions of our bodily organs.

CHANGES DURING MUSCULAR CONTRACTION

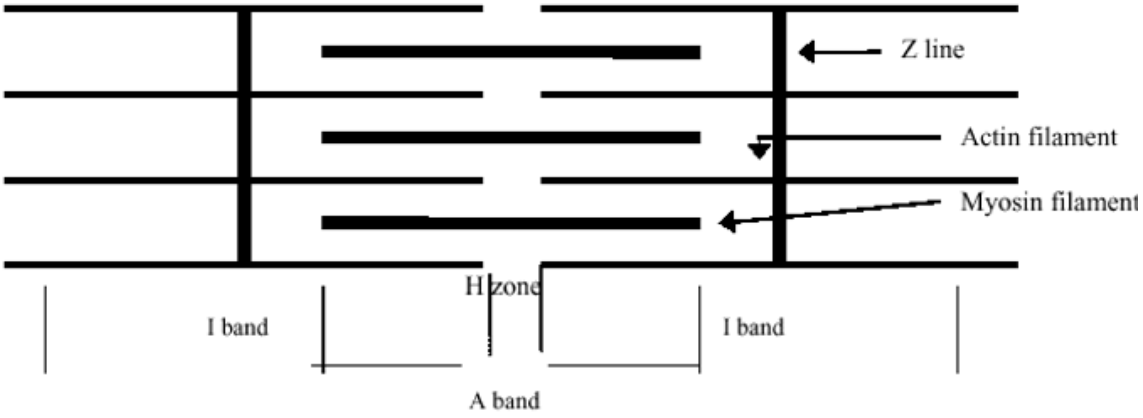
Muscle contraction is the activation of tension-generating sites within muscle fibers. In physiology, muscle contraction does not mean muscle shortening because muscle tension can be produced without changes in muscle length such as holding a heavy book or a dumbbell at the same position.



Sarcomere at rest



Sarcomere during contraction



Calcium Release: Excitation/Contraction Coupling

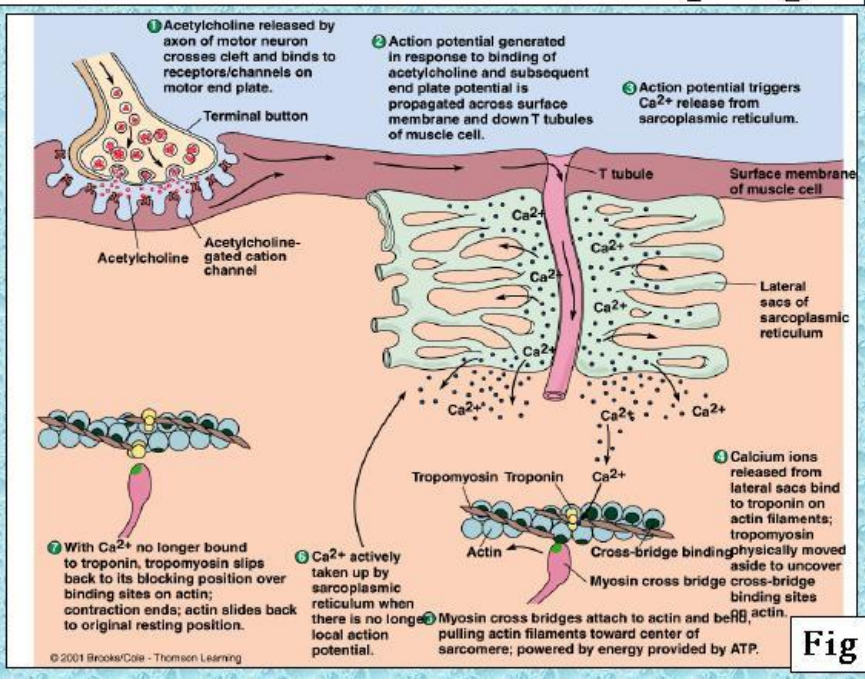
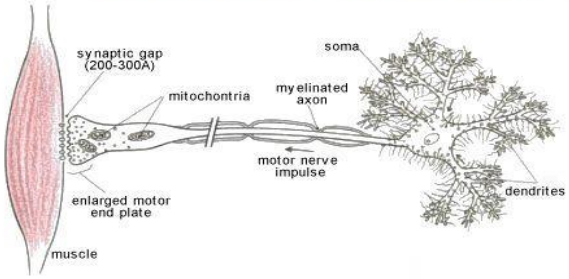


Fig 8-12

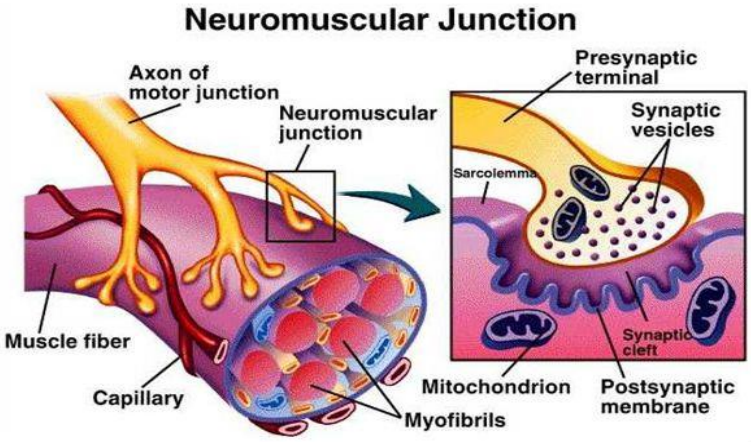
Skeletal Muscle Contraction



Motor Neuron: conducts impulse from brain and brings it to the muscle fiber.

Neuromuscular Junction: connection between neuron and muscle.

Neurotransmitter: chemicals at ends of connection that stimulates fiber.



The following steps are involved in muscle contraction:

(1) The sequence of events leading to contraction is initiated somewhere in the central nervous system, either as voluntary activity from the brain or as reflex activity from the spinal cord.

(2) A motor neuron in the ventral horn of the spinal cord is activated, and an action potential passes outward in a ventral root of the spinal cord.

(3) The axon branches to supply a number of muscle fibers called a motor unit, and the action potential is conveyed to a motor end plate on each muscle fiber.

(4) At the motor end plate, the action potential causes the release of packets or quanta of **acetylcholine** into the **synaptic clefts** on the surface of the muscle fiber.

(5) Acetylcholine causes the electrical **resting potential** under the motor end plate to change, and this then initiates an action potential which passes in both directions along the surface of the muscle fiber.

(6) At the opening of each transverse tubule onto the muscle fiber surface, the action potential spreads inside the muscle fiber.

(7) At each point where a transverse tubule touches part of the sarcoplasmic reticulum, it causes the sarcoplasmic reticulum to release Ca^{++} ions.

(8) The calcium ions result in movement of troponin and tropomyosin on their thin filaments, and this enables the myosin molecule heads to "grab and swivel" their way along the thin filament. This is the driving force of muscle contraction.

Contraction is turned off by the following sequence of events:

(9) Acetylcholine at the neuromuscular junction is broken down by acetylcholinesterase, and this terminates the stream of action potentials along the muscle fiber surface.

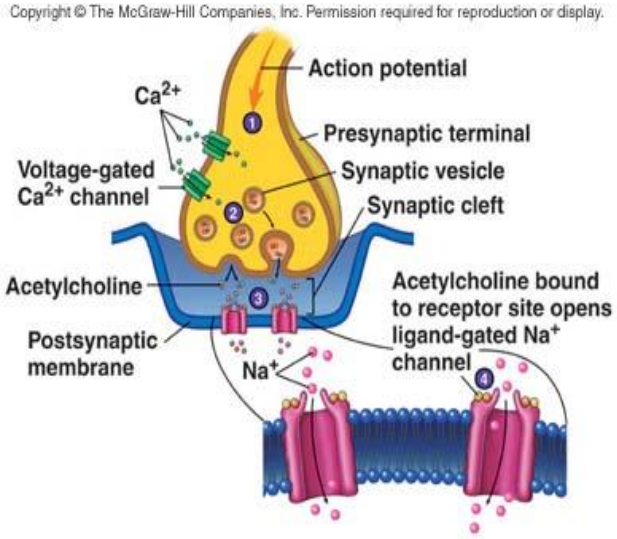
(10) The sarcoplasmic reticulum ceases to release calcium ions, and immediately starts to resequester all the calcium ions that have been released.

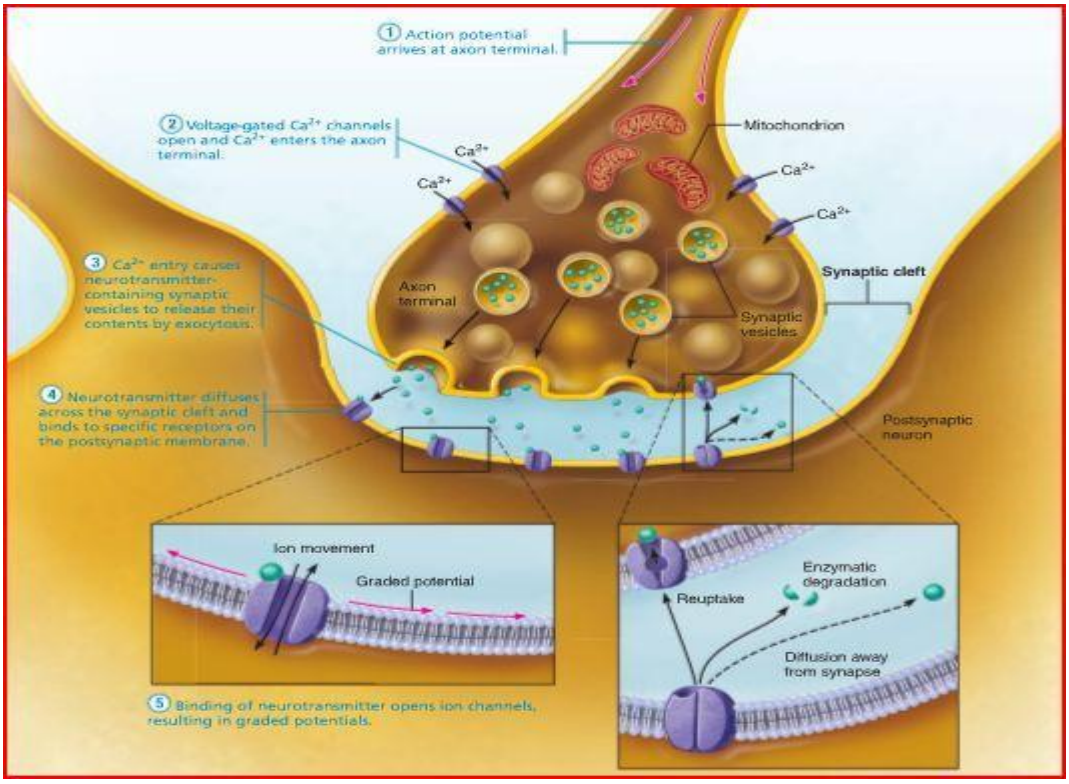
(11) In the absence of calcium ions, a change in the configuration of troponin and tropomyosin then blocks the action of the myosin molecule heads, and contraction ceases.

(12) In the living animal, an external stretching force, such as gravity or an antagonistic muscle, pulls the muscle back to its original length.

NEUROMUSCULAR JUNCTION

A neuromuscular junction (or myoneural junction) is a chemical synapse formed by the contact between a motor neuron and a muscle fiber. It is at the neuromuscular junction that a motor neuron is able to transmit a signal to the muscle fiber, causing muscle contraction.

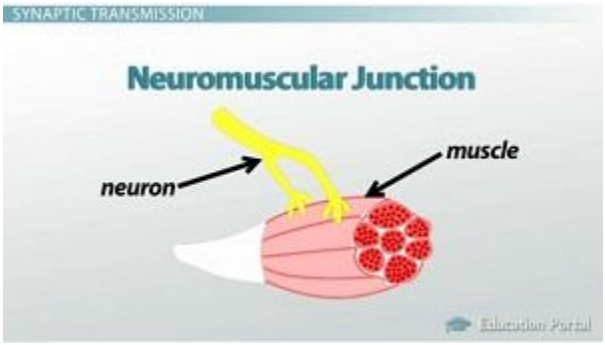




A neuromuscular junction is a synapse between a motor neuron and skeletal muscle. This lesson describes the events of synaptic transmission leading to contraction of skeletal muscle. Myasthenia gravis is described as a neuromuscular disease.

Synaptic Transmission

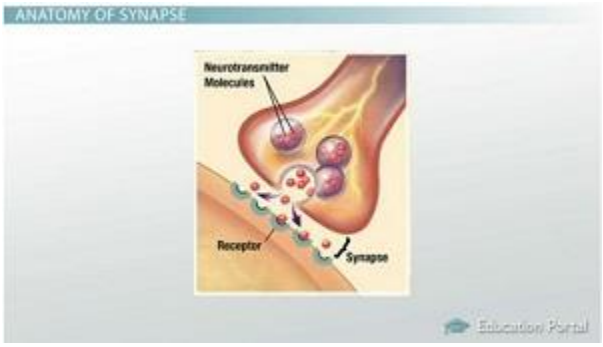
The space between the motor neuron and the skeletal muscle cell is simply referred to as a **synapse**. More specifically, the synapse between a motor neuron and a skeletal muscle cell is referred to as a **myoneural** or **neuromuscular junction**.



A neuromuscular junction between a motor neuron and skeletal muscle cell

Synaptic transmission includes all the events within the synapse leading to excitation of the muscle. Let me make a quick note that other synapses occur between other cells - for example, nerve to nerve and nerve to gland. For example, the adult human brain is thought to contain 100-500 trillion synaptic connections, and those are in between neurons. In this lesson, we will describe the anatomy of a **neuromuscular junction** and then discuss the events of synaptic transmission.

Anatomy of a Synapse



A diagram of a synapse between a muscle cell and neuron

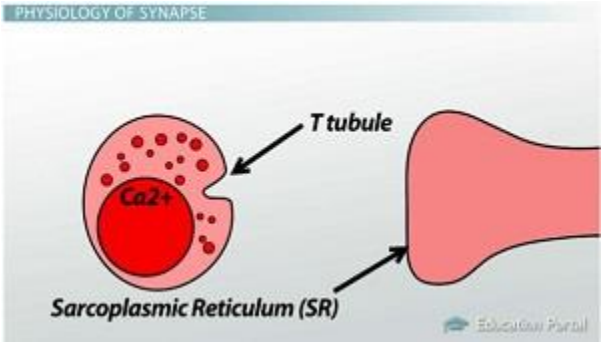
The neuron is sending the transmission and is thus referred to as the **pre-synaptic cell**, while the muscle is receiving the transmission and is referred to as the **post-synaptic cell**. **Neurotransmitters** are molecules stored in the pre-synaptic cell that are secreted into the synapse. Neurotransmitters, in turn, bind to **receptors** on the post-synaptic cell membrane, and these receptors are specific for that neurotransmitter.

Physiology of a Synapse

Synaptic transmission carries the excitatory signal from the neuron to the muscle cell, much like a bridge could connect two land masses. **Calcium** enters the excited neuron, and the calcium stimulates exocytosis of the neurotransmitter. The neurotransmitter secreted by the somatic motor neurons is **acetylcholine**.

So, the acetylcholine diffuses across the cleft and binds to acetylcholine receptors within the muscle cell membrane. Like a key unlocking a door, acetylcholine opens ion channels, and sodium ions diffuse into the muscle cell. It's important to note that acetylcholine does not remain in the synaptic cleft forever, but rather an enzyme called **acetylcholinesterase** catalyzes the breakdown of acetylcholine, and where is it located - in the synaptic cleft. This enzyme breaks down acetylcholine and therefore prevents overcontraction, or prevents contraction for lasting longer than necessary.

Since sodium is a positive ion, it **depolarizes** and thus excites the skeletal muscle cell membrane as it enters. Now, the excitatory impulse has transferred from the motor neuron to the muscle cell, much like a car would cross a bridge from one land mass to the next.



Calcium is released into the cell interior, causing contraction.

Invaginations of the cell membrane referred to as **T-tubules** will then carry that excitatory impulse deep into the muscle cell's interior. The excitatory impulse then triggers release of calcium into the cell's interior coming from the **sarcoplasmic reticulum** or simply the **SR**.

ELECTROMYOGRAM

An electromyogram (EMG) measures the electrical activity of muscles at rest and during contraction. Nerve conduction studies measure how well and how fast the nerves can send electrical signals.

Nerves control the muscles in the body with electrical signals called impulses. These impulses make the muscles react in specific ways. Nerve and muscle problems cause the muscles to react in abnormal ways.

An EMG is done to:

- Find diseases that damage muscle tissue, nerves, or the junctions between nerve and muscle. These problems may include a herniated disc, amyotrophic lateral sclerosis (ALS), or myasthenia gravis (MG).
- Find the cause of weakness, paralysis, or muscle twitching. Problems in a muscle, the nerves supplying a muscle, the spinal cord, or the area of the brain that controls a muscle can cause these symptoms. The EMG does not show brain or spinal cord diseases.

Electromyography (**EMG**) is an electrodiagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles. EMG is performed using an instrument called an **electromyograph** to produce a record called an **electromyogram**. An electromyograph detects the electric potential generated by muscle cells when these cells are electrically or neurologically activated. The signals can be analyzed to detect medical abnormalities, activation level, to analyze the biomechanics of human or animal movement.

EMG testing has a variety of clinical and biomedical applications. EMG is used as a diagnostics tool for identifying neuromuscular diseases, or as a research tool for studying kinesiology, and disorders of motor control. EMG signals are also used as a control signal for prosthetic devices such as prosthetic hands, arms, and lower limbs.

EMG is usually performed with another electrodiagnostic medicine test that measures the conducting function of nerves. This is called a nerve conduction studies (NCS). Needle EMG and NCSs are typically indicated when there is pain in the limbs, weakness from spinal nerve compression, or concern about some other neurologic injury or disorder. Spinal nerve injury does not cause neck, mid back pain or low back pain, and for this reason, evidence has not shown EMG or NCS to be helpful in diagnosing causes of axial lumbar pain, thoracic pain, or cervical spine pain. Needle EMG may aid with the diagnosis of nerve compression or injury (such as carpal tunnel syndrome), nerve root injury (such as sciatica), and with other problems of the muscles or nerves. Medical conditions include amyotrophic lateral sclerosis, myasthenia gravis, and muscular dystrophy.

Electromyography (EMG) is a diagnostic procedure to assess the health of muscles and the nerve cells that control them (motor neurons).

Motor neurons transmit electrical signals that cause muscles to contract. An EMG translates these signals into graphs, sounds or numerical values that a specialist interprets.

An EMG uses tiny devices called electrodes to transmit or detect electrical signals.

During a needle EMG, a needle electrode inserted directly into a muscle records the electrical activity in that muscle.

A nerve conduction study, another part of an EMG, uses electrodes taped to the skin (surface electrodes) to measure the speed and strength of signals traveling between two or more points.

EMG results can reveal nerve dysfunction, muscle dysfunction or problems with nerve-to-muscle signal transmission.

Your doctor may order an EMG if you have signs or symptoms that may indicate a nerve or muscle disorder. Such symptoms may include:

- Tingling
- Numbness
- Muscle weakness
- Muscle pain or cramping
- Certain types of limb pain

EMG results are often necessary to help diagnose or rule out a number of conditions such as:

- Muscle disorders, such as muscular dystrophy or polymyositis
- Diseases affecting the connection between the nerve and the muscle, such as myasthenia gravis
- Disorders of nerves outside the spinal cord (peripheral nerves), such as carpal tunnel syndrome or peripheral neuropathies
- Disorders that affect the motor neurons in the brain or spinal cord, such as amyotrophic lateral sclerosis or polio
- Disorders that affect the nerve root, such as a herniated disk in the spine

EMG is a low-risk procedure, and complications are rare. There's a small risk of bleeding, infection and nerve injury where a needle electrode is inserted.

When muscles along the chest wall are examined with a needle electrode, there's a very small risk that it could cause air to leak into the area between the lungs and chest wall, causing a lung to collapse (pneumothorax).

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SCHOOL OF BIO & CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – II - Human Anatomy & Physiology – SBMA1303

UNIT II - CARDIOVASCULAR SYSTEM

Blood - Blood is a constantly circulating fluid providing the body with nutrition, oxygen, and waste removal. Blood is mostly liquid, with numerous cells and proteins suspended in it, making blood "thicker" than pure water. The average person has about 5 liters (more than a gallon) of blood.

A liquid called plasma makes up about half of the content of blood. Plasma contains proteins that help blood to clot, transport substances through the blood, and perform other functions. Blood plasma also contains glucose and other dissolved nutrients.

• Red blood cells, which carry oxygen to the tissues
• White blood cells, which fight infections
• Platelets, smaller cells that help blood to clot
Blood is conducted through blood vessels (arteries and veins). Blood is prevented from clotting in the blood vessels by their smoothness, and the finely tuned balance of clotting factors.

Blood has many different functions, including:

- transporting oxygen and nutrients to the lungs and tissues
- forming blood clots to prevent excess blood loss
- carrying cells and antibodies that fight infection
- bringing waste products to the kidneys and liver, which filter and clean the blood
- regulating body temperature

The blood that runs through the veins, arteries, and capillaries is known as whole blood, a mixture of about 55 percent plasma and 45 percent blood cells.

Constituents of Blood

Blood accounts for 7% of the human body weight, with an average density of approximately 1060 kg/m^3, very close to pure water's density of 1000 kg/m^3. The average adult has a blood volume of roughly 5 litres, which is composed of plasma and several kinds of cells. These blood cells (which are also called *corpuscles* or "formed elements") consist of erythrocytes (red blood

cells, RBCs), leukocytes (white blood cells), and thrombocytes (platelets). By volume, the red blood cells constitute about 45% of whole blood, the plasma about 54.3%, and white cells about 0.7%.

Components of Blood - Normally, 7-8% of human body weight is from blood. In adults, this amounts to 4.5-6 quarts of blood. This essential fluid carries out the critical functions of transporting oxygen and nutrients to our cells and getting rid of carbon dioxide, ammonia, and other waste products. In addition, it plays a vital role in our immune system and in maintaining a relatively constant body temperature. Blood is a highly specialized tissue composed of more than 4,000 different kinds of components. Four of the most important ones are red cells, white cells, platelets, and plasma.

Red cells or **erythrocytes** are relatively large microscopic cells without nuclei. In this latter trait, they are similar to the primitive prokaryotic cells of bacteria. Red cells normally make up 40-50% of the total blood volume. They transport oxygen from the lungs to all of the living tissues of the body and carry away carbon dioxide. The red cells are produced continuously in our bone marrow from stem cells at a rate of about 2-3 million cells per second.

Hemoglobin is the gas transporting protein molecule that makes up 95% of a red cell. Each red cell has about 270,000,000 iron-rich hemoglobin molecules. People who are anemic generally have a deficiency in red cells, and subsequently feel fatigued due to a shortage of oxygen. The red color of blood is primarily due to oxygenated red cells. Human fetal hemoglobin molecules differ from those produced by adults in the number of amino acid chains. Fetal hemoglobin has three chains, while adults produce only two.

White cells or **leukocytes**, exist in variable numbers and types but make up a very small part of blood's volume--normally only about 1% in healthy people. Leukocytes are not limited to blood. They occur elsewhere in the body as well, most notably in the spleen, liver, and lymph glands. Most are produced in our bone marrow from the same kind of stem cells that produce red blood cells. Others are produced in the thymus gland, which is at the base of the neck. Some white cells (called lymphocytes) are the first responders for our immune system. They seek out,

identify, and bind to alien protein on bacteria, viruses, and fungi so that they can be removed. Other white cells (called granulocytes and macrophages) then arrive to surround and destroy the alien cells. They also have the function of getting rid of dead or dying blood cells as well as foreign matter such as dust and asbestos. Red cells remain viable for only about 4 months before they are removed from the blood and their components recycled in the spleen. Individual white cells usually only last 18-36 hours before they also are removed, though some types live as much as a year. The description of white cells presented here is a simplification. There are actually many specialized sub-types of them that participate in different ways in our immune responses.

Platelets or **thrombocytes** are cell fragments without nuclei that work with blood clotting chemicals at the site of wounds. They do this by adhering to the walls of blood vessels, thereby plugging the rupture in the vascular wall. They also can release coagulating chemicals which cause clots to form in the blood that can plug up narrowed blood vessels. Thirteen different blood clotting factors, in addition to platelets, need to interact for clotting to occur.
Individual platelets are about 1/3 the size of red cells. They have a lifespan of 9-10 days. Like the red and white blood cells, platelets are produced in bone marrow from stem cells.

Plasma

Plasma is the relatively clear, yellow tinted water (92+%), sugar, fat, protein and salt solution which carries the red cells, white cells, and platelets. Normally, 55% of our blood's volume is made up of plasma. As the heart pumps blood to cells throughout the body, plasma brings nourishment to them and removes the waste products of metabolism. Plasma also contains blood clotting factors, sugars, lipids, vitamins, minerals, hormones, enzymes, antibodies, and other proteins.

Blood Groups

The ABO Blood Group System. There are four major blood groups determined by the presence or absence of two antigens – A and B – on the surface of red blood cells: Group A – has only the A antigen on red cells (and B antibody in the plasma) Group B – has only the B antigen on red cells (and A antibody in the plasma).

The most important blood groups in transfusion are the ABO blood group system and the group D of the Rh system.

Blood groups or antigens are determined by either sugars or proteins on the surface of the red blood cell. The ABO system has A and B antigens and the Rh system has many antigens but D is the most important.

The ABO Blood Group System

There are four major blood groups determined by the presence or absence of two antigens – A and B – on the surface of red blood cells:

- Group A – has only the A antigen on red cells (and B antibody in the plasma)
- Group B – has only the B antigen on red cells (and A antibody in the plasma)
- Group AB – has both A and B antigens on red cells (but neither A nor B antibody in the plasma)
- Group O – has neither A nor B antigens on red cells (but both A and B antibody are in the plasma)

Type O-negative blood does not have any antigens. It is called the "universal donor" type because it is compatible with any blood type. Type AB-positive blood is called the "universal recipient" type because a person who has it can receive blood of any type.

O positive is the most common blood type and most likely to be transfused. O negative donors are the "Universal Donor." People with O negative blood are universal red blood cell donors. This means that their red blood cells can be transfused to any blood type.

Coagulation (also known as **clotting**) is the process by which blood changes from a liquid to a gel, forming a clot. It potentially results in hemostasis, the cessation of blood loss from a damaged vessel, followed by repair. The mechanism of coagulation involves activation, adhesion, and aggregation of platelets along with deposition and maturation of fibrin. Disorders of coagulation are disease states which can result in bleeding (hemorrhage or bruising) or obstructive clotting (thrombosis)

Coagulation factors

Number	Function	Associated genetic

		disorders
I (fibrinogen)	Forms clot (fibrin)	Congenital afibrinogenemia, Familial renal amyloidosis
II (prothrombin)	Its active form (IIa) activates I, V, X, VII, VIII, XI, XIII, protein C, platelets	Prothrombin G20210A, Thrombophilia
III (tissue factor or tissue thromboplastin)	Co-factor of VIIa (formerly known as factor III)	
IV Calcium	Required for coagulation factors to bind to phospholipid (formerly known as factor IV)	
V (proaccelerin, labile factor)	Co-factor of X with which it forms the prothrombinase complex	Activated protein C resistance
VI	*Unassigned* – old name of Factor Va	
VII (stable factor, proconvertin)	Activates IX, X	congenital proconvertin/factor VII deficiency
VIII (Antihemophilic factor A)	Co-factor of IX with which it forms the tenase complex	Haemophilia A
IX (Antihemophilic factor B or Christmas factor)	Activates X: forms tenase complex with factor VIII	Haemophilia B
X (Stuart-Prower factor)	Activates II: forms prothrombinase complex with factor V	Congenital Factor X deficiency
XI (plasma thromboplastin	Activates IX	Haemophilia C

antecedent)		
XII (Hegman factor)	Activates factor XI, VII and prekallikrein	Hereditary angioedema type III
XIII (fibrin-stabilizing factor)	Crosslinks fibrin	Congenital Factor XIIIa/b deficiency

Hemoglobin is contained in red blood cells, which efficiently carries oxygen from the lungs to the tissues of the body. Hemoglobin also helps in the transportation of carbon dioxide and hydrogen ions back to the lungs.

Hemoglobin is able to bind to gaseous nitric oxide (NO) as well as O_2. As red blood cells passes through the capillary beds of the lungs, gills (in fish), or other respiratory organs, oxygen is diffused into the erythrocytes and hemoglobin binds O_2 and NO. Hemoglobin then unloads its cargo in the capillaries. There O_2 is able to diffuse into the body cells. The NO relaxes the walls of the capillaries, allowing them to expand which in effects helps the delivery of O_2 to the cells.

Hemoglobin consists of four subunits, each with a cofactor called a heme group that has an iron atom center. The iron is the main component that actually binds to oxygen, thus each hemoglobin molecule is able to carry four molecules of O_2. Hemoglobin is a protein that is used to carry oxygen through the blood stream from the lungs to the tissues. This is important for survival. Hemoglobin has a lower affinity for oxygen the lower the concentration of oxygen gets. This has great implications for the human body and has helped us adapt very effectively. The lower affinity and lower concentrations means that when we are working out, our bodies are low on oxygen which means hemoglobin has less affinity for oxygen and can more easily drop the oxygen off at human tissues. This gives us greater oxygen in our oxygen dependent state. On the other hand, when oxygen concentration is high, the hemoglobin has a higher affinity for oxygen and therefore does not drop the oxygen where it is not needed. This is a very complex and smart system that has evolved to keep hemoglobin as an important biological molecule for a very long time. myoglobin is used to store oxygen in muscles. This myoglobin has a slighty higher affinity

for oxygen than hemoglobin especially at lower levels. This is because myoglobin has an easier job in that it only needs to store oxygen and release it for the muscles, while hemoglobin also has to transport the oxygen and release it in the correct areas.

The heart is a muscular organ about the size of a closed fist that functions as the body's circulatory pump. It takes in deoxygenated blood through the veins and delivers it to the lungs for oxygenation before pumping it into the various arteries (which provide oxygen and nutrients to body tissues by transporting the blood throughout the body). The heart is located in the thoracic cavity medial to the lungs and posterior to the sternum.

On its superior end, the base of the heart is attached to the aorta pulmonary arteries and veins, and the vena cava. The inferior tip of the heart, known as the apex, rests just superior to the **diaphragm**. The base of the heart is located along the body's midline with the apex pointing toward the left side. Because the heart points to the left, about 2/3 of the heart's mass is found on the left side of the body and the other 1/3 is on the right.

Pericardium

The heart sits within a fluid-filled cavity called the pericardial cavity. The walls and lining of the pericardial cavity are a special membrane known as the pericardium. Pericardium is a type of serous membrane that produces serous fluid to lubricate the heart and prevent friction between the ever beating heart and its surrounding organs. Besides lubrication, the pericardium serves to hold the heart in position and maintain a hollow space for the heart to expand into when it is full. The pericardium has 2 layers—a visceral layer that covers the outside of the heart and a parietal layer that forms a sac around the outside of the pericardial cavity.

Structure of the Heart Wall

The heart wall is made of 3 layers: epicardium, myocardium and endocardium.

- *Epicardium*. The epicardium is the outermost layer of the heart wall and is just another name for the visceral layer of the pericardium. Thus, the epicardium is a thin layer of serous membrane

that helps to lubricate and protect the outside of the heart. Below the epicardium is the second, thicker layer of the heart wall: the myocardium.

- *Myocardium*. The myocardium is the muscular middle layer of the heart wall that contains the **cardiac muscle tissue**. Myocardium makes up the majority of the thickness and mass of the heart wall and is the part of the heart responsible for pumping blood. Below the myocardium is the thin endocardium layer.

- *Endocardium*. Endocardium is the simple squamous endothelium layer that lines the inside of the heart. The endocardium is very smooth and is responsible for keeping blood from sticking to the inside of the heart and forming potentially deadly blood clots.

The thickness of the heart wall varies in different parts of the heart. The atria of the heart have a very thin myocardium because they do not need to pump blood very far—only to the nearby ventricles. The ventricles, on the other hand, have a very thick myocardium to pump blood to the lungs or throughout the entire body. The right side of the heart has less myocardium in its walls than the left side because the left side has to pump blood through the entire body while the right side only has to pump to the lungs.

Chambers of the Heart

The heart contains 4 chambers: the right atrium, left atrium, right ventricle, and left ventricle. The atria are smaller than the ventricles and have thinner, less muscular walls than the ventricles. The atria act as receiving chambers for blood, so they are connected to the veins that carry blood to the heart. The ventricles are the larger, stronger pumping chambers that send blood out of the heart. The ventricles are connected to the arteries that carry blood away from the heart.

The chambers on the right side of the heart are smaller and have less myocardium in their heart wall when compared to the left side of the heart. This difference in size between the sides of the heart is related to their functions and the size of the 2 circulatory loops. The right side of the heart maintains pulmonary circulation to the nearby lungs while the left side of the heart pumps blood all the way to the extremities of the body in the systemic circulatory loop.

Valves of the Heart

The heart functions by pumping blood both to the lungs and to the systems of the body. To prevent blood from flowing backwards or "regurgitating" back into the heart, a system of one-way valves are present in the heart. The heart valves can be broken down into two types: atrioventricular and semilunar valves.

- *Atrioventricular valves*. The atrioventricular (AV) valves are located in the middle of the heart between the atria and ventricles and only allow blood to flow from the atria into the ventricles. The AV valve on the right side of the heart is called the tricuspid valve because it is made of three cusps (flaps) that separate to allow blood to pass through and connect to block regurgitation of blood. The AV valve on the left side of the heart is called the mitral valve or the bicuspid valve because it has two cusps. The AV valves are attached on the ventricular side to tough strings called chordae tendineae. The chordae tendineae pull on the AV valves to keep them from folding backwards and allowing blood to regurgitate past them.

- *Semilunar valves*. The semilunar valves, so named for the crescent moon shape of their cusps, are located between the ventricles and the arteries that carry blood away from the heart. The semilunar valve on the right side of the heart is the **pulmonary valve**, so named because it prevents the backflow of blood from the pulmonary trunk into the right ventricle. The semilunar valve on the left side of the heart is the**aortic valve**, named for the fact that it prevents the **aorta** from regurgitating blood back into the left ventricle. The semilunar valves are smaller than the AV valves and do not have chordae tendineae to hold them in place. Instead, the cusps of the semilunar valves are cup shaped to catch regurgitating blood and use the blood's pressure to snap shut.

Conduction System of the Heart

The heart is able to both set its own rhythm and to conduct the signals necessary to maintain and coordinate this rhythm throughout its structures. About 1% of the cardiac muscle cells in the heart are responsible for forming the conduction system that sets the pace for the rest of the cardiac muscle cells.

The conduction system starts with the pacemaker of the heart—a small bundle of cells known as the sinoatrial (SA) node. The SA node is located in the wall of the right atrium inferior to the superior vena cava. The SA node is responsible for setting the pace of the heart as a whole and directly signals the atria to contract. The signal from the SA node is picked up by another mass of conductive tissue known as the atrioventricular (AV) node.

The AV node is located in the right atrium in the inferior portion of the interatrial septum. The AV node picks up the signal sent by the SA node and transmits it through the atrioventricular (AV) bundle. The AV bundle is a strand of conductive tissue that runs through the interatrial septum and into the interventricular septum. The AV bundle splits into left and right branches in the interventricular septum and continues running through the septum until they reach the apex of the heart. Branching off from the left and right bundle branches are many Purkinje fibers that carry the signal to the walls of the ventricles, stimulating the cardiac muscle cells to contract in a coordinated manner to efficiently pump blood out of the heart.

Coronary Systole and Diastole

At any given time the chambers of the heart may found in one of two states:

- *Systole*. During systole, cardiac muscle tissue is contracting to push blood out of the chamber.
- *Diastole*. During diastole, the cardiac muscle cells relax to allow the chamber to fill with blood. Blood pressure increases in the major arteries during ventricular systole and decreases during ventricular diastole. This leads to the 2 numbers associated with blood pressure—systolic blood pressure is the higher number and diastolic blood pressure is the lower number. For example, a blood pressure of 120/80 describes the systolic pressure (120) and the diastolic pressure (80).

The Cardiac Cycle

The cardiac cycle includes all of the events that take place during one heartbeat. There are 3 phases to the cardiac cycle: atrial systole, ventricular systole, and relaxation.

- *Atrial systole*: During the atrial systole phase of the cardiac cycle, the atria contract and push blood into the ventricles. To facilitate this filling, the AV valves stay open and the semilunar valves stay closed to keep arterial blood from re-entering the heart. The atria are much smaller than the ventricles, so they only fill about 25% of the ventricles during this phase. The ventricles remain in diastole during this phase.

- *Ventricular systole*: During ventricular systole, the ventricles contract to push blood into the aorta and pulmonary trunk. The pressure of the ventricles forces the semilunar valves to open and the AV valves to close. This arrangement of valves allows for blood flow from the ventricles into the arteries. The cardiac muscles of the atria repolarize and enter the state of diastole during this phase.

- *Relaxation phase*: During the relaxation phase, all 4 chambers of the heart are in diastole as blood pours into the heart from the veins. The ventricles fill to about 75% capacity during this phase and will be completely filled only after the atria enter systole. The cardiac muscle cells of the ventricles repolarize during this phase to prepare for the next round of depolarization and contraction. During this phase, the AV valves open to allow blood to flow freely into the ventricles while the semilunar valves close to prevent the regurgitation of blood from the great arteries into the ventricles.

Blood Flow through the Heart

Deoxygenated blood returning from the body first enters the heart from the superior and **inferior vena cava**. The blood enters the right atrium and is pumped through the tricuspid valve into the right ventricle. From the right ventricle, the blood is pumped through the pulmonary semilunar valve into the pulmonary trunk.

The pulmonary trunk carries blood to the lungs where it releases carbon dioxide and absorbs oxygen. The blood in the lungs returns to the heart through the pulmonary veins. From the pulmonary veins, blood enters the heart again in the left atrium.

The left atrium contracts to pump blood through the bicuspid (mitral) valve into the left ventricle. The left ventricle pumps blood through the aortic semilunar valve into the aorta. From the aorta,

blood enters into systemic circulation throughout the body tissues until it returns to the heart via the vena cava and the cycle repeats.

The Electrocardiogram

The electrocardiogram (also known as an EKG or ECG) is a non-invasive device that measures and monitors the electrical activity of the heart through the skin. The EKG produces a distinctive waveform in response to the electrical changes taking place within the heart.

The first part of the wave, called the P wave, is a small increase in voltage of about 0.1 mV that corresponds to the depolarization of the atria during atrial systole. The next part of the EKG wave is the QRS complex which features a small drop in voltage (Q) a large voltage peak (R) and another small drop in voltage (S). The QRS complex corresponds to the depolarization of the ventricles during ventricular systole. The atria also repolarize during the QRS complex, but have almost no effect on the EKG because they are so much smaller than the ventricles.

The final part of the EKG wave is the T wave, a small peak that follows the QRS complex. The T wave represents the ventricular repolarization during the relaxation phase of the cardiac cycle. Variations in the waveform and distance between the waves of the EKG can be used clinically to diagnose the effects of heart attacks, congenital heart problems, and electrolyte imbalances.

Heart Sounds - The sounds of a normal heartbeat are known as “lubb” and “dupp” and are caused by blood pushing on the valves of the heart. The “lubb” sound comes first in the heartbeat and is the longer of the two heart sounds. The “lubb” sound is produced by the closing of the AV valves at the beginning of ventricular systole. The shorter, sharper “dubb” sound is similarly caused by the closing of the semilunar valves at the end of ventricular systole. During a normal heartbeat, these sounds repeat in a regular pattern of lubb-dubb pause. Any additional sounds such as liquid rushing or gurgling indicate a structure problem in the heart. The most likely causes of these extraneous sounds are defects in the atrial or ventricular septum or leakage in the valves.

Blood pressure (**BP**) is the pressure exerted by circulating blood upon the walls of blood vessels. When used without further specification, "blood pressure" usually refers to the arterial pressure in the systemic circulation. Blood pressure is usually expressed in terms of the systolic (maximum) pressure over diastolic (minimum) pressure and is measured in millimeters of mercury (mm Hg). It is one of the vital signs along with respiratory rate, heart rate, oxygen saturation, and body temperature. Normal resting systolic (diastolic) blood pressure in an adult is approximately 120 mm Hg (80 mm Hg), abbreviated "120/80 mm Hg".

The exact causes of high blood pressure are often not clear. Your blood pressure may be strongly influenced by:

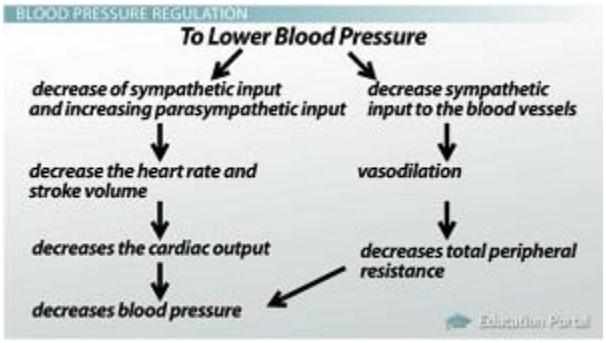
- family history
- eating patterns, including salty foods
- alcohol intake
- weight
- How much physical activity you do.

Blood Pressure Regulation

If blood pressure within the aorta or the carotid sinus increases, the walls of these arteries stretch and stimulate increased activity within the baroreceptor. This information is then sent via nerves to the cardio regulatory center within the medulla, which responds by initiating mechanisms that decrease the blood pressure to a normal level. Let's take a look at what happens to bring your blood pressure back down to a normal level when it gets too high.

To lower blood pressure, we first see a decrease of sympathetic input and an increase in parasympathetic input to the heart. We previously learned that the sympathetic nervous system can increase heart rate and stimulate the heart muscle to pump with more force. We also learned that the parasympathetic nervous system can decrease the heart rate. Therefore, by shutting off the sympathetic stimulation and boosting the parasympathetic stimulation, we decrease the heart rate and stroke volume, which decreases the cardiac output and decreases blood pressure. Second, if the baroreceptors are detecting that blood pressure is too high, the cardio regulatory center of the medulla will also decrease sympathetic input to the blood vessels. This causes vasodilation, which decreases total peripheral resistance and decreases blood pressure.

The opposite happens when the baroreceptors of the aorta or carotid sinus detect a drop in blood pressure. A decrease in blood pressure causes a decrease in action potentials sent to the cardio regulatory center of the medulla. Therefore, to raise blood pressure, the body will first cause an increase in sympathetic nerve activity to the SA node, causing it to fire more frequently, which increases the heart rate. The heart muscle is also stimulated to pump with more force, and this increases the stroke volume. When heart rate and stroke volume increase, we see an increase in cardiac output. As we learned, an increase in cardiac output causes an increased blood pressure, restoring blood pressure back to a normal level. Second, this causes an increased sympathetic input to the blood vessels, which stimulate the smooth muscle to contract, causing vasoconstriction, which increases total peripheral resistance and increases blood pressure.



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DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – III – Human Anatomy & Physiology – SBMA1303

UNIT III – DIGESTIVE AND EXCRETORY SYSTEM

Digestion is the process by which food and liquid are broken down into smaller parts so that the body can use them to build and nourish cells, and to provide energy.

The digestive system, which extends from the mouth to the anus, is responsible for receiving food, breaking it down into nutrients (a process called digestion), absorbing the nutrients into the bloodstream, and eliminating the indigestible parts of food from the body. The digestive tract consists of the

- Mouth
- Throat and esophagus
- Stomach
- Small intestine
- Large intestine
- Rectum and anus

The digestive system also includes organs that lie outside the digestive tract:

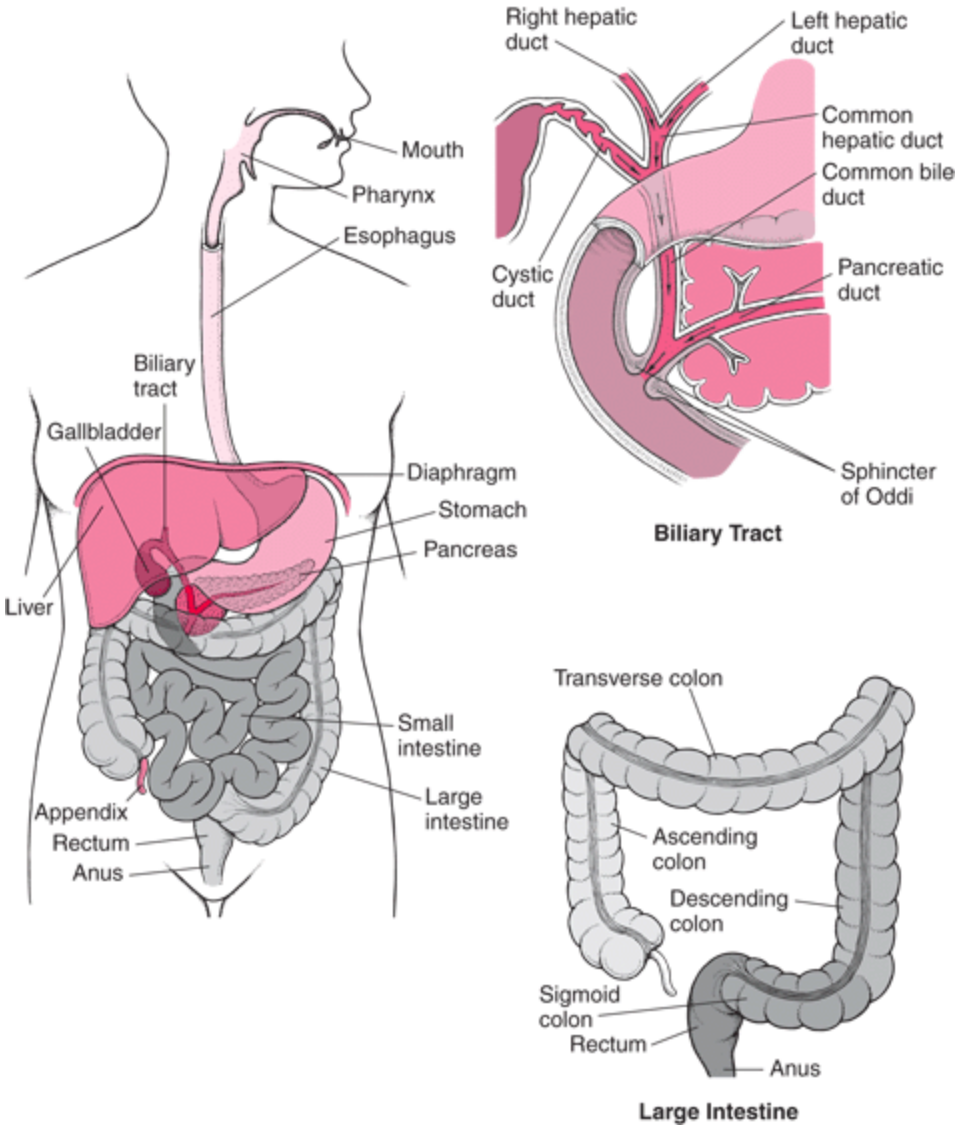
- The pancreas
- The liver
- The gallbladder

The MOUTH is the entrance to both the digestive and the respiratory systems. The inside of the mouth is lined with mucous membranes. When healthy, the lining of the mouth (oral mucosa) is reddish pink. The gums (gingivae) are paler pink and fit snugly around the teeth.

The roof of the mouth (palate) is divided into two parts. The front part has ridges and is hard (hard palate). The back part is relatively smooth and soft (soft palate). The moist mucous membranes lining the mouth continue outside, forming the pink and shiny portion of the lips, which meets the skin of the face at the vermilion border. The lip mucosa, although moistened by saliva, is prone to drying.

At the back of the mouth hangs a narrow muscular structure called the uvula, which can be seen when a person says "Ahh." The uvula hangs from the back of the soft palate, which separates the back of the nose from the back of the mouth.

On the floor of the mouth lies the tongue, which is used to taste and mix food. The tongue is not normally smooth. It is covered with tiny projections (papillae) that contain taste buds, which sense the taste of food. The sense of taste is relatively simple, distinguishing sweet, sour, salty, bitter, and savory (also called umami, the taste of the flavoring agent monosodium glutamate). These tastes can be detected all over the tongue, but certain areas are more sensitive for each taste. Sweet detectors are located at the tip of the tongue. Salt detectors are located at the front sides of the tongue. Sour detectors are located along the sides of the tongue. Bitter detectors are located on the back one third of the tongue. Smell is sensed by olfactory receptors high in the nose. The sense of smell is much more complex than that of taste, distinguishing many subtle variations. The senses of taste and smell work together to enable people to recognize and appreciate flavors



The STOMACH is a large, bean-shaped, hollow muscular organ consisting of three regions:

- Cardia
- Body (fundus)
- Antrum

Food and fluids enter the stomach from the esophagus by passing through the lower esophageal sphincter.

The upper stomach serves as a storage area for food. Here, the cardia and body of the stomach relax to accommodate food that enters the stomach. Then the antrum (lower stomach) contracts rhythmically, mixing the food with acid and enzymes (stomach juices) and grinding the food down into small pieces so that it is more easily digested. The cells lining the stomach secrete three important substances: mucus, hydrochloric acid, and the precursor of pepsin (an enzyme that breaks down proteins). Mucus coats the cells of the stomach lining to protect them from being damaged by acid and enzymes. Any disruption of this layer of mucus, such as that resulting from infection by the

bacterium *Helicobacter pylori* (Helicobacter pylori Infection) or from aspirin , can result in damage that leads to a stomach ulcer (Peptic Ulcer).

Hydrochloric acid provides the highly acidic environment needed for pepsin to break down proteins. The stomach's high acidity also serves as a barrier against infection by killing most bacteria. Acid secretion is stimulated by nerve impulses to the stomach, gastrin (a hormone released by the stomach), and histamine (a substance released by the stomach). Pepsin is the only enzyme that digests collagen, which is a protein and a major part of meat.

SMALL INTESTINE

The duodenum is the first segment of the small intestine, and the stomach releases food into it. Food enters the duodenum through the pyloric sphincter in amounts that the small intestine can digest. When full, the duodenum signals the stomach to stop emptying.

The duodenum receives pancreatic enzymes from the pancreas and bile from the liver and gallbladder These fluids, which enter the duodenum through an opening called the sphincter of Oddi, are important in aiding digestion and absorption. Waves of rhythmic muscular contractions (called peristalsis) also aid digestion and absorption by churning up food and mixing it with intestinal secretions.

The first few inches of the duodenal lining are smooth, but the rest of the lining has folds, small projections (villi), and even smaller projections (microvilli). These villi and microvilli increase the surface area of the duodenal lining, allowing for greater absorption of nutrients.

The jejunum and ileum make up the rest of the small intestine and are located below the duodenum. These parts of the small intestine are largely responsible for the absorption of fats and other nutrients. Churning movements facilitate absorption. Absorption is also enhanced by the vast surface area made up of folds, villi, and microvilli. The intestinal wall is richly supplied with blood vessels that carry the absorbed nutrients to the liver through the portal vein. The intestinal wall releases mucus, which lubricates the intestinal contents, and water, which helps dissolve the digested fragments. Small amounts of enzymes that digest proteins, sugars, and fats are also released.

The consistency of the intestinal contents changes gradually as the contents travel through the small intestine. In the duodenum, food is diluted with pancreatic enzymes and bile, which decrease stomach acidity. The contents continue to travel through the lower small intestine, becoming more liquid as they mix with water, mucus, bile, and pancreatic enzymes. Ultimately, the small intestine absorbs most of the nutrients and all but about 1 liter of fluid before emptying into the large intestine.

The LARGE INTESTINE consists of the

- Cecum and ascending (right) colon
- Transverse colon
- Descending (left) colon
- Sigmoid colon (which is connected to the rectum)

The cecum, which is at the beginning of the ascending colon, is the point at which the small intestine joins the large intestine. Projecting from the cecum is the appendix, which is a small finger-shaped tube that serves no known function. The large intestine secretes mucus and is largely responsible for the absorption of water from the stool.

The LIVER is a large organ with several functions only some of which are related to digestion.

The nutrients of food are absorbed into the intestinal wall, which is supplied with many tiny blood vessels (capillaries). The capillaries carry the absorbed nutrients into veins that join larger veins and eventually enter the liver as the portal vein.

Blood from the portal vein is processed in two ways:

- Bacteria and other foreign particles absorbed from the intestine are removed from the blood.
- Many nutrients absorbed from the intestine are further broken down so they can be used by the body.

The liver does the necessary processing at high speed and passes the blood, full of nutrients, into the general circulation.

The liver manufactures about half of the body's cholesterol. The rest comes from food. About 80% of the cholesterol made by the liver is used to make bile.

GALL BLADDER & BILIARY DUCT

Bile is a greenish yellow, thick, sticky fluid. It consists of bile salts, electrolytes, bile pigments, cholesterol, and other fats. The gallbladder is the storage sac that holds bile.

Bile flows out of the liver through the right and left hepatic ducts, which come together to form the common hepatic duct. This duct then joins with a duct coming from the gallbladder, called the cystic duct, to form the common bile duct. The pancreatic duct joins the common bile duct just where it empties into the duodenum through the sphincter of Oddi.

Between meals, bile salts are stored in the gallbladder, and only a small amount of bile flows into the intestine. Food that enters the duodenum triggers a series of hormonal and nerve signals that cause the gallbladder to contract. As a result, bile flows into the duodenum and mixes with food contents.

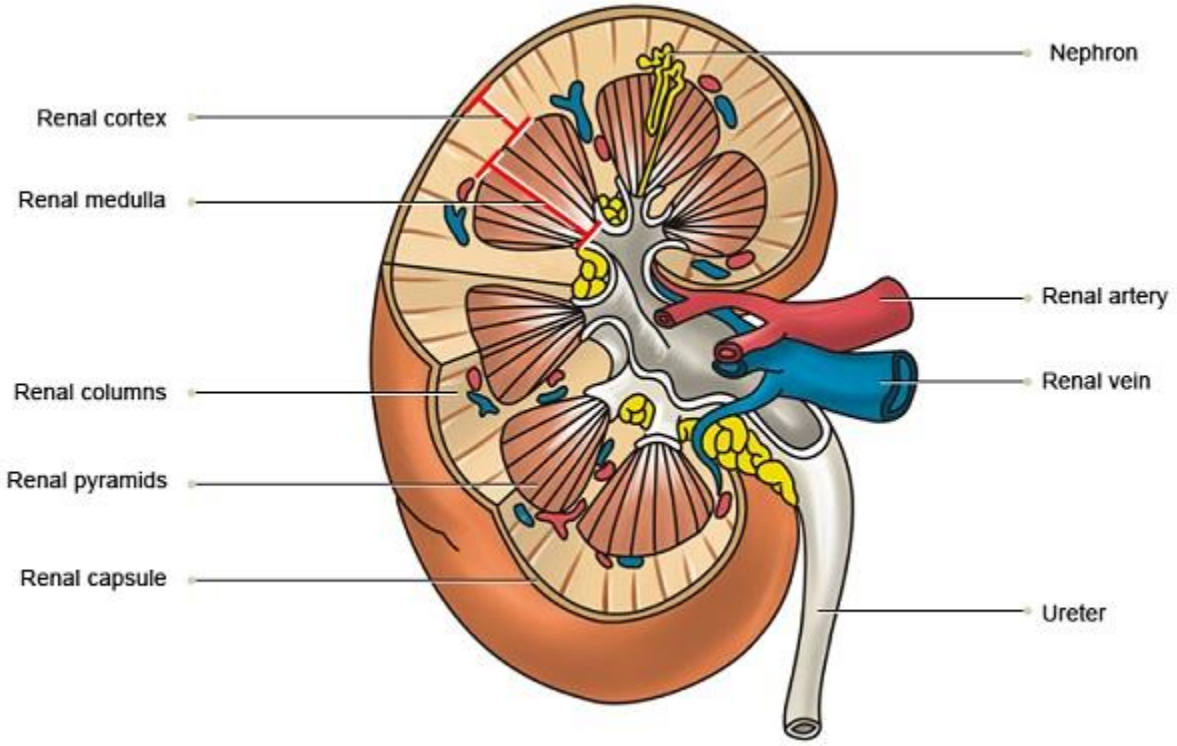
Bile has two important functions: It assists in the digestion and absorption of fats, and it is responsible for the elimination of certain waste products from the body, particularly hemoglobin from destroyed red blood cells and excess cholesterol. Specifically, bile is responsible for the following actions:

- Bile salts make cholesterol, fats, and fat-soluble vitamins more soluble (more dissolved), which aids in their absorption.
- Bile salts stimulate the secretion of water by the large intestine to help move the contents along.
- Bilirubin (the main pigment in bile) is excreted in bile as a waste product of destroyed red blood cells, giving stool a green-brown color.
- Drugs and other waste products are excreted in bile and later eliminated from the body.
- Various proteins that play important roles in bile's absorptive function are secreted in bile.

Bile salts are reabsorbed by the last portion of the small intestine, extracted by the liver, and resecreted into bile. This recirculation of bile salts is known as the enterohepatic circulation. All the bile salts in the body circulate about 10 to 12 times a day. During each pass, small amounts of bile salts reach the large intestine, where some are reabsorbed and the rest are excreted in the stool.

STRUCTURE OF KIDNEY

Nephrons, the urine-producing functional structures of the kidney, span the cortex and medulla. The initial filtering portion of a nephron is the renal corpuscle which is located in the cortex. This is followed by a renal tubule that passes from the cortex deep into the medullary pyramids.



Kidneys are paired organs found on each side of the back portion of the abdominal cavity. The larger left kidney is located a bit higher than the right kidney. Unlike other organs found in the abdomen, the kidneys are located behind the lining (peritoneum) of the abdominal cavity, thus they are considered retroperitoneal organs. These bean-shaped organs are protected by the back muscles and the ribs, as well as the fat (adipose tissue) that surrounds them like a protective padding.

The bean-shaped kidneys have an outer convex side and an inner concave side called the renal hilus, where the renal artery, vein, and ureter are found.

A thin connective tissue called the renal capsule surrounds each kidney. This capsule maintains the kidneys' shape and protects the inner tissues.

Inside the renal capsule is the outer layer called the renal cortex, a soft, dense, and vascular tissue. Deep to this layer is the renal medulla, which consists of several renal pyramids, the cone-shaped structures with apices pointing toward the kidney's center.

Each apex of the renal pyramid is connected to a minor calyx, a hollow collecting tube for urine. These minor calyces merge and form three major calyces that also merge into the renal pelvis at the hilus of the kidney. From here, urine drains into the larger ureter.

The nephron is the kidney's functional unit that removes waste from the body. Each kidney has more than a million nephrons in the renal cortex, which gives it a granular appearance on sagittal section.

The nephron consists of a renal corpuscle, a tubule, and a capillary network that originates from the small cortical arteries. Each renal corpuscle is composed of a glomerulus (a network of capillaries) and a Bowman's capsule(the cup-shaped chamber that surrounds it.

The glomerulus connects to a long, convoluted renal tubule which is divided into three functional parts. These consist of the loop of Henle (nephritic loop), the proximal convoluted tubule, and the distal convoluted tubule, which empties into the collecting ducts. These collecting ducts fuse together and enter the papillae of the renal medulla.

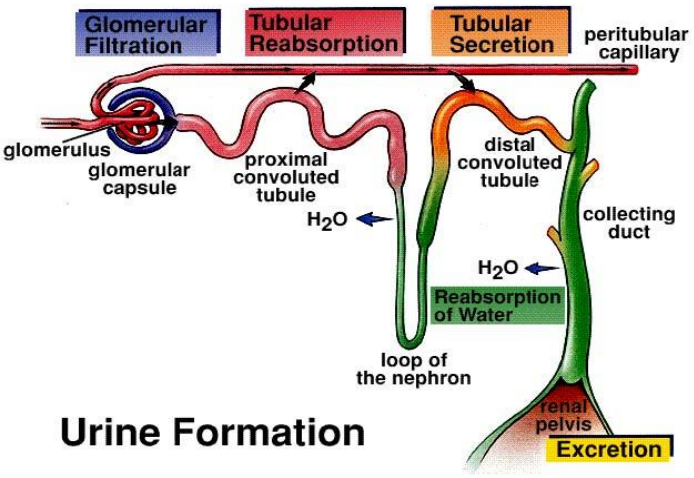
Urine passes through the renal medulla as a fluid with high sodium content and leaves through the renal papillae, into the renal calyces, into the renal pelvis, and into the bladder through the ureter.

The urinary system depends on proper kidney structure and function. Some of these core actions include:

- **Excretes waste:** The kidneys get rid of toxins, urea, andexcess salts. Urea is a nitrogen-based waste product of cell metabolism that is produced in the liver and transported by the blood to the kidneys.
- **Maintains water balance:** The kidneys help maintain water and electrolyte balance in the body. They react to changes in the water level, which may increase or decrease throughout the day.
- **Regulates blood pressure:** The kidneys help regulate blood pressure by producing angiotensin, a substance that constricts blood vessels and signals the body to retain waterand sodium when blood pressure is low.
- **Regulates red blood cells:** The kidneys produce erythropoietin, a hormone that stimulates your bone marrow to produce more red blood cells when the bodydoes not get enough oxygen.
- **Regulates acid levels:** Acids are products of metabolism. The kidneys help maintain proper acid-base balance to keep the body health

PHYSIOLOGY OF URINE FORMATION

The kidneys filter unwanted substances from the blood and produce **urine** to excrete them. There are three main steps of **urine formation**: glomerular filtration, reabsorption, and secretion. These processes ensure that only waste and excess water are removed from the body.



Filtration

Blood enters the afferent arteriole and flows into the glomerulus. Blood in the glomerulus has both filterable blood components and non-filterable blood components. Filterable blood components move toward the inside of the glomerulus while non-filterable blood components bypass the filtration process by exiting through the efferent arteriole. Filterable Blood components will then take a plasma like form called glomerular filtrate. A few of the filterable blood components are water, nitrogenous waste, nutrients and salts (ions). Nonfilterable blood components include formed elements such as blood cells and platelets along with plasma proteins. The glomerular filtrate is not the same consistency as urine, as much of it is reabsorbed into the blood as the filtrate passes through the tubules of the nephron.

Reabsorption

Within the peritubular capillary network, molecules and ions are reabsorbed back into the blood. Sodium Chloride reabsorbed into the system increases the osmolarity of blood in comparison to the glomerular filtrate. This reabsorption process allows water (H_2O) to pass from the glomerular filtrate back into the circulatory system.

Glucose and various amino acids also are reabsorbed into the circulatory system. These nutrients have carrier molecules that claim the glomerular molecule and release it back into the circulatory system. If all of the carrier molecules are used up, excess glucose or amino acids are set free into the urine. A complication of diabetes is the inability of the body to reabsorb glucose. If too much glucose appears in the glomerular filtrate it increases the osmolarity of the filtrate, causing water

to be released into the urine rather than reabsorbed by the circulatory system. Frequent urination and unexplained thirst are warning signs of diabetes, due to water not being reabsorbed.

Glomerular filtrate has now been separated into two forms: Reabsorbed Filtrate and Non-reabsorbed Filtrate. Non-reabsorbed filtrate is now known as tubular fluid as it passes through the collecting duct to be processed into urine.

Secretion

Some substances are removed from blood through the peritubular capillary network into the distal convoluted tubule or collecting duct. These substances are Hydrogen ions, creatinine, and drugs. Urine is a collection of substances that have not been reabsorbed during glomerular filtration or tubular reabsorption.

ROLE OF KIDNEY IN THE REGULATION OF SALT, WATER AND ACID BASE BALANCE

It is the job of the kidneys to maintain the water-salt balance of the blood. They also maintain blood volume as well as blood pressure. Simple examples of ways that this balance can be changed include ingestion of water, dehydration, blood loss and salt ingestion.

Reabsorption of water

Direct control of water excretion in the kidneys is exercised by the anti-diuretic hormone (ADH), released by the posterior lobe of the pituitary gland. ADH causes the insertion of water channels into the membranes of cells lining the collecting ducts, allowing water reabsorption to occur. Without ADH, little water is reabsorbed in the collecting ducts and dilute urine is excreted. There are several factors that influence the secretion of ADH. The first of these happen when the blood plasma gets too concentrated. When this occurs, special receptors in the hypothalamus release ADH. When blood pressure falls, stretch receptors in the aorta and carotid arteries stimulate ADH secretion to increase volume of the blood.

Reabsorption of Salt

The Kidneys also regulate the salt balance in the blood by controlling the excretion and the reabsorption of various ions. As noted above, ADH plays a role in increasing water reabsorption in the kidneys, thus helping to dilute bodily fluids. The kidneys also have a regulated mechanism for reabsorbing sodium in the distal nephron. This mechanism is controlled by aldosterone, a steroid hormone produced by the adrenal cortex. Aldosterone promotes the excretion of potassium ions and the reabsorption of sodium ions. The release of Aldosterone is initiated by the kidneys. The juxtaglomerular apparatus is a renal structure consisting of the macula densa, mesangial cells, and juxtaglomerular cells. Juxtaglomerular cells (JG cells, also known as granular cells) are the site of renin secretion. Renin is an enzyme that converts angiotensinogen (a large plasma protein produced by the liver) into Angiotensin I and eventually into Angiotensin

II which stimulates the adrenal cortex to produce aldosterone. The reabsorption of sodium ions is followed by the reapsorption of water. This causes blood pressure as well as blood volume to increase.

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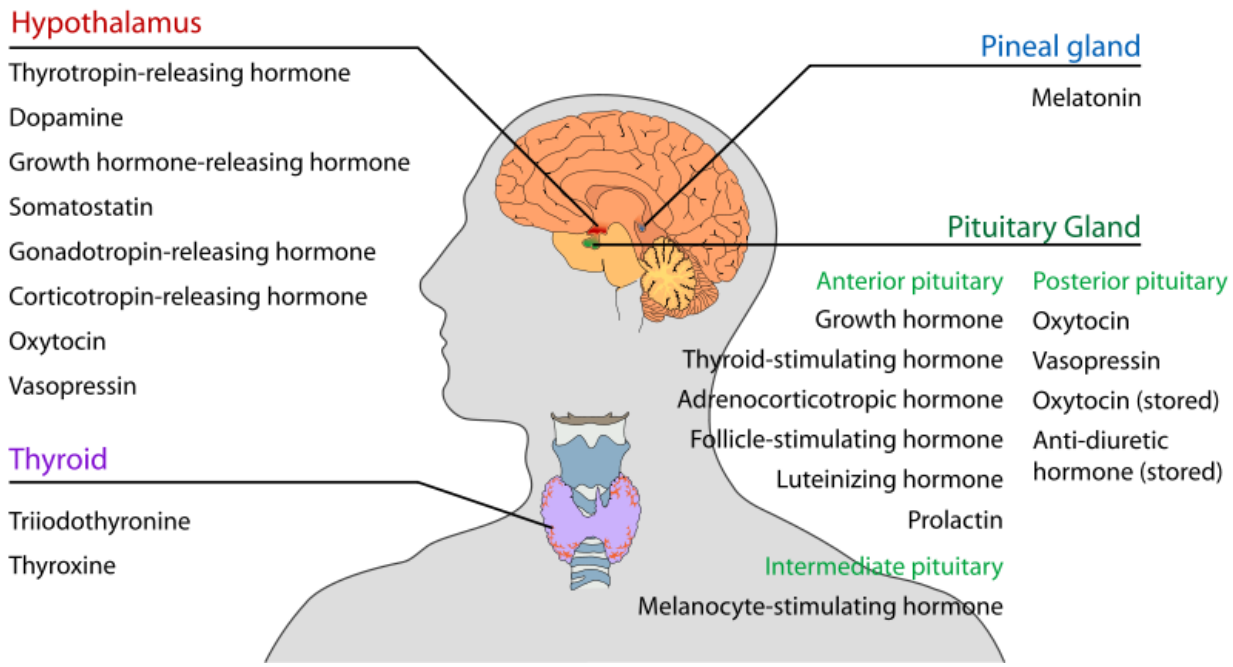
Unit IV - ENDOCRINE AND NERVOUS SYSTEM

The **endocrine system** is the collection of glands that produce hormones that regulate metabolism, growth and development, tissue function, sexual function, reproduction, sleep, and mood, among other things.

The **endocrine system** refers to the collection of glands of an organism that secrete hormones directly into the circulatory system to be carried towards distant target organs. The major endocrine glands include the pineal gland, pituitary gland, pancreas, ovaries, testes, thyroid gland, parathyroid gland, hypothalamus, and adrenal glands.

In contrast, exocrine glands, such as salivary glands, sweat glands, and glands within the gastrointestinal tract, tend to be much less vascular and have ducts or a hollow lumen.

The kidney secretes endocrine hormones such as erythropoietin and renin. Hormones can consist of amino acid complexes, steroids, or prostaglandins.



Pituitary gland (hypophysis)

The pituitary gland (or hypophysis) is an endocrine gland about the size of a pea and weighing 0.5 grams (0.018 oz) in humans.

Anterior Pituitary Lobe (Adenohypophysis)

Secreted hormone	Abbreviation	From cells	Effect
Growth hormone (somatotropin)	GH	Somatotrophs	Stimulates growth and cell reproduction Stimulates Insulin-like growth factor 1 release from liver
Thyroid-stimulating hormone (thyrotropin)	TSH	Thyrotrophs	Stimulates thyroxine (T4) and triiodothyronine (T3) synthesis and release from thyroid gland Stimulates iodine absorption by thyroid gland
Adrenocorticotropic hormone (corticotropin)	ACTH	Corticotrophs	Stimulates corticosteroid (glucocorticoid and mineralcorticoid) and androgen synthesis and release from adrenocortical cells
Beta-endorphin	–	Corticotrophs	Inhibits perception of pain
Follicle-stimulating hormone	FSH	Gonadotrophs	In females: Stimulates maturation of ovarian follicles in ovary In males: Stimulates maturation of seminiferous tubules In males: Stimulates spermatogenesis In males: Stimulates production of androgen-binding protein from Sertoli cells of the testes
Luteinizing hormone	LH	Gonadotrophs	In females: Stimulates ovulation In females: Stimulates formation of corpus

			luteum In males: Stimulates testosterone synthesis from Leydig cells (interstitial cells)
Prolactin	PRL	Lactotrophs	Stimulates milk synthesis and release from mammary glands Mediates sexual gratification
Melanocyte-stimulating hormone	MSH	Melanotropes in the Pars intermedia of the Anterior Pituitary	Stimulates melanin synthesis and release from skin/hair melanocytes

Posterior Pituitary Lobe (Neurohypophysis)

Stored hormone	Abbreviation	From cells	Effect
Oxytocin		Magnocellular neurosecretory cells	In females: uterine contraction during birthing, lactation (letdown reflex) when nursing
Vasopressin (antidiuretic hormone)	ADH or AVP	Parvocellular neurosecretory neurons	Increases water permeability in the distal convoluted tubule and collecting duct of nephrons, thus promoting water reabsorption and increasing blood volume

THYROID GLAND

Secreted hormone	Abbreviation	From cells	Effect
Triiodothyronine	T3	Thyroid epithelial cell	Stimulates body oxygen

			and energy consumption, thereby increasing the basal metabolic rate Stimulates RNA polymerase I and II, thereby promoting protein synthesis
Thyroxine (tetraiodothyronine)	T4	Thyroid epithelial cells	(Less active form of thyroid hormone) (Acts as a prohormone to triiodothyronine) Stimulates body oxygen and energy consumption, thereby increasing the basal metabolic rate Stimulates RNA polymerase I and II, thereby promoting protein synthesis
Calcitonin		Parafollicular cells	Stimulates osteoblasts and thus bone construction Inhibits Ca^{2+} release from bone, thereby reducing blood Ca^{2+}

PANCREAS

The pancreas is a mixocrine gland and it secretes both enzymes and hormones.

Secreted hormone	From cells	Effect
Insulin (Primarily)	β Islet cells	Intake of glucose, glycogenesis and glycolysis in liver and muscle from blood. Intake of lipids and synthesis of triglycerides in adipocytes. Other anabolic effects
Glucagon (Also Primarily)	α Islet cells	Glycogenolysis and gluconeogenesis in liver. Increases blood glucose level.

Somatostatin	δ Islet cells	Inhibit release of insulin Inhibit release of glucagon Suppress the exocrine secretory action of pancreas.
Pancreatic polypeptide	PP cells	Self regulate the pancreas secretion activities and effect the hepatic glycogen levels.

ADRENAL GLANDS

ADRENAL CORTEX

Secreted hormone	From cells	Effect
Glucocorticoids (chiefly cortisol)	zona fasciculata and zona reticularis cells	Stimulates gluconeogenesis Stimulates fat breakdown in adipose tissue Inhibits protein synthesis Inhibits glucose uptake in muscle and adipose tissue Inhibits immunological responses (immunosuppressive) Inhibits inflammatory responses (anti-inflammatory)
Mineralocorticoids (chiefly aldosterone)	Zona glomerulosa cells	Stimulates active sodium reabsorption in kidneys Stimulates passive water reabsorption in kidneys, thus increasing blood volume and blood pressure Stimulates potassium and H^+ secretion into nephron of kidney and subsequent excretion
Androgens (including DHEA and testosterone)	Zona fasciculata and Zona reticularis cells	In males: Relatively small effect compared to androgens from testes In females: masculinizing effects

ADRENAL MEDULLA

Secreted hormone	From cells	Effect

Adrenaline (epinephrine) (Primarily)	Chromaffin cells	Fight-or-flight response Boost the supply of oxygen and glucose to the brain and muscles (by increasing heart rate and stroke volume, vasodilation, increasing catalysis of glycogen in liver, breakdown of lipids in fat cells) Dilate the pupils Suppress non-emergency bodily processes (e.g., digestion)
Noradrenaline (norepinephrine)	Chromaffin cells	Fight-or-flight response Boost the supply of oxygen and glucose to the brain and muscles (by increasing heart rate and stroke volume, vasoconstriction and increased blood pressure, breakdown of lipids in fat cells) Increase skeletal muscle readiness.
Dopamine	Chromaffin cells	Increase heart rate and blood pressure
Enkephalin	Chromaffin cells	Regulate pain

TESTES

Secreted hormone	From cells	Effect
Androgens (chiefly testosterone)	Leydig cells	Anabolic: growth of muscle mass and strength, increased bone density, growth and strength, Virilizing: maturation of sex organs, formation of scrotum,

		deepening of voice, growth of beard and axillary hair.
Estradiol	Sertoli cells	Prevent apoptosis of germ cells
Inhibin	Sertoli cells	Inhibit production of FSH

OVARIAN FOLLICLE

Secreted hormone	From cells	Effect
Progesterone	Granulosa cells, theca cells	Support pregnancy Convert endometrium to secretory stage Make cervical mucus thick and impenetrable to sperm. Inhibit immune response, e.g., towards the human embryo Decrease uterine smooth muscle contractility Inhibit lactation Inhibit onset of labor. Raise epidermal growth factor-1 levels Increase core temperature during ovulation Reduce spasm and relax smooth muscle (widen bronchi and regulate mucus) Anti-inflammatory Reduce gall-bladder activity Normalize blood clotting and

		vascular tone, zinc and copper levels, cell oxygen levels, and use of fat stores for energy Assist in thyroid function and bone growth by osteoblasts Increase resilience in bone, teeth, gums, joint, tendon, ligament, and skin Promote healing by regulating collagen Provide nerve function and healing by regulating myelin Prevent endometrial cancer by regulating effects of estrogen
Estrogens	Granulosa cells	Promote formation of female secondary sex characteristics Accelerate height growth Accelerate metabolism (burn fat) Reduce muscle mass Stimulate endometrial growth Increase uterine growth Maintain blood vessels and skin Reduce bone resorption, increase bone formation Protein synthesis: Increase hepatic production of binding proteins

		Coagulation: Increase circulating level of factors 2, 7, 9, 10, antithrombin III, plasminogen Increase platelet adhesiveness Increase HDL, triglyceride, height growth Decrease LDL, fat deposition Fluid balance: Regulate salt (sodium) and water retention Increase growth hormone Increase cortisol, SHBG Gastrointestinal tract: Reduce bowel motility Increase cholesterol in bile Melanin: Increase pheomelanin, reduce eumelanin Cancer: Support hormone-sensitive breast cancers (Suppression of production in the body of estrogen is a treatment for these cancers.)

		Lung function: Promote lung function by supporting alveoli.

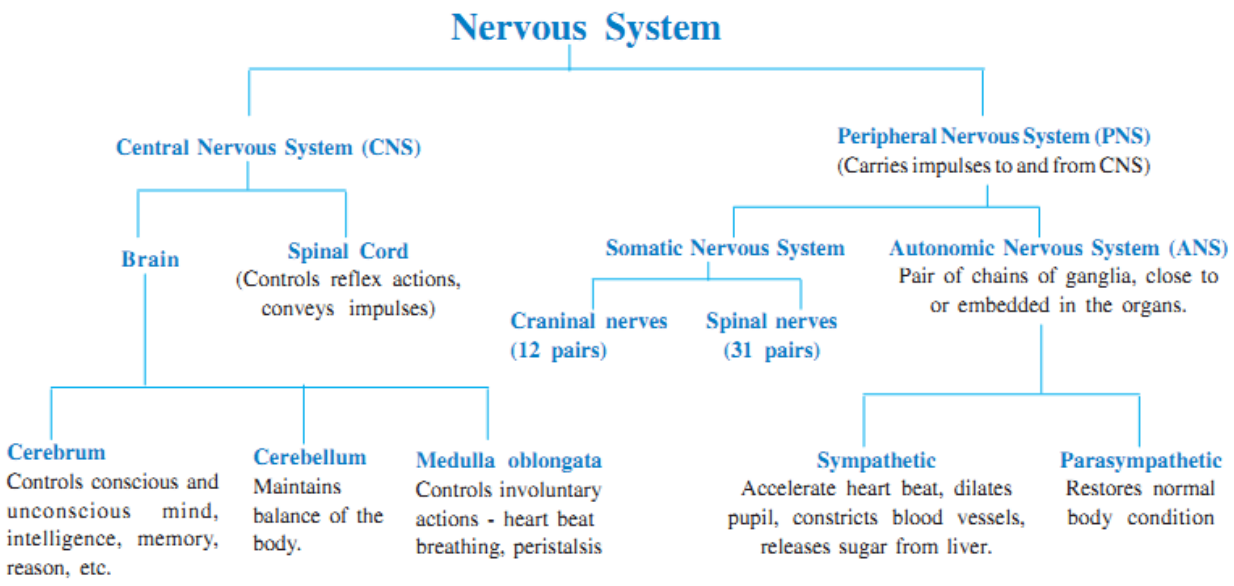
PARATHYROID GLAND

Secreted hormone	Abbreviation	From cells	Effect
Parathyroid hormone	PTH	Parathyroid chief cell	Stimulates Ca^{2+} release from bone, thereby increasing blood Ca^{2+} Stimulates osteoclasts, thus breaking down bone Stimulates Ca^{2+} reabsorption in kidney Stimulates activated vitamin D production in kidney Stimulates PO^{3-}_4 release from bones, thereby increasing blood PO^{3-}_4. Inhibits PO^{3-}_4 reabsorption in kidney, so more PO^{3-}_4 is excreted

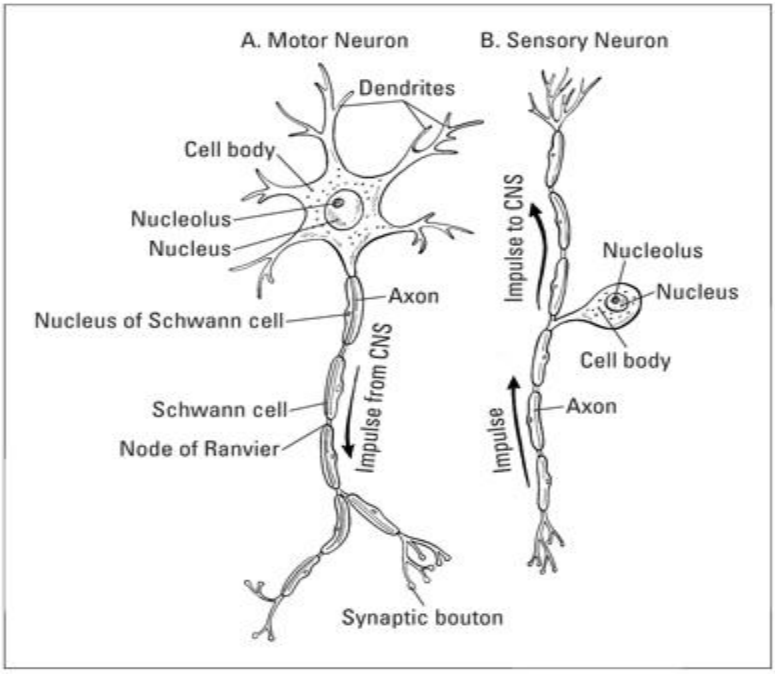
NERVOUS SYSTEM

- The **nervous system** is the part of an animal's body that coordinates its voluntary and involuntary actions and transmits signals to and from different parts of its body.
- In vertebrate species it consists of two main parts, the central nervous system (CNS) and the peripheral nervous system (PNS).

- The CNS contains the brain and spinal cord.
- The PNS consists mainly of nerves, which are enclosed bundles of the long fibers or axons that connect the CNS to every other part of the body.
- Nerves that transmit signals from the brain are called *motor* or *efferent* nerves, while those nerves that transmit information from the body to the CNS are called *sensory* or *afferent*. Most nerves serve both functions and are called *mixed* nerves.
- The PNS is divided into a) somatic and b) autonomic nervous system, and c) the enteric nervous system. Somatic nerves mediate voluntary movement.
- The autonomic nervous system is further subdivided into the sympathetic and the parasympathetic nervous systems.
- The sympathetic nervous system is activated in cases of emergencies to mobilize energy, while the parasympathetic nervous system is activated when organisms are in a relaxed state.
- The enteric nervous system functions to control the gastrointestinal system. Both autonomic and enteric nervous systems function involuntarily.
- Nerves that exit from the cranium are called cranial nerves while those exiting from the spinal cord are called spinal nerves.
- At the cellular level, the nervous system is defined by the presence of a special type of cell, called the neuron, also known as a "nerve cell".
- Neurons have special structures that allow them to send signals rapidly and precisely to other cells. They send these signals in the form of electrochemical waves traveling along thin fibers called axons, which cause chemicals called neurotransmitters to be released at junctions called synapses.
- A cell that receives a synaptic signal from a neuron may be excited, inhibited, or otherwise modulated.
- The connections between neurons can form neural circuits and also neural networks that generate an organism's perception of the world and determine its behavior. Along with neurons, the nervous system contains other specialized cells called glial cells (or simply glia), which provide structural and metabolic support.



- A **neuron** or **nerve cell** is an electrically excitable cell that processes and transmits information through electrical and chemical signals.
- These signals between neurons occur via synapses, specialized connections with other cells. Neurons can connect to each other to form neural networks.
- Neurons are the core components of the brain and spinal cord of the central nervous system (CNS), and of the ganglia of the peripheral nervous system (PNS).
- Specialized types of neurons include: sensory neurons which respond to touch, sound, light and all other stimuli affecting the cells of the sensory organs that then send signals to the spinal cord and brain.
- motor neurons that receive signals from the brain and spinal cord to cause muscle contractions and affect glandular outputs, and interneurons which connect neurons to other neurons within the same region of the brain, or spinal cord in neural networks.



A typical neuron consists of a cell body (soma), dendrites, and an axon.

The term neurite is used to describe either a dendrite or an axon, particularly in its undifferentiated stage.

Dendrites are thin structures that arise from the cell body, often extending for hundreds of micrometres and branching multiple times, giving rise to a complex "dendritic tree".

An axon (also called a nerve fiber when myelinated) is a special cellular extension (process) that arises from the cell body.

The cell body of a neuron frequently gives rise to multiple dendrites, but never to more than one axon, although the axon may branch hundreds of times before it terminates. At the majority of synapses, signals are sent from the axon of one neuron to a dendrite of another.

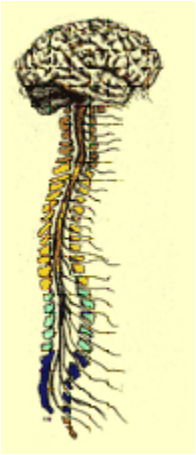
All neurons are electrically excitable, maintaining voltage gradients across their membranes by means of metabolically driven ion pumps, which combine with ion channels embedded in the membrane to generate intracellular-versus-extracellular concentration differences of ions such as sodium, potassium, chloride, and calcium.

Changes in the cross-membrane voltage can alter the function of voltage-dependent ion channels. If the voltage changes by a large enough amount, an all-or-none electrochemical pulse called an action potential is generated, which travels rapidly along the cell's axon, and activates synaptic connections with other cells when it arrives.

Glial cells

Glial cells are non-neuronal cells that provide support and nutrition, maintain homeostasis, form myelin, and participate in signal transmission in the nervous system. In the human brain, it is estimated that the total number of glia roughly equals the number of neurons, although the proportions vary in different brain areas. Among the most important functions of glial cells are to support neurons and hold them in place; to supply nutrients to neurons; to insulate neurons electrically; to destroy pathogens and remove dead neurons; and to provide guidance cues directing the axons of neurons to their targets. A very important type of glial cell (oligodendrocytes in the central nervous system, and Schwann cells in the peripheral nervous system) generates layers of a fatty substance called myelin that wraps around axons and provides electrical insulation which allows them to transmit action potentials much more rapidly and efficiently.

What is the Central Nervous System?



The central nervous system (CNS) controls most functions of the body and mind. It consists of two parts: the brain and the spinal cord. The brain is the center of our thoughts, the interpreter of our external environment, and the origin of control over body movement. Like a central computer, it interprets information from our eyes (sight), ears (sound), nose (smell), tongue (taste), and skin (touch), as well as from internal organs such as the stomach.

The spinal cord is the highway for communication between the body and the brain. When the spinal cord is injured, the exchange of information between the brain and other parts of the body is disrupted.

Many organs and tissues in the body can recover after injury without intervention. Unfortunately,

CELLS OF THE NERVOUS SYSTEM

Neurons

Cells called neurons connect with one another to send and receive messages in the brain and spinal cord. Many neurons working together are responsible for every decision made, every emotion or sensation felt, and every action taken.

The complexity of the central nervous system is amazing. There are approximately 100 billion neurons in the brain and spinal cord combined. As many as 10,000 different subtypes of neurons

have been identified, each specialized to send and receive certain types of information.

Each neuron is made up of a cell body, which houses the nucleus. Axons and dendrites form extensions from the cell body.

Astrocytes

Astrocytes, a kind of glial cell, are the primary support cells of the brain and spinal cord. They make and secrete proteins called neurotrophic factors. They also break down and remove proteins or chemicals that might be harmful to neurons (for example, glutamate, a neurotransmitter that in excess causes cells to become overexcited and die by a process called excitotoxicity). Astrocytes aren't always beneficial: After injury, they divide to make new cells that surround the injury site, forming a glial scar that is a barrier to regenerating axons.

Microglia

Microglia are immune cells for the brain. After injury, they migrate to the site of injury to help clear away dead and dying cells. They can also produce small molecules called cytokines that trigger cells of the immune system to respond to the injury site. This clean-up process is likely to play an important role in recovery of function following a spinal injury.

Oligodendrocytes

Oligodendrocytes are glial cells that produce a fatty substance called myelin which wraps around axons in layers. Axon fibers insulated by myelin can carry electrical messages (also called action potentials) at a speed of 100 meters per second, while fibers without myelin can only carry messages at a speed of one meter per second

How We Control Movement and Sense the World

Synapses and Neurotransmission

Messages are passed from neuron to neuron through synapses, small gaps between the cells, with the help of chemicals called neurotransmitters. To transmit an action potential message across a synapse, neurotransmitter molecules are released from one neuron (the "pre-synaptic" neuron) across the gap to the next neuron (the "post-synaptic" neuron). The process continues until the message reaches its destination.

There are millions and millions of connections between neurons within the spinal cord alone. These connections are made during development, using positive (neurotrophic factors) and

negative (inhibitory proteins) signals to fine-tune them. Amazingly, a single axon can form synapses with as many as 1,000 other neurons.

What Causes Paralysis

There is a logical and physical topographical organization to the anatomy of the central nervous system, which is an elaborate web of closely connected neural pathways. This ordered relationship means that different segmental levels of the cord control different things and injury to a particular part of the cord will impact neighboring parts of the body.

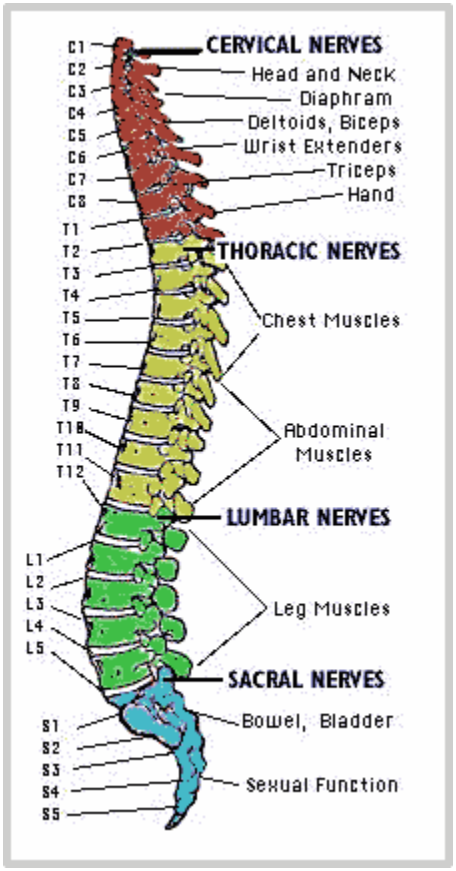
Paralysis occurs when communication between the brain and spinal cord fails. This can result from injury to neurons in the brain (a stroke), or in the spinal cord. Trauma to the spinal cord affects only the areas below the level of injury. On the other hand, poliomyelitis (a viral infection) or Lou Gehrig's disease (ALS, amyotrophic lateral sclerosis) can affect neurons in the entire spinal cord.

The **spinal cord** is a long, thin, tubular bundle of nervous tissue and support cells that extends from the medulla oblongata in the brainstem to the lumbar region of the vertebral column. The brain and spinal cord together make up the central nervous system (CNS). The spinal cord begins at the occipital bone and extends down to the space between the first and second lumbar vertebrae; it does not extend the entire length of the vertebral column. The enclosing bony vertebral column protects the relatively shorter spinal cord. The spinal cord functions primarily in the transmission of neural signals between the brain and the rest of the body but also contains neural circuits that can independently control numerous reflexes and central pattern generators.

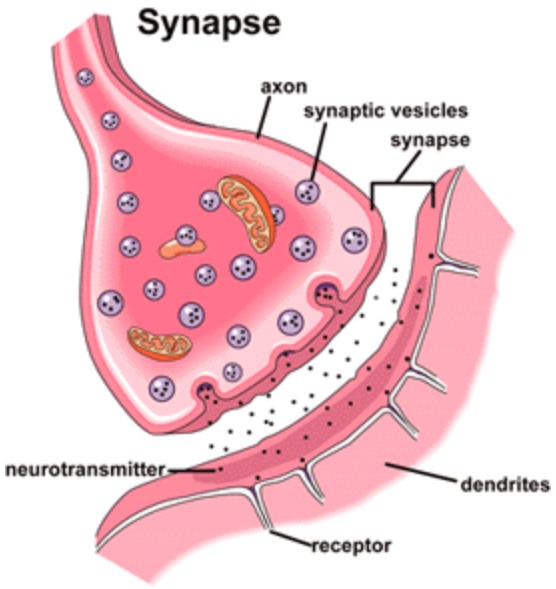
The spinal cord is the main pathway for information connecting the brain and peripheral nervous system. The length of the spinal cord is much shorter as compared to the length of the vertebral column. The human spinal cord extends from the foramen magnum and continues through to the conus medullaris near the second lumbar vertebra, terminating in a fibrous extension known as the filum terminale. It is about 45 cm (18 in) long in men and around 43 cm (17 in) in women, ovoid-shaped, and is enlarged in the cervical and lumbar regions. The cervical enlargement, located from C5 to T1 spinal segments, is where sensory input comes from and motor output goes to the arms. The lumbar enlargement, located between L1 and S3 spinal segments, handles sensory input and motor output coming from and going to the legs.

The spinal cord is continuous with the caudal portion of the medulla, running from the base of the skull to the body of the first lumbar vertebra. It does not run the full length of the vertebral column in adults. It is made of 31 segments that each contain sensory nerve root and motor nerve root. There are 31 spinal cord nerve segments in a human spinal cord:

- 8 cervical segments forming 8 pairs of cervical nerves
- 12 thoracic segments forming 12 pairs of thoracic nerves
- 5 lumbar segments forming 5 pairs of lumbar nerves
- 5 sacral segments forming 5 pairs of sacral nerves
- 1 coccygeal segment



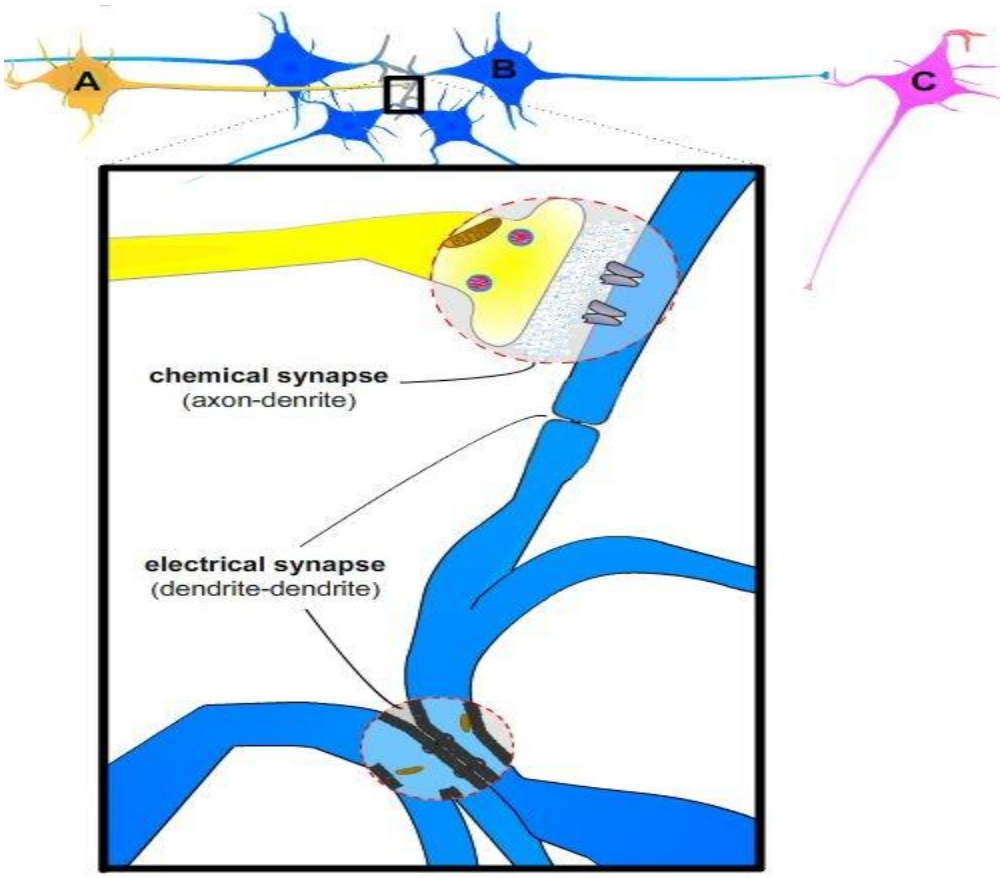
SYNAPSE



Synapase - a junction between two nerve cells, consisting of a minute gap across which impulses pass by diffusion of a neurotransmitter.

Neurotransmission

Neurotransmission (or **synaptic transmission**) is communication between neurons as accomplished by the movement of chemicals or electrical signals across a synapse. For any interneuron, its function is to receive INPUT "information" *from other neurons through synapses*, to process that information, then to send "information" as OUTPUT *to other neurons through synapses*. Consequently, an interneuron cannot fulfill its function if it is not connected to other neurons in a network. A network of neurons (or neural network) is merely a group of neurons through which information flows from one neuron to another. The image below represents a neural network. "Information" flows between the blue neurons through electrical synapses.



At electrical synapses, two neurons are physically connected to one another through gap junctions. Gap junctions permit changes in the electrical properties of one neuron to effect the other, and vice versa, so the two neurons essentially behave as one. Electrical neurotransmission is communication between two neurons at electrical synapses.

Chemical transmission occurs at chemical synapses. In chemical neurotransmission, the presynaptic neuron and the postsynaptic neuron are separated by a small gap — the synaptic cleft. The synaptic cleft is filled with extracellular fluid (the fluid bathing all the cells in the brain). The synaptic cleft creates a physical barrier for the electrical signal carried by one neuron to be transferred to another neuron. In electrical terms, the synaptic cleft would be considered a "short" in an electrical circuit. The function of neurotransmitter is to overcome this electrical short. It does so by acting like a chemical messenger, thereby linking the action potential of one neuron with a synaptic potential in another.

The core component of the nervous system in general and the brain in particular, is the neuron or nerve cell, the "brain cells" of popular language. A neuron is an electrically excitable cell that

processes and transmits information by electro-chemical signalling. Unlike other cells, neurons never divide, and neither do they die off to be replaced by new ones. The average human brain has about 100 billion neurons (or nerve cells) and many more neuroglia (or glial cells) which serve to support and protect the neurons (although see the end of this page for more information on glial cells). Each neuron may be connected to up to 10,000 other neurons, passing signals to each other via as many as 1,000 trillion synaptic connections, equivalent by some estimates to a computer with a 1 trillion bit per second processor.

Information transmission within the brain, such as takes place during the processes of memory encoding and retrieval, is achieved using a combination of chemicals and electricity. It is a very complex process involving a variety of interrelated steps, but a quick overview can be given here.

A typical neuron possesses a soma (the bulbous cell body which contains the cell nucleus), dendrites (long, feathery filaments attached to the cell body in a complex branching "dendritic tree") and a single axon (a special, extra-long, branched cellular filament, which may be thousands of times the length of the soma).

Every neuron maintains a voltage gradient across its membrane, due to metabolically-driven differences in ions of sodium, potassium, chloride and calcium within the cell, each of which has a different charge. If the voltage changes significantly, an electrochemical pulse called an action potential (or nerve impulse) is generated. This electrical activity can be measured and displayed as a wave form called brain wave or brain rhythm

This pulse travels rapidly along the cell's axon, and is transferred across a specialized connection known as a synapse to a neighbouring neuron, which receives it through its feathery dendrites. A synapse is a complex membrane junction or gap (the actual gap, also known as the synaptic cleft, is of the order of 20 nanometres, or 20 millionths of a millimetre) used to transmit signals between cells, and this transfer is therefore known as a synaptic connection. Although axon-dendrite synaptic connections are the norm, other variations (e.g. dendrite-dendrite, axon-axon, dendrite-axon) are also possible. A typical neuron fires 5 - 50 times every second.

Each individual neuron can form thousands of links with other neurons in this way, giving a typical brain well over 100 trillion synapses (up to 1,000 trillion, by some estimates). Functionally related neurons connect to each other to form neural networks (also known as neural nets or assemblies). The connections between neurons are not static, though, they change

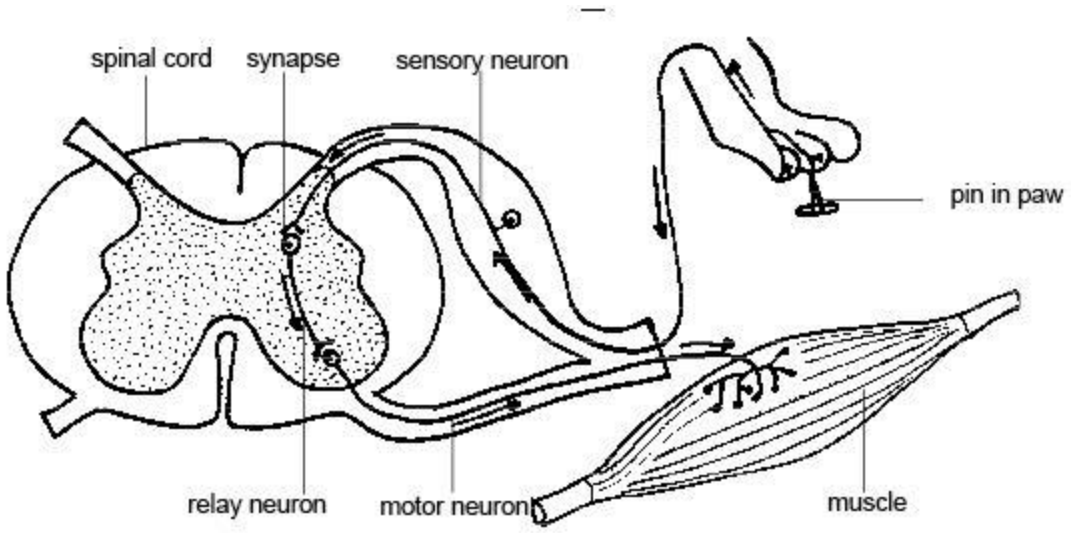
over time. The more signals sent between two neurons, the stronger the connection grows (technically, the amplitude of the post-synaptic neuron's response increases), and so, with each new experience and each remembered event or fact, the brain slightly re-wires its physical structure.

The interactions of neurons is not merely electrical, though, but electro-chemical. Each axon terminal contains thousands of membrane-bound sacs called vesicles, which in turn contain thousands of neurotransmitter molecules each. Neurotransmitters are chemical messengers which relay, amplify and modulate signals between neurons and other cells. The two most common neurotransmitters in the brain are the amino acids glutamate and GABA; other important neurotransmitters include acetylcholine, dopamine, adrenaline, histamine, serotonin and melatonin.

The electro-chemical signal released by a particular neurotransmitter may be such as to encourage to the receiving cell to also fire, or to inhibit or prevent it from firing. Different neurotransmitters tend to act as excitatory (e.g. acetylcholine, glutamate, aspartate, noradrenaline, histamine) or inhibitory (e.g. GABA, glycine, seratonin), while some (e.g. dopamine) may be either. Subtle variations in the mechanisms of neurotransmission allow the brain to respond to the various demands made on it, including the encoding, consolidation, storage and retrieval of memories.

As has been mentioned, in addition to neurons, the brain contains about an equal mass of glial cells (neuroglia or simply glia), the most common types being oligodendrocytes, astrocytes and microglia. Because they are so much smaller than neurons, there are up to 10 times as many in number, and different areas of the brain have higher or lower concentrations of glia. It used to be thought that the role of glial cells was limited to the physical support, nutrition and repair of the neurons of the central nervous system. However, more recent research suggests that glia, particularly astrocytes, actually perform a much more active role in brain communication and neuroplasticity, although the extent and mechanics of of this role is still uncertain, and a substantial amount of contemporary brain research is now focused on glials cell

THE REFLEX ARC



A **reflex arc** is a neural pathway that controls a reflex action. In higher animals, most sensory neurons do not pass directly into the brain, but synapse in the spinal cord. This characteristic allows reflex actions to occur relatively quickly by activating spinal motor neurons without the delay of routing signals through the brain, although the brain will receive sensory input while the reflex is carried out.

Components of a Reflex Arc

Stimulus: In the example above, the stimulus is the contact with the hot pot. This contact causes a nerve impulse that will travel to the spinal cord via the sensory neurons.

Sensory neurons: These neurons carry the nerve impulse to the spinal cord. Similar to the interneuron and motor neuron, sensory neurons receive incoming impulses at the dendrites. The impulses move away from the cell body along the axon to the synaptic terminal where the impulse is sent to the next interneuron with the help of a neurotransmitter (acetylcholine).

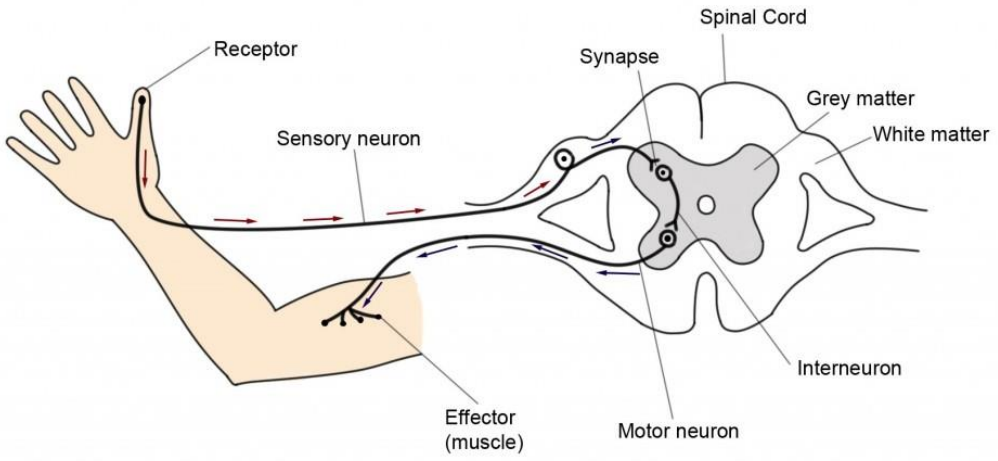
Interneurons: The interneuron is also known as relay neuron. These neurons are fully contained in the central nervous system. The interneuron serves as the connection between the sensory neurons and the motor neurons.

The synapse is a tiny space between two neurons. When an impulse gets to the end of one neuron and has to be sent down the next neuron, the synapse acts as a bridge. The signal arrives at the end of one neuron (close to the synapse) as an electrical signal, crosses the synapse as a chemical

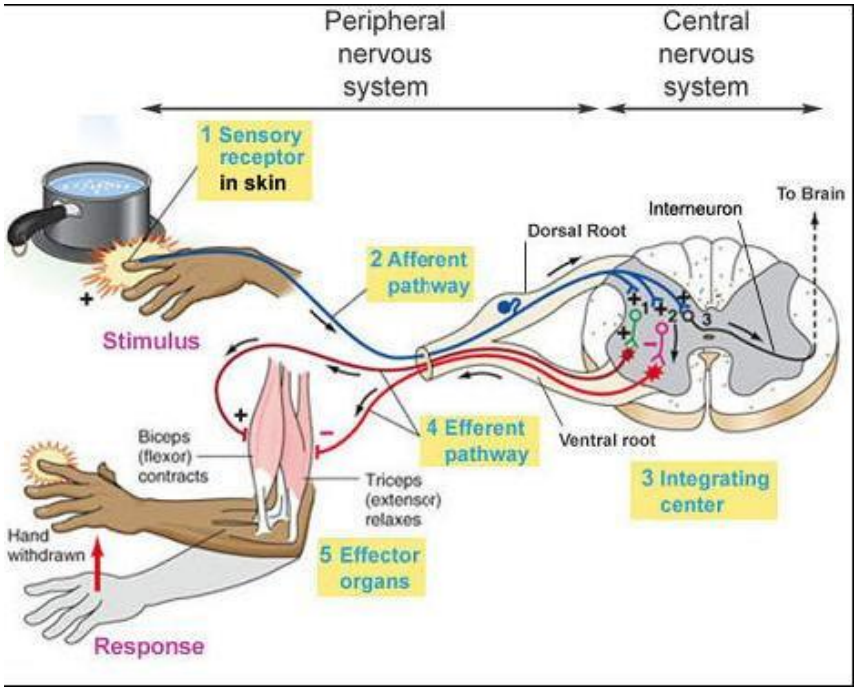
signal (with the help of a neurotransmitter known as acetylcholine released by the synaptic vesicles at the synaptic terminal) and continues as an electrical signal in the next neuron.

Motor neurons: These neurons send nerve impulses away from the central nervous system to effector organs or muscle fiber in our example above. This causes the muscle fiber to contract, resulting in you snatching your hand away from the hot pot.

Response: To respond to the stimulus of the reflex arc, the muscle needs to contract to pull the hand quickly away from the hot pot. For this to happen, the impulse travels to the synaptic terminal of the motor neuron. Synaptic vesicles at the synaptic terminal will then release acetylcholine which will cross the synapse and bind to the receptors on the muscle fibers to trigger the muscle contraction known as the 'response'.



PAIN



The pain stimulus is processed in the brain, which then sends an impulse down the spinal cord and via appropriate nerves which command the body to react, for instance by withdrawing the hand from a very hot object.

Perception of the pain stimulus: from the pain receptors to the brain

Pain receptors

Pain receptors are present everywhere in the body, especially the skin, surfaces of the joints, periosteum (the specialised lining around the bone), walls of the arteries, and certain structures in the skull. Other organs, such as the gut and muscles, have fewer pain receptors. It is interesting to note that the brain itself does not have any pain receptors at all, and is therefore insensitive to pain.

Pain receptors are free nerve endings. There are three types of pain receptor stimuli: mechanical, thermal and chemical. A mechanical stimulus would be, for example, high pressure or stretching, and a thermal pain stimulus would be extreme heat or cold.

Chemical pain receptors can be stimulated by chemicals from the outside world (e.g. acids), but also by certain products present in the body and released as a result of trauma, inflammation or

other painful stimuli. Examples of these substances are bradykinins, serotonin, potassium ions and acids (such as lactic acid, which causes muscle pain after heavy exercise).

Compounds called prostaglandins are released with painful stimuli, and although they don't directly stimulate pain receptors, they do increase their sensitivity. Paracetamol and non-steroidal anti-inflammatory drugs (NSAIDs) decrease the effect of prostaglandins, that is why they work as painkillers. Paracetamol operates in the central nervous system and the NSAIDs are peripheral-acting substances.

Pain nerve fibres – fast pain and slow pain

From the pain receptors, the pain stimulus is transmitted through peripheral nerves to the spinal cord and from there to the brain. This happens via two different types of nerve fibre: "fast pain" and "slow pain" fibres.

What is "fast pain" and "slow pain"?

A pain stimulus, e.g. if you cut yourself, consists of two sensations. The first one is the so-called "fast pain" sensation, and is experienced as a sharp pain. After a few seconds, this becomes a sensation of "slow pain", which is a duller and more of a burning pain. This slow pain normally lasts for a few days or weeks, but if inappropriately processed by the body, it can last for several months and give rise to chronic pain.

Fast pain, like pricking yourself with a needle or touching a burning object, is mainly related to painful stimuli of the skin, mouth and anus.

It is transmitted by relatively thick nerve fibres, although this term is relative because they are still microscopically thin, with a diameter of two- to five-thousandth of a millimetre. These nerves are called A-delta fibres. Because of their relative thickness, they allow the pain stimulus to be transferred very fast (at a speed of 5 to 30 metres per second), hence the name. This allows the body to withdraw immediately from the painful and harmful stimulus in order to avoid further damage.

Fast pain is well localised, meaning that a person can normally describe very accurately where exactly the pain is. The pain is sharp and "cutting".

The pain does not radiate, i.e. you feel it on a very particular spot. It is difficult to overcome this type of pain, even with strong painkillers. This means that if surgery needs to be performed, the pain of the incision cannot be taken away with strong opioids alone.

However, infiltration of the affected area or the nerve with a local anaesthetic will take away all sensation, including any sharp pain. This is what happens in surgery performed under local anaesthetic.

Slow pain, which starts immediately after the fast pain, is transmitted by very thin nerve fibres called C-nerve fibres (their diameter is between 0.2 and one thousandth of a millimetre). Because of their size, the pain impulse can only be transmitted slowly to the brain, at a speed of less than 2 metres per second. The response of the body is to hold the affected body part immobile (guarding, spasm or rigidity), so that healing can take place.

Slow pain can also be the primary type of pain originating in internal organs such as the gut and the uterus – but not the brain, which is insensitive to pain. Whereas localised pain on the skin, like a small cut, is painful, localised trauma to an internal organ is not painful. For instance, when a surgeon makes a cut in your bowel, this is not painful at all – but for the surgeon to get to the bowel, he has to cut through skin, and that is why you need anaesthetic.

However, massive injury to an internal organ can be severely painful, for example if a whole segment of bowel dies off (infarcts). Other examples include when a cystic duct is obstructed because of gallstones, when the urine bladder becomes overdistended because of a stone or enlarged prostate, and the well-known pain of labour.

This pain is poorly localised and is felt more diffusely, unlike pain on the skin, which can be exactly pinpointed. It also often radiates (e.g. gallbladder pain can be felt from the front to the back) or is referred to other parts of the body (e.g. pain from a heart attack can be felt in the neck or the arm). Opioids are very effective in treating this type of pain. Local anaesthetics block all nerve transmission, so they also effectively remove this type of pain if the appropriate nerves can be blocked.

Characteristics of fast pain and slow pain	
Slow pain	**Fast pain**
Transmitted by very thin nerve fibres	Transmitted by relatively thicker (and therefore faster conducting) nerve fibres

Poorly localised	Well localised
All internal organs (except the brain)	Mainly skin, mouth, anus
Body wants to be immobile to allow healing (guarding, spasm, rigidity)	Immediate withdrawal of stimulation to avoid further damage
Pain often radiates, or is referred	Pain does not radiate
Effective relief from opioids	Little relief from opioids
Examples: labour pain, pain starting after fast pain from an injury	Examples: pain from a surgical incision

Pain transmission in the spinal cord and the brain

The peripheral nerves (nerves outside the central nervous system) carry the pain impulse to the spinal cord. In the spinal cord, fast pain and slow pain are carried up to the brain via different pathways. The impulse of the fast pain goes to specific and limited areas on the surface of the brain (the cortex), allowing for the relatively precise localisation of the pain stimulus.

The impulse from slow pain is distributed diffusely in the brain. Each area of the brain elicits a different response, which explains the whole range of symptoms that pain can cause, such as suffering, sleeping difficulties (because the pain stimulates the "wake centre"), and a depressed mood.

What can the body do to temper the pain sensation?

A very common remedy is "rubbing the pain better". When you get hurt, you instinctively rub the painful area, which partly relieves the pain. The reason is that rubbing or pressing stimulates certain other nerve fibres, and their input in the spinal cord receives preference over the input from the nerve fibres transmitting the pain.

When a pain stimulus reaches the brain, the brain itself sends a signal back to the spinal cord via a very complex system of nerve connections to diminish the transmission of the pain impulse that has been sent up to the brain. In a nutshell, the brain puts a "brake" on the pain impulse as it enters the spinal cord. Important molecules in this process are enkephalin and serotonin.

In the pain-processing parts of the brain there also exists a system of natural opioids. When a pain impulse reaches the brain, these opioids are released from their storage areas and bind with receptors in the pain pathway to block the transmission and perception of pain. Examples of these natural opioids are enkephalin, endorphin and dynorphin. How precisely this all works is

not completely understood, but when opioids (e.g. morphine) are administered by medical staff to a patient with pain, these administered opioids bind with the same receptors in the brain to block pain perception.

Electroencephalography (**EEG**) is an electrophysiological monitoring method to record electrical activity of the brain. It is typically noninvasive, with the electrodes placed along the scalp, although invasive electrodes are sometimes used in specific applications. EEG measures voltage fluctuations resulting from ionic current within the neurons of the brain. In clinical contexts, EEG refers to the recording of the brain's spontaneous electrical activity over a period of time, as recorded from multiple electrodes placed on the scalp. Diagnostic applications generally focus on the spectral content of EEG, that is, the type of neural oscillations (popularly called "brain waves") that can be observed in EEG signals.

EEG is most often used to diagnose epilepsy, which causes abnormalities in EEG readings. It is also used to diagnose sleep disorders, coma, encephalopathies, and brain death. EEG used to be a first-line method of diagnosis for tumors, stroke and other focal brain disorders, but this use has decreased with the advent of high-resolution anatomical imaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT).

An **electroencephalogram (EEG)** is a test used to evaluate the electrical activity in the brain. Brain cells communicate with each other through electrical impulses. An EEG can be used to help detect potential problems associated with this activity.

The test tracks and records brain wave patterns. Small, flat metal discs called electrodes are attached to the scalp with wires. The electrodes analyze the electrical impulses in the brain and send signals to a computer, where the results are recorded.

An EEG is used to detect problems in the electrical activity of the brain that may be associated with certain brain disorders. The measurements given by an EEG are used to confirm or rule out various conditions, including:

- seizure disorders (such as epilepsy)
- a head injury
- encephalitis (an inflammation of the brain)
- a brain tumor
- encephalopathy (a disease that causes brain dysfunction)

- memory problems
- sleep disorders
- stroke
- dementia

An electroencephalogram (EEG) is a test that measures and records the electrical activity of your brain. Special sensors (electrodes) are attached to your head and hooked by wires to a computer. The computer records your brain's electrical activity on the screen or on paper as wavy lines. Certain conditions, such as seizures, can be seen by the changes in the normal pattern of the brain's electrical activity.

Why It Is Done

An electroencephalogram (EEG) may be done to:

- Diagnose epilepsy and see what types of seizures are occurring. EEG is the most useful and important test in confirming a diagnosis of epilepsy.
- Check for problems with loss of consciousness or dementia.
- Help find out a person's chance of recovery after a change in consciousness.
- Find out if a person who is in a coma is brain-dead.
- Study sleep disorders, such as narcolepsy.
- Watch brain activity while a person is receiving general anesthesia during brain surgery.
- Help find out if a person has a physical problem (problems in the brain, spinal cord, or nervous system) or a mental health problem.

How to Prepare

Before the day of the electroencephalogram (EEG) test, tell your doctor if you are taking any medicines. Your doctor may ask you to stop taking certain medicines (such as sedatives and tranquilizers, muscle relaxants, sleeping aids, or medicines used to treat seizures) before the test. These medicines can affect your brain's usual electrical activity and cause abnormal test results.

Do not eat or drink foods that have caffeine (such as coffee, tea, cola, and chocolate) for 12 hours before the test.Since the electrodes are attached to your scalp, make sure your hair is clean and free of sprays, oils, creams, and lotions. Shampoo your hair and rinse with clear water the evening before or the morning of the test. Do not put any hair conditioner or oil on after shampooing.

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SCHOOL OF BIO & CHEMICAL ENGINEERING

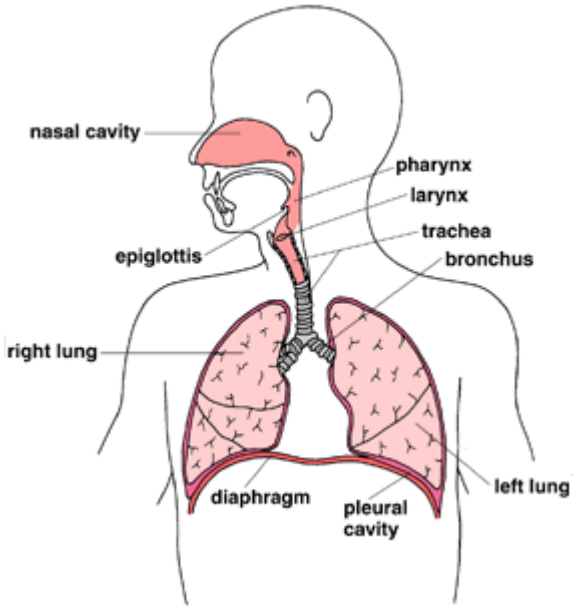
DEPARTMENT OF ENGINEERING

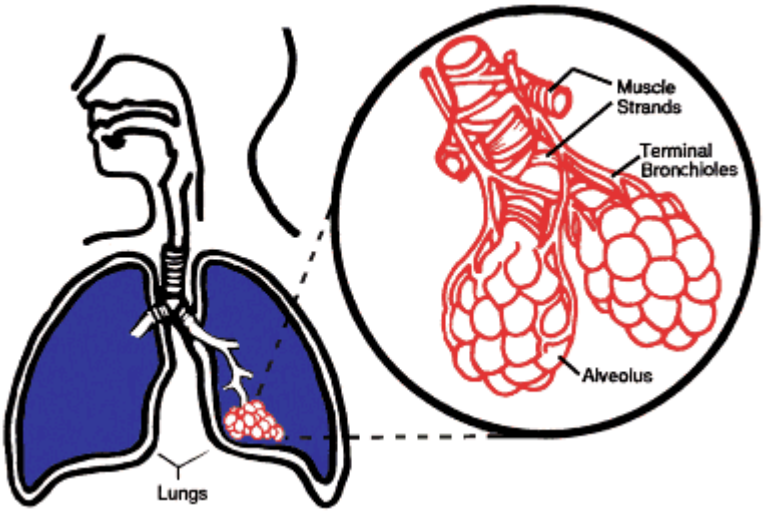
UNIT – V – Human Anatomy & Physiology – SBMA1303

Unit V - RESPIRATORY AND SENSORY SYSTEM

Respiratory System:

- Primary function is to obtain oxygen for use by body's cells & eliminate carbon dioxide that cells produce
- Includes respiratory airways leading into (& out of) lungs plus the lungs themselves
- Pathway of air: nasal cavities (or oral cavity) > pharynx > trachea > primary bronchi (right & left) > secondary bronchi > tertiary bronchi > bronchioles > alveoli (site of gas exchange)





The exchange of gases (O2 & CO2) between the alveoli & the blood occurs by simple diffusion: O2 diffusing from the alveoli into the blood & CO2 from the blood into the alveoli. Diffusion requires a concentration gradient. So, the concentration (or pressure) of O2 in the alveoli must be

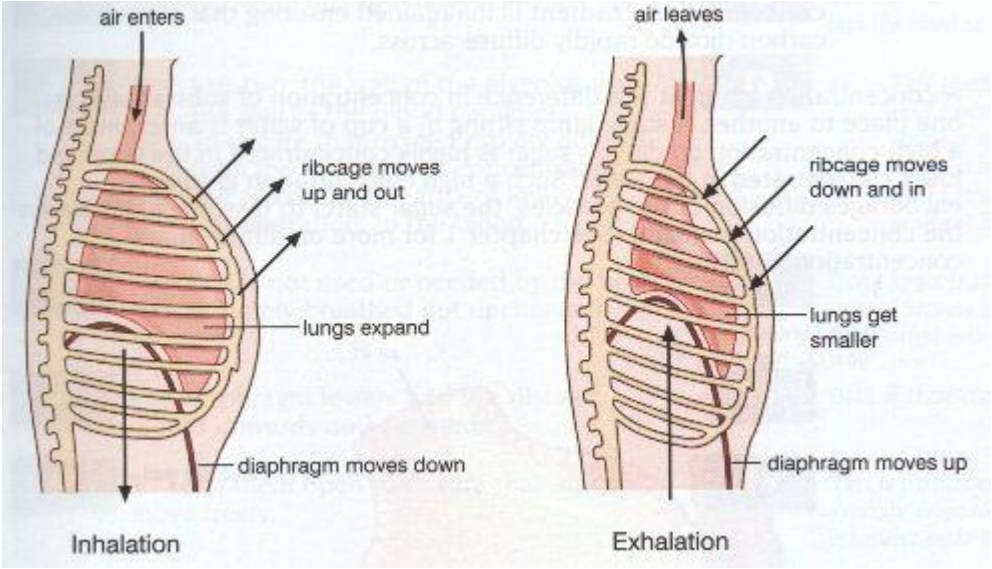
kept at a higher level than in the blood & the concentration (or pressure) of CO2 in the alveoli must be kept at a lower lever than in the blood. We do this, of course, by breathing - continuously bringing fresh air (with lots of O2 & little CO2) into the lungs & the alveoli.

Breathing is an active process - requiring the contraction of skeletal muscles. The primary muscles of respiration include the external intercostals muscles (located between the ribs) and the diaphragm (a sheet of muscle located between the thoracic & abdominal cavities).

The external intercostals plus the diaphragm contract to bring about inspiration:

- **Contraction of external intercostal muscles** > elevation of ribs & sternum > increased front- to-back dimension of thoracic cavity > lowers air pressure in lungs > air moves into lungs

- **Contraction of diaphragm** > diaphragm moves downward > increases vertical dimension of thoracic cavity > lowers air pressure in lungs > air moves into lungs:



Exchange and transport of gases in the blood

- External respiration

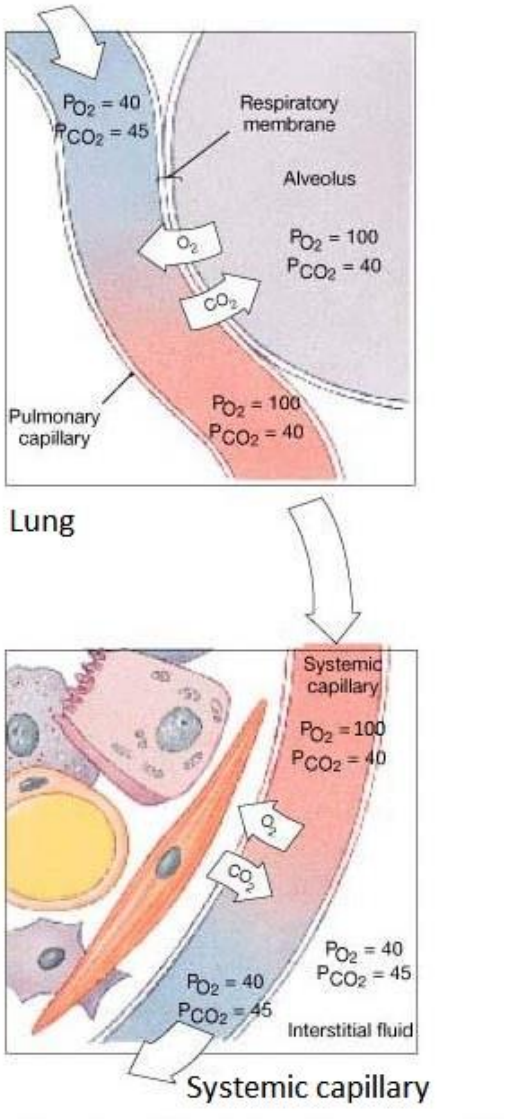
    - exchange of O2 & CO2 between external environment & the cells of the body
    - efficient because alveoli and capillaries have very thin walls & are very abundant (your lungs have about 300 million alveoli with a total surface area of about 75 square meters)
- Internal respiration - intracellular use of O2 to make ATP
- occurs by simple diffusion along partial pressure gradients

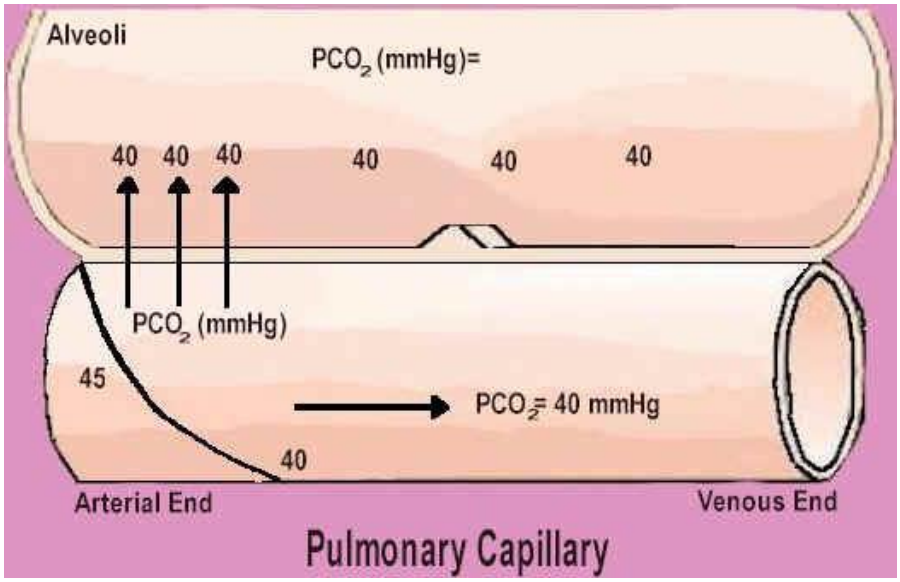
Partial Pressures of O2 and CO2in the body (normal, resting conditions

Alveoli

- PO2 = 100 mm Hg
- PCO2 = 40 mm Hg

- Alveolar capillaries
    - Entering the alveolar capillaries
        - PO2 = 40 mm Hg (relatively low because this blood has just returned from the systemic circulation & has lost much of its oxygen)
        - PCO2 = 45 mm Hg (relatively high because the blood returning from the systemic circulation has picked up carbon dioxide)





While in the alveolar capillaries, the diffusion of gasses occurs: oxygen diffuses from the alveoli into the blood & carbon dioxide from the blood into the alveoli.

- Leaving the alveolar capillaries
  - PO2 = 100 mm Hg
  - PCO2 = 40 mm Hg

Blood leaving the alveolar capillaries returns to the left atrium & is pumped by the left ventricle into the systemic circulation. This blood travels through arteries & arterioles and into the systemic, or body, capillaries. As blood travels through arteries & arterioles, no gas exchange occurs.

- Entering the systemic capillaries
  - PO2 = 100 mm Hg
  - PCO2 = 40 mm Hg
- Body cells (resting conditions)
  - PO2 = 40 mm Hg
  - PCO2 = 45 mm Hg

Because of the differences in partial pressures of oxygen & carbon dioxide in the systemic capillaries & the body cells, oxygen diffuses from the blood & into the cells, while carbon dioxide diffuses from the cells into the blood.

- Leaving the systemic capillaries
  - PO2 = 40 mm Hg
  - PCO2 = 45 mm Hg

Blood leaving the systemic capillaries returns to the heart (right atrium) via venules & veins (and no gas exchange occurs while blood is in venules & veins). This blood is then pumped to the lungs (and the alveolar capillaries) by the right ventricle.

How are oxygen & carbon dioxide transported in the blood?

- Oxygen is carried in blood:

1 - Bound to hemoglobin (98.5% of all oxygen in the blood)

2 - Dissolved in the plasma (1.5%)

Because almost all oxygen in the blood is transported by hemoglobin, the relationship between the concentration (partial pressure) of oxygen and hemoglobin saturation (the % of hemoglobin molecules carrying oxygen) is an important one.

Pulmonary function tests (PFTs) are a group of tests that measure how well your lungs work. This includes how well you're able to breathe and how effective your lungs are able to bring oxygen to the rest of your body.

What are pulmonary function tests?

Pulmonary function tests (PFTs) are non-invasive tests that show how well the lungs are working. The tests measure lung volume, capacity, rates of flow, and gas exchange. This information can help your healthcare provider diagnose and decide the treatment of certain lung disorders.

There are 2 types of disorders that cause problems with air moving in and out of the lungs:

- **Obstructive.** This is when air has trouble flowing out of the lungs due to resistance. This causes a decreased flow of air.
- **Restrictive.** This is when the chest muscles can't expand enough. This creates problems with air flow.

PFT can be done with 2 methods:

- **Spirometry.** A spirometer is a device with a mouthpiece hooked up to a small electronic machine.
- **Plethysmography.** You sit or stand inside an air-tight box that looks like a short, square telephone booth to do the tests.

PFT measures:

- **Tidal volume (VT).** This is the amount of air inhaled or exhaled during normal breathing.
- **Minute volume (MV).** This is the total amount of air exhaled per minute.
- **Vital capacity (VC).** This is the total volume of air that can be exhaled after inhaling as much as you can.
- **Functional residual capacity (FRC).** This is the amount of air left in lungs after exhaling normally.
- **Residual volume.** This is the amount of air left in the lungs after exhaling as much as you can.
- **Total lung capacity.** This is the total volume of the lungs when filled with as much air as possible.
- **Forced vital capacity (FVC).** This is the amount of air exhaled forcefully and quickly after inhaling as much as you can.

- **Forced expiratory volume (FEV).** This is the amount of air expired during the first, second, and third seconds of the FVC test.
- **Forced expiratory flow (FEF).** This is the average rate of flow during the middle half of the FVC test.
- **Peak expiratory flow rate (PEFR).** This is the fastest rate that you can force air out of your lungs.

Normal values for PFTs vary from person to person. The amount of air inhaled and exhaled in your test results are compared to the average for someone of the same age, height, sex, and race. Results are also compared to any of your previous test results. If you have abnormal PFT measurements or if your results have changes, you may need other tests.

There are many different reasons why pulmonary function tests (PFTs) may be done. They are sometimes done in healthy people as part of a routine physical. Or you may have PFTs if your healthcare provider needs help to diagnose you with a health problem such as:

- Allergies
- Respiratory infections
- Trouble breathing from injury to the chest or a recent surgery
- Chronic lung conditions, such as asthma, bronchiectasis, emphysema, or chronic bronchitis
- Asbestosis, a lung disease caused by inhaling asbestos fibers
- Restrictive airway problems from scoliosis, tumors, or inflammation or scarring of the chest wall
- Sarcoidosis, a disease that causes lumps of inflammatory cells around organs such as the liver, lungs, and spleen
- Scleroderma, a disease that causes thickening and hardening of connective tissue

PFTs may be used to check lung function before surgery or other procedures in patients who have lung or heart problems, who are smokers, or who have other health conditions. Another use of PFTs is to assess treatment for asthma, emphysema, and other chronic lung problems. Your healthcare provider may also have other reasons to advise PFTs.

Because pulmonary function testing is not an invasive procedure, it is safe and quick for most people. But the person must be able to follow clear, simple directions.

All procedures have some risks. The risks of this procedure may include:

- Dizziness during the tests
- Feeling short of breath
- Coughing
- Asthma attack brought on by deep inhalation

In some cases, a person shouldn’t have PFTs. Reasons for this can include:

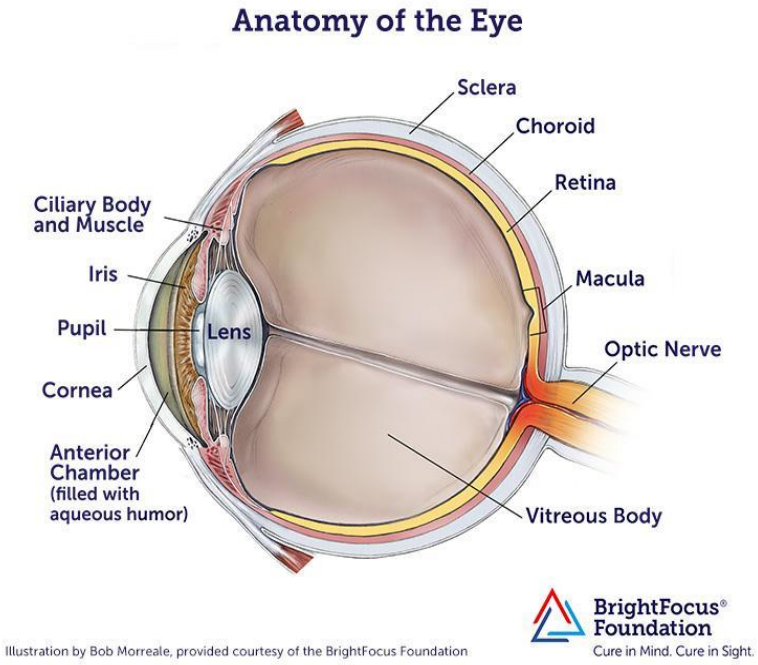
- Recent eye surgery, because of increased pressure inside the eyes during the procedure
- Recent belly (abdominal) or chest surgery
- Chest pain, recent heart attack, or an unstable heart condition
- A bulging blood vessel (aneurysm) in the chest, belly, or brain
- Active tuberculosis (TB) or respiratory infection, such as a cold or the flu

Certain things can make PFTs less accurate. These include:

- Use of medicines that open the airways (bronchodilators)
- Use of pain medicines
- Pregnancy
- Stomach bloat that affects the ability to take deep breaths
- Extreme tiredness or other conditions that affect a person's ability to do the tests

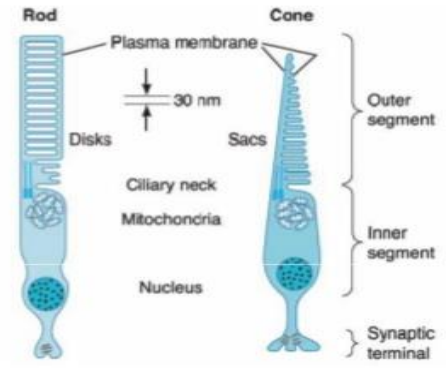
STRUCTURE OF HUMAN EYE

Eye is like a camera. The external object is seen like the camera takes the picture of any object. Light enters the eye through a small hole called the **pupil** and is focused on the **retina**, which is like a camera film. Eye also has a focusing **lens**, which focuses images from different distances on the retina. The colored ring of the eye, the **iris**, controls the amount of light entering the eye. It closes when light is bright and opens when light is dim. A tough white sheet called **sclera** covers the outside of the eye. Front of this sheet (sclera) is transparent in order to allow the light to enter the eye, the **cornea**. Ciliary muscles in ciliary body control the focusing of lens automatically. **Choroid** forms the vascular layer of the eye supplying nutrition to the eye structures. Image formed on the retina is transmitted to brain by **optic nerve**. The image is finally perceived by brain. A jelly like substance called **vitreous** humor fill the space between lens and retina. The lens, iris and cornea are nourished by clear fluid, **aqueous** humor, formed by the ciliary body and fill the space between lens and cornea. This space is known as **anterior chamber**. The fluid flows from ciliary body to the pupil and is absorbed through the channels in the angle of anterior chamber. The delicate balance of aqueous production and absorption controls pressure within the eye.

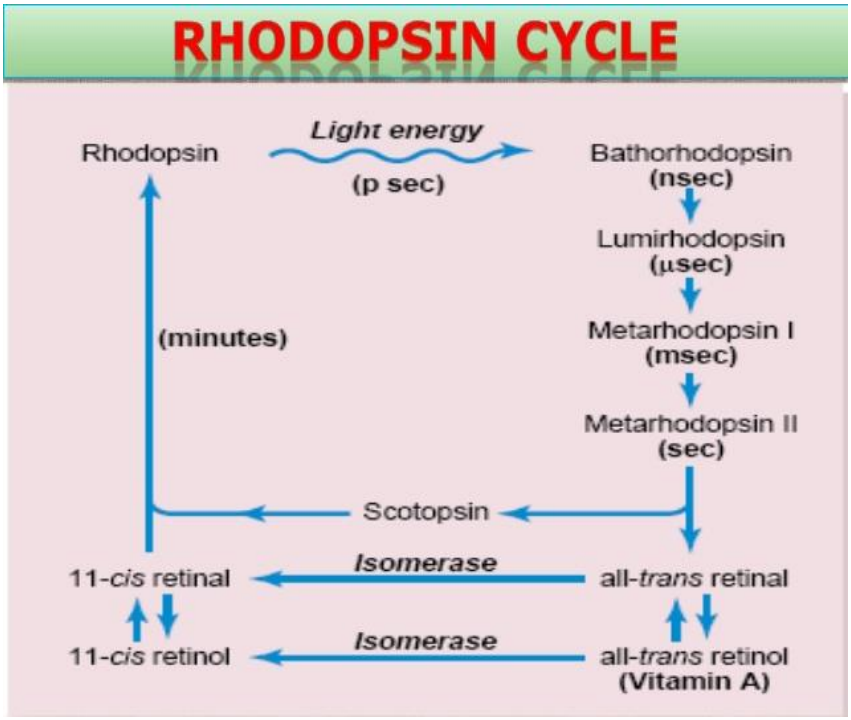


Visual Receptors in the Retina

- Rods are responsible for **vision in low light (night vision)** and provide **only black and white vision.**
- Cones are responsible for **color vision.**
- Each rod and cone is divided into an **outer segment**, an **inner segment** that includes a nuclear region, and a **synaptic zone.**



Schematic diagram of a rod and a cone



The human eye is the organ which gives us the sense of sight, allowing us to observe and learn more about the surrounding world than we do with any of the other four senses. We use our eyes in almost every activity we perform, whether reading, working, watching television, writing a letter, driving a car, and in countless other ways.

The eye allows us to see and interpret the shapes, colors, and dimensions of objects in the world by processing the light they reflect or emit. The eye is able to detect bright light or dim light, but it cannot sense objects when light is absent.

Process of vision

Light waves from an object (such as a tree) enter the eye first through the cornea, which is the clear dome at the front of the eye. It is like a window that allows light to enter the eye. The light then progresses through the pupil, the circular opening in the center of the colored iris.

Fluctuations in the intensity of incoming light change the size of the eye's pupil. As the light entering the eye becomes brighter, the pupil will constrict (get smaller), due to the pupillary light response. As the entering light becomes dimmer, the pupil will dilate (get larger).

Initially, the light waves are bent or converged first by the cornea, and then further by the crystalline lens (located immediately behind the iris and the pupil), to a nodal point (N) located immediately behind the back surface of the lens. At that point, the image becomes reversed (turned backwards) and inverted (turned upside-down).

The light continues through the vitreous humor, the clear gel that makes up about 80% of the eye's volume, and then, ideally, back to a clear focus on the retina, behind the vitreous. The small central area of the retina is the macula, which provides the best vision of any location in the retina. If the eye is considered to be a type of camera (albeit, an extremely complex one), the retina is equivalent to the film inside of the camera, registering the tiny photons of light interacting with it.

Within the layers of the retina, light impulses are changed into electrical signals. Then they are sent through the optic nerve, along the visual pathway, to the occipital cortex at the posterior (back) of the brain. Here, the electrical signals are interpreted or "seen" by the brain as a visual image.

If the incoming light from a far away object focuses before it gets to the back of the eye, that eye's refractive error is called "myopia" (nearsightedness). If incoming light from something far away has not focused by the time it reaches the back of the eye, that eye's refractive error is "hyperopia" (farsightedness).

In the case of "astigmatism," one or more surfaces of the cornea or lens (the eye structures which focus incoming light) are not spherical (shaped like the side of a basketball) but, instead, are cylindrical or toric (shaped a bit like the side of a football). As a result, there is no distinct point of focus inside the eye but, rather, a smeared or spread-out focus. Astigmatism is the most common refractive error.

After age 40, and most noticeably after age 45, the human eye is affected by presbyopia. This natural condition results in greater difficulty maintaining a clear focus at a near distance with an eye which sees clearly far away.

Presbyopia is caused by a lessening of flexibility of the crystalline lens, as well as to a weakening of the ciliary muscles which control lens focusing. Both are attributable to the aging process.

An eye can see clearly at a far distance naturally, or it can be made to see clearly artificially, such as with the aid of eyeglasses or contact lenses, or else following a photorefractive procedure such as LASIK (laser-assisted in situ keratomileusis). Nevertheless, presbyopia eventually will affect the near focusing of every human eye.

Eye growth

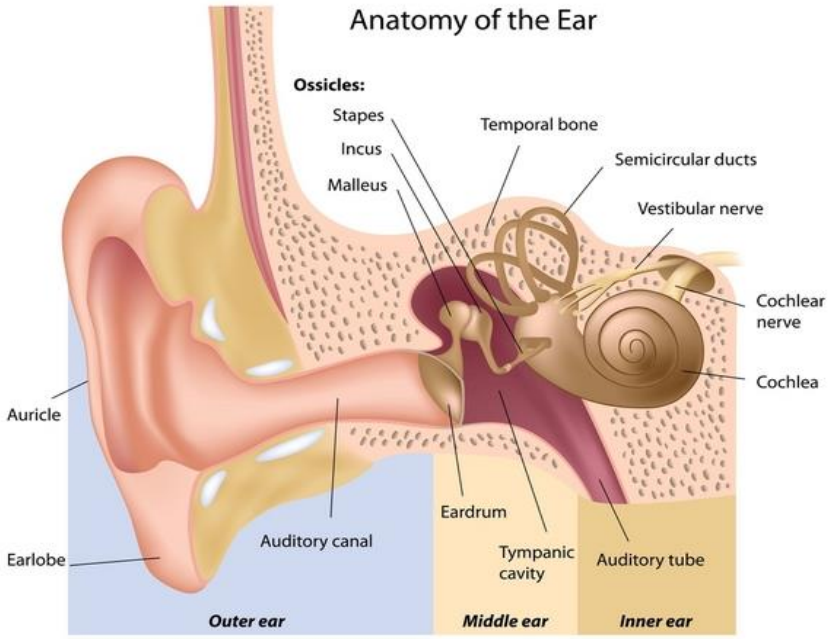
The average newborn's eyeball is about 18 millimeters in diameter, from front to back (axial length). In an infant, the eye grows slightly to a length of approximately 19½ millimeters.

The eye continues to grow, gradually, to a length of about 24-25 millimeters, or about 1 inch, in adulthood. A ping-pong ball is about 1½ inch in diameter, which makes the average adult eyeball about 2/3 the size of a ping-pong ball.

The eyeball is set in a protective cone-shaped cavity in the skull called the "orbit" or "socket." This bony orbit also enlarges as the eye grows.

extraocular muscles - The orbit is surrounded by layers of soft, fatty tissue. These layers protect the eye and enable it to turn easily. Traversing the fatty tissue are three pairs of extraocular muscles, which regulate the motion of each eye: the medial & lateral rectus muscles, the superior & inferior rectus muscles, and the superior & inferior oblique muscles.

STRUCTURE OF EAR



The ear is made up of three parts: the outer, middle, and inner ear. All three parts of the ear are important for detecting sound by working together to move sound from the outer part through the middle and into the inner part of the ear. Ears also help to maintain balance.

The outer ear includes:

- auricle (cartilage covered by skin placed on opposite sides of the head)
- auditory canal (also called the ear canal)
- eardrum outer layer (also called the tympanic membrane)

The outer part of the ear collects sound. Sound travels through the auricle and the auditory canal, a short tube that ends at the eardrum.

The middle ear includes:

- eardrum

- cavity (also called the tympanic cavity)
- ossicles (3 tiny bones that are attached)
    - malleus (or hammer) long handle attached to the eardrum
    - incus (or anvil) the bridge bone between the malleus and the stapes
    - stapes (or stirrup) the footplate; the smallest bone in the body

Sound entering the outer ear travels through the middle ear and causes the eardrum and ossicles in the middle ear to vibrate. As it travels, it amplifies (becomes louder) and changes from air to liquid.

The inner ear includes:

- oval window connects the middle ear with the inner ear
- semicircular ducts filled with fluid; attached to cochlea and nerves; send information on balance and head position to the brain
- cochlea spiral-shaped organ of hearing; transforms sound into signals that get sent to the brain
- auditory tube drains fluid from the middle ear into the throat behind the nose

When the stapes moves, it pushes the oval window, which then moves the cochlea. The cochlea takes the fluid vibration of sounds from the surrounding semicircular ducts and translates them into signals that are sent to the brain by nerves like the vestibular nerve and cochlear nerve.

The brain and auditory system work together to control how we hear and how we balance ourselves. The human ear is a complex organ and many scientists consider hearing to be the most complex of the human senses.

Sound can be detected whether a person is on land, underwater or in the air. Hearing is our ability to perceive sound by detecting vibrations that travel through our ears. The main purpose of the ear is to turn sound waves from the air into electrical signals that are interpreted by the brain.

Sound: Rapid Air Waves Through the Ear

Sound travels through the auricle and the auditory canal, a short tube that ends at the eardrum. Sound entering the outer ear travels through the middle ear and causes the eardrum and ossicles in the middle ear to vibrate. As it travels, it amplifies (gets louder) and changes from air to liquid. When the stapes moves, it pushes the oval window, which then moves the cochlea. The cochlea takes the fluid vibration of sounds from the surrounding semicircular ducts, translates them into signals sent to the brain by nerves like the vestibular nerve and cochlear nerve. The brain translates the information into recognizable sound patterns. It is a complex process but it occurs in a split-second of time.

Vocalized and Non-Vocalized Sound

The human ear can detect different tones and loudness levels, which can help a person determine the direction of something (locate where the sound comes from), and helps to pick out specific sounds despite lots of background noise. Specifically, when someone is speaking, the sounds may be vocalized or non-vocalized.

Vocalized sounds require a combination of air passing through the vocal cords and mouth shapes.

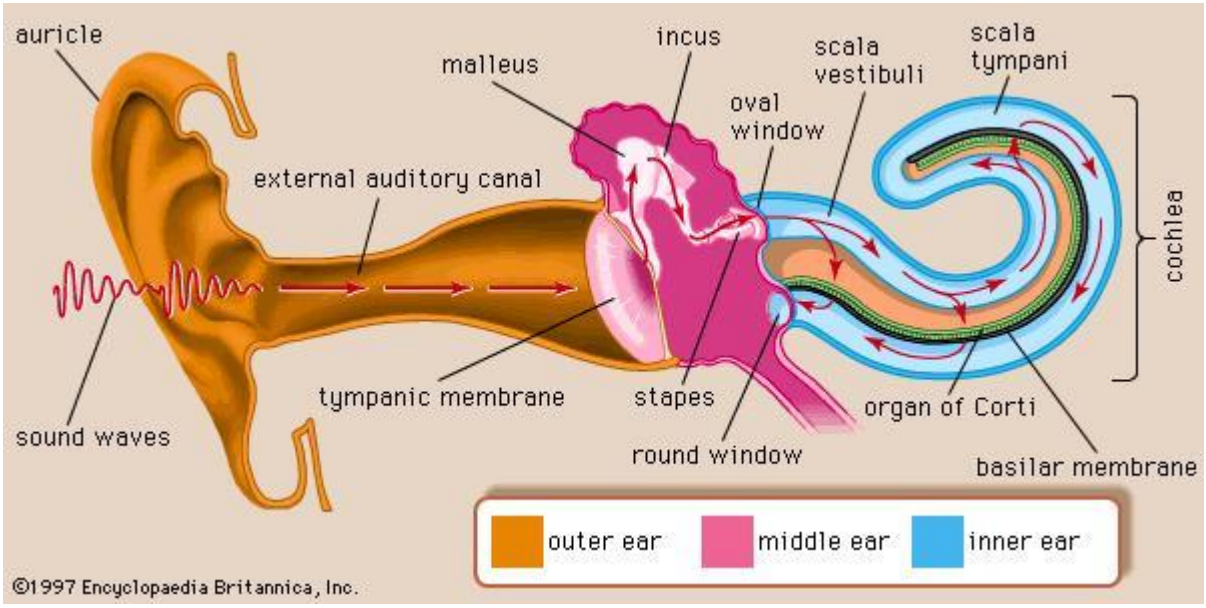
When a person is speaking, the vocal cords are in vibration. There is no closure of the throat or mouth with these sounds. And, in almost all languages, words must contain at least one vowel.

Non-vocalized sounds are created strictly from mouth shapes. Lip-reading is the process of visually detecting non-vocalized sounds. When a person is speaking, the quietest sounds are those that are actually easier to detect visually. When a person can see someone speak, they can understand him or her better. This combination of seeing what is heard contributes to a better sense of understanding.

Auditory Pathways

The auditory pathways begin in the nerve fibers in the inner ear, where sound waves get converted into nerve impulses. These impulses then travel via the auditory nerve to the highest cerebral levels in the cortex of the brain

MECHANISM OF HEARING



The mechanism of hearing. Sound waves enter the outer ear and travel through the external auditory canal until they reach the tympanic membrane, causing the membrane and the attached chain of auditory ossicles to vibrate. The motion of the stapes against the oval window sets up waves in the fluids of the cochlea, causing the basilar membrane to vibrate. This stimulates the sensory cells of the organ of Corti, atop the basilar membrane, to send nerve impulses to the brain.

The ear consists of three sections specializing in different functions. The outer ear consists of the pinna which focuses and collects sound waves into the ear tube (external auditory meatus); the sound waves cause the tympanic membrane (ear drum) to vibrate. In the middle ear, vibrations of the tympanic membrane are transmitted across to the membranous oval window by the movement of three ear ossicles (malleus, incus, stapes). A lever system between these bones and the relative area of contact of the malleus with the tympanic membrane and the stapes with the oval window amplifies the movement of the tympanic membrane. Finally there is the inner ear which consists of a complex system of canals and cavities within the skull bone. Auditory receptors are found here which help in the conduction of message to the brain for interpretation.

The sound waves are directed towards the ear canal by the pinna.

The waves that enter the canal are concentrated and made to strike against the tympanum.

The vibrations are picked up by the malleus on the other side.

These vibrations are transmitted to the fenestra ovalis via the incus and the stapes.

The vibrations that strike the oval window are amplified 22 times more than those that struck the tympanum.

These vibrations travel along the vestibular canal to the end of the cochlea and then to the tympanic canal. The vibrations are also transmitted via the Reisnner's membrane to the basilar membrane and then to the tympanic canal.

Note that the vibrations travel along the vestibular and tympanic canals in the opposite directions.

From the basilar membrane the vibrations are picked up by the sensory hair cells of the organ of corti and transmitted as action potentials to the neurons of the auditory nerve fibres.

The exact mechanism of transformation of the sound waves into the action potentials is not known.

The action potentials are then transmitted as nerve impulses to the auditory cortex of the brain through the auditory nerve