P.G.Diploma in Yoga Vijnan
Paper - III

HUMAN BIOLOGY

राष्ट्रियसंस्कृतविद्यापीठम्, तिरुपतिः
(मानितविश्वविद्यालयः)

Directorate of Distance Education

Rashtriya Sanskrit Vidyapeetha
(Deemed University)
Tirupati - 517 064 (A.P.)

HUMAN BIOLOGY

CONTENTS

INTRODUCTION TO HUMAN BIOLOGY FOR YOGA VIGNYAN STUDENTS

Human Biology is a fascinating subject and an interdisciplinary academic field which is closely related to biology, biological anthropology, nutrition and medicines which are in turn are related to human beings. In other words, Biology is the study of life, what life needs to survive, what makes life possible, how life evolves and changes, and how life forms interact with one another.

The word Biology is made up of two smaller words 'Bio' and 'logy'. Bio means life and Logy translates into a study of science. When we put these two words together, we get Bio-logy, or Biology, the science of life. Human Biology is a broad field, covering the minute workings of chemical machines inside our cells, to broad scale concepts of ecosystems and global climate change. Biologists study intimate details of the human brain, the composition of our genes, and even the functioning of our reproductive system. The Human Biology gives all the details of the various subjects interrelated with human biology.

As a student of yoga vignyan every one should be well aware of human biology. This forms the basis for movement of body parts during asanas and the chemical changes taking place at the mental level in case of pranayamas. So this course material is aimed at students of yoga vignyan to make easy understanding of human body starting from the minute structure, the cell (the basic unit of living structure) to various systems. It retains the straight forward approach to the description of body systems and their function (or how they work). The human body here is described system by system. The student must, remember that physiology is an integrated subject and that, although the systems are considered in separate sections, they all function together for the human body to operate as a healthy unit. The first chapter gives an overview of cell structure, the basic unit of the living being. Followed by system wise discussion. A section on introductory biochemistry is included, forming the basis of a deeper understanding of body function. There is a chapter on immunology (immunity), for better understanding of one's defense mechanism.

OBJECTIVE OR LEARNING OUTCOME

The topics will help student to understand human biology as a nut shell. After reading this student should be able to recollect and apply the knowledge of human biology in practical classes of asanas and pranayamas. Should also be able to apply the same, in future training sessions.

SECTION I

CELL - STRUCTURE & FUNCTIONS

1. CELL - STRUCTURE AND FUNCTIONS

The Cell:

1.1 Discovery of the Cell
1.2 Variation in Cell Number, Shape and Size
1.3 Cell Structure and Function (organelles)
1.4 Comparison of Plant and Animal Cells
1.5 Summary

Learning outcomes:

After studying this section you should be able to:

- **Describe the discovery of cell and its structure**
- **Explain the functions of the following cell organelles: Nucleus, mitochondria, ribosome's, endoplasmic reticulum, Golgi apparatus, lysosomes, microtubules and microfilaments.**
- **Compare between animal and plant cell**

Introduction:

Living organisms carry out certain basic functions. Different sets of organs perform the various functions. Basic structural unit of an organ is called Cell. The most basic similarity is that all living things are composed of one or more cells. This is known as the **Cell Theory**.

1.1 Discovery of the Cell:

In 1655, the English scientist Robert Hooke, while examining a dried section of cork tree with a crude light microscope, he observed small chambers and named them cells. Over the next 175 years, research led to the formation of the cell theory, first proposed by the German botanist Matthias Jacob Schleiden and the German physiologist Theodore Schwann in 1838 and formalized by the German researcher Rudolf Virchow in 1858.
In its modern form, this theorem has four basic parts:

1. The cell is the basic structural and functional unit of life; all organisms are composed of cells.
2. All cells are produced by the division of preexisting cells (in other words, through reproduction). Each cell contains genetic material that is passed down during this process.
3. All basic chemical and physiological functions - for example, repair, growth, movement, immunity, communication, and digestion - are carried out inside of cells.

4. The activities of cells depends on the activities of subcellular structures within the cell (these subcellular structures include organelles, the plasma membrane, and, if present, the nucleus)

1.2 Variation in Cell Number, Shape and Size:

There are millions of living organisms. They are of different shapes and sizes. Their organs also vary in shape, size and number of cells.

Number of Cells:

Human body has trillions of cells which vary in shapes and sizes. Different groups of cells perform a variety of functions. Organisms made of more than one cell are called **multicellular** organisms. An organism with billions of cells begins life as a **single cell** which is the fertilized egg. The fertilized egg cell multiplies and the number of cells increases as development proceeds.

The single-celled organisms are called **unicellular** organisms. A single celled organism performs all the necessary functions that multicellular organisms perform. A single-celled organism, like amoeba, captures and digests food, respires, excretes, grows and reproduces. Similar functions in multicellular organisms are carried out by groups of specialized cells forming different tissues. Tissues, in turn, form organs.

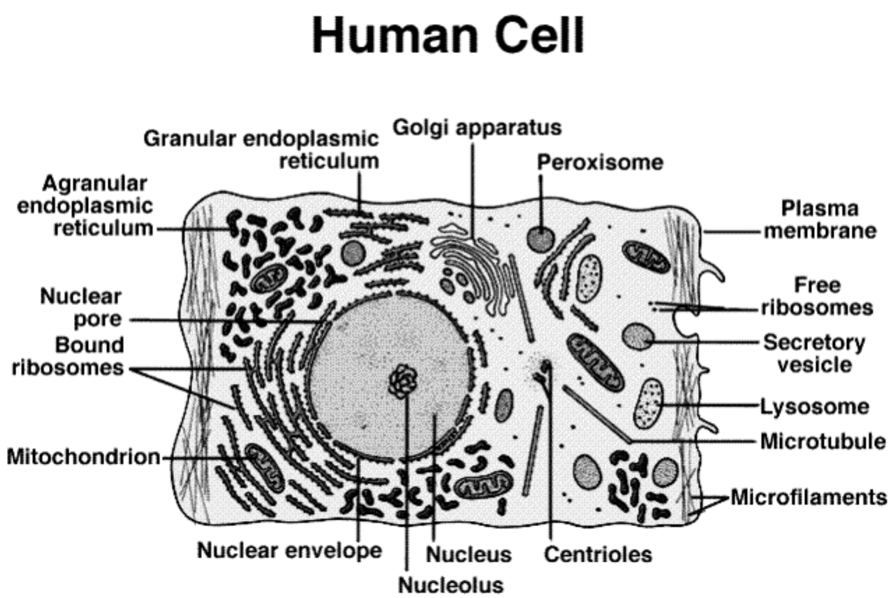
Shape of Cells:

Generally, cells are round, spherical or elongated. Some cells are long and pointed at both ends. They exhibit spindle shape. Cells sometimes are quite long. Some are branched like the nerve cell or a neuron. The nerve cell receives and transfers messages, thereby helping to control and coordinate the working of different parts of the body. Components of the cell are enclosed in a membrane. This membrane provides shape to the cells of plants and animals. Cell wall is an additional covering over the cell membrane in plant cells. It gives shape and rigidity to these cells.

1.3 Cell Structure and Function:

Each organ in the system performs different functions such as digestion, assimilation and absorption. Similarly, different organs of a plant perform specific/specialized functions. For example, roots help in the absorption of water and minerals. Each organ is further made up of smaller parts called **tissues**. A tissue is a group of similar cells performing a specific function.

Parts of the Cell



Cell Membrane or "Fluid Mosaic" Model:

The cell membrane functions as a semi-permeable barrier, allowing a very few molecules across it while fencing the majority of organically produced chemicals inside the cell. The basic components of a cell are cell membrane, cytoplasm and nucleus. The cytoplasm and nucleus are enclosed within the cell membrane, also called the plasma membrane. The membrane separates cells from one another and also the cell from the surrounding medium. The plasma membrane is porous and allows the movement of substances or materials both inward and outward. The cell membrane gives shape to the cell. In addition to the cell membrane, there is an outer thick layer in cells of plants called **cell wall**. This additional layer surrounding the cell membrane is required by the plants for protection. Plant cells need protection against variations in temperature, high wind speed, atmospheric moisture, etc.

Cytoplasm:

It is the jelly-like substance present between the cell membrane and the nucleus. Various other components, or **organelles**, of cells are present in the cytoplasm. These are mitochondria, Golgi bodies, ribosomes, etc.

Nucleus or the Cell's CPU:

It is an important component of the living cell. It is generally spherical and located in the centre of the cell. It can be stained and seen easily with the help of a microscope. Nucleus is separated from the cytoplasm by a membrane called the **nuclear membrane**. This membrane is also porous and allows the movement of materials between the cytoplasm and the inside of the nucleus. With a microscope of higher magnification, we can see a smaller spherical body in the nucleus. It is called the **nucleolus**. In addition, nucleus contains thread-like structures called **chromosomes**. These carry **genes** and help in inheritance or transfer of characters from the parents to the offspring. The chromosomes can be seen only when the cell divides. You can visualize genes as memory stick or CD which we use to carry data from one computer to another or we can carry music as well. Similarly genes carry genetic codes which are responsible for the unique physical character of an animal or a plant. Nucleus acts as control centre of the activities of the cell. The entire content of a living cell is known as protoplasm. It includes the cytoplasm and the nucleus. Protoplasm is called the living substance of the cell.

Endoplasmic Reticulum (ER):

The ER is a system of membranous tubular canals that begins just outside the nucleus and branches throughout the cytoplasm. if ribosomes are attached to the ER, it is called **ROUGH Endoplasmic Reticulum**. The function of rough ER is protein synthesis.

If no ribosomes are attached to the ER, it is called **SMOOTH Endoplasmic Reticulum**. The function of smooth ER is synthesis of lipids (Lipids are required for the growth of the cell membrane and for the membranes of the organelles within the cell and are often used to make **hormones**) and also to detoxify drugs and chemicals in the cell (takes place in peroxisome vesicles which are often attached to smooth ER).

The endoplasmic reticulum membranes provide an increase in surface area where chemical reactions can occur. The channels of the reticulum provide both storage space for products synthesized by the cell and transportation routes through which material can travel through other parts of the cell. The endoplasmic reticulum is also the cell's membrane factory. Phospholipids and cholesterol, the main components of membranes throughout the cell, are synthesized in the smooth ER. Most of the proteins leaving the endoplasmic reticulum are still not mature. They must undergo further processing in another organelle, the **Golgi apparatus**, before they are ready to perform their functions within or outside the cell.

Ribosomes:

Consist of **rRNA** and **proteins** each ribosome is made of 2 **non-identical subunits** rRNA is produced in the nucleolus and joined with proteins -- then migrate through the nuclear pore to the cytoplasm for final assembly. Ribosomes attach themselves to the endoplasmic reticulum. Function is **site** for **PROTEIN SYNTHESIS.**

Polysomes:

Free-floating structures within the cytoplasm. Generally produce proteins that will be used ***inside*** the cell. Consist of **clusters** of **ribosomes** bunched together, each of which is transcribing the same type of protein.

Golgi apparatus:

The Golgi Apparatus, named after an Italian anatomist of the nineteenth century, are **stacks** of **flattened**, **hollow cavities** enclosed by membranes, which are often continuous with the membranes of the endoplasmic reticulum. Located near to the nucleus and ER. The **stack** is made of a half-dozen or more ***saccuoles***. Looks like a flattened stack of hollow tubes. Each sac in the organelle contains enzymes that modify proteins as they pass through. Thus, the Golgi apparatus functions in **modification**, **assembly**, **packaging**, **storage** and **secretion** of substances. It receives newly manufactured protein (from the ER) on its inner surface. Within the Golgi apparatus, the proteins are **sorted out**, **labeled**, and **packaged into vesicles** that "*pinch off*" the outer surface of the saccuoles. These vesicles can then be transported to where they are needed within the cell, or can move to the cell membrane for export to the outside of the cell by **exocytosis**.

Vacuoles and Vesicles: Storage Depots:

A **VESICLE** is small **vacuole** vacuoles and vesicles are formed by: 1) pinching off from the Golgi apparatus 2) endocytosis of the cell membrane 3) extension of the ER membrane (for example, the large central vacuole of a plant cell). Are used for **transport** and **storage** of materials**. Plant cells** usually have one large **Central Vacuole**. The plant cell's central vacuole functions in 1) water storage 2) food storage 3) waste storage 4) cell support**.** is thought to be an extension of the ER membrane.

Lysosomes: Cellular "Stomachs"

Special vesicles which are formed by the Golgi apparatus. Contain powerful hydrolytic enzymes. Functions in 1) **cellular digestion** 2) **autodigestion** or disposal of damaged cell components like mitochondria 3) **breakdown of a whole cell** (by releasing their contents into the cell cytoplasm). For this reason, they are sometimes called "***suicide sacs***." Lysosomes are known to contain over 40 different enzymes that can digest almost anything in the cell, including **proteins**, **RNA**, **DNA**, and **carbohydrates**. Lysosomes also appear to perform other digestive processes, such as those connected with **phagocytosis** and **pinocytosis**. Lysosomes help destroy invading bacteria.

Peroxisomes are also single-membrane organelles. Peroxisomal enzymes remove hydrogen atoms from small molecules and join the hydrogen atoms to oxygen to form hydrogen peroxide, and then break it down into water and oxygen.

Mitochondria: the Cell's Powerhouse

Mitochondria are the **largest organelles** in an animal cell, after the nucleus. Are sausage-shaped or filamentous structures surrounded by a **double-layered membrane** Mitochondria vary in diameter from 0.5 to 1 micrometer and in length up to 7 micrometers (About the size of bacteria). The mitochondrion has **two membranes**: an outer and an inner. The inner is convoluted into shelf-like folds called ***cristae***. The enzymes responsible for cellular respiration are arranged, in assembly-line fashion, on the **cristae**. This is where energy is produced. Function is aerobic energy metabolism (also called cellular respiration). Converts **glucose** and **fatty acids** to **ATP**, the cell's primary energy molecule, as well as lesser amounts of other energy rich molecules. The overall formula for cellular respiration is: Carbohydrate + O2 " CO2 + H2O + **ENERGY** (i.e. ATP)**.** In the end, **38 molecules of ATP** (adenosine triphosphate) are formed for every molecule of sugar that is used up in respiration.

Besides supplying energy, mitochondria also help control the concentration of water, calcium, and other charged particles (ions) in the cytoplasm. Mitochondria have some of their own DNA molecules and ribosomes that resemble those of **prokaryotic** cells. Human mitochondrial DNA is a closed, circular molecule having 16,569 nucleotide pairs long. Mitochondria are also self-replicating. They "reproduce" by splitting in half. Mitochondria may have evolved from bacteria that once developed a close relationship with primitive eukaryotic cells, and then lost the capacity to live outside the cell. Another interesting characteristic of human mitochondria is fact that all of a person's mitochondria are descendants of those of his or her mother.

Chloroplasts & Plastids: Food Makers for the World:

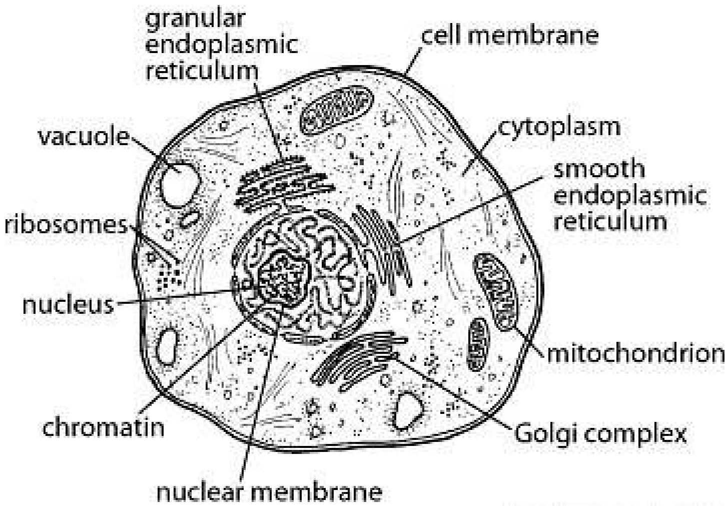
Found in plant cells only. Membrane-bound structures that usually contain **pigments** and give plant cells their colors. The most prominent plastid is the chloroplast. some plastids are storage bodies for starch, proteins, oils.

Chloroplast:

These are the **double-membrane bound organelles** in which **PHOTOSYNTHESIS** (the conversion of light energy to carbohydrates) occurs. **Chlorophyll** is the chemical that absorbs the energy of the sun to provide the energy required for reducing **CO2** to **Glucose**. Process is basically the **opposite** of cellular respiration: CO2 + H2O + ENERGY (i.e. ATP) “Carbohydrate + O2 inside the chloroplast are membranous stacks of ***grana*** (look like **pancakes**!) Where the chlorophyll is located.

Centrioles:

Animal cells have two cylindrical bodies, called **centrioles**, located near the nucleus. The centrioles appear as sets of triple tubules. Centrioles play a part in cell division. Centrioles are short cylinders with a 9+0 pattern of microtubular triplets. Each animal cell has one pair of centrioles lying at right angles to each other next to the nucleus centrioles which **give** rise to basal bodies. Basal bodies direct the formation of cilia and flagella which assist in the formation of the spindle apparatus in cell division.



1.4 Comparison of Plant and Animal Cells

There are a few differences between a plant and animal cell.

1. Plant cells have a cell wall surrounding the cell membrane, and animal cells only have a membrane.
2. Plant cells contain chloroplasts which are used for photosynthesis.
3. Plant cells have a large vacuole (it's like a fluid sack), compared to an animal cell.
4. Animal cells are 'blobby', but cells in plants are more structured due to the cell wall, and form a lattice like structure which helps with rigidness.

1.6. Summary:

- Prokaryotic and eukaryotic cells are the two main types of cells. Eukaryotic cells are more complex and have membrane-bound organelles. Humans are made entirely of eukaryotic cells.
- The surface-to-volume ratio determines when a cell needs to divide.
- The plasma membrane is made of a phospholipids' bilayer with proteins and cholesterol molecules interspersed. Surface carbohydrates are used for cell identification.
- The functions of the plasma membrane are to maintain the cell's integrity, regulate movement of substances into and out of the cell, aid in cell-to-cell recognition, promote communication between cells, and stick cells together to form tissue and organs.
- The plasma membrane functions in endocytosis and exocytosis.
- Molecules also cross the plasma membrane along a concentration gradient by simple diffusion and facilitated diffusion. Molecules concentrate by active transport, which requires energy.

- Water moves across the plasma membrane by osmosis.
- Organelles are contained in the cytoplasm and are surrounded by a membrane.
- The nucleus contains the genetic information for the organism and the nucleolus produces ribosomal RNA used in the synthesis of proteins.
- Smooth endoplasmic reticulum functions in communication and in the production of plasma membrane. Rough endoplasmic reticulum contains ribosome's and functions to produce proteins.
- The Golgi complex packages cell products for export from the cell.
- Lysosomes contain substances that can digest diseased or dying cells as well as invaders.
- Mitochondria are the energy-processing center of the cell.
- Microtubules, microfilaments, and intermediate filaments support the cell structurally. Microtubules and microfilaments also function in cell movement.
- Cells use two pathways, cellular respiration and fermentation, to break down glucose and turn it into usable energy in the form of ATP.
- Cellular respiration requires oxygen and produces 36 ATP through the three phases of glycolysis, the citric acid cycle, and the electron transport chain.
- Fermentation is the breakdown of glucose without oxygen. In animals the end product is lactic acid, while in plants it is alcohol. In both cases only two ATP are generated.

Self assessment questions:

1. Explain the structure and functions of following cellular components

Call Membrane, Nucleus, Mitochondria, Golgi apparatus, Endoplasmic Reticulum, Lysosomes

Section II

Communication

- **The blood**
- **The cardiovascular**
- **system**
- **The lymphatic system**
- **The nervous system**
- **The special senses**
- **The endocrine system**

2. THE BLOOD

Learning outcomes:
After studying this section, you should able to:

- **Describe the functions of blood and chemical composition of plasma**
- **Discuss the structure, function and formation of red blood cells.**
- **Discuss the functions and formation of different white blood cells.**
- **Outline the role of platelets in blood clotting mechanism.**
- **Describe blood grouping systems**

Introduction:

Blood is a red colored, thick and slightly alkaline, fluid which keeps circulating through the blood vessels in our body. It is a specialized liquid connective tissue.

Functions of the Blood –

Have three major functions;
1) transportation-Blood transports materials to and from all the cells of the body Wastes produced by the cells carried away in the blood to organs which remove the wastes.

2) Regulation-Blood acts as a regulator absorb heat from warm areas of the body and release the heat in cooler areas. The blood usually maintains a constant pH and water balance.

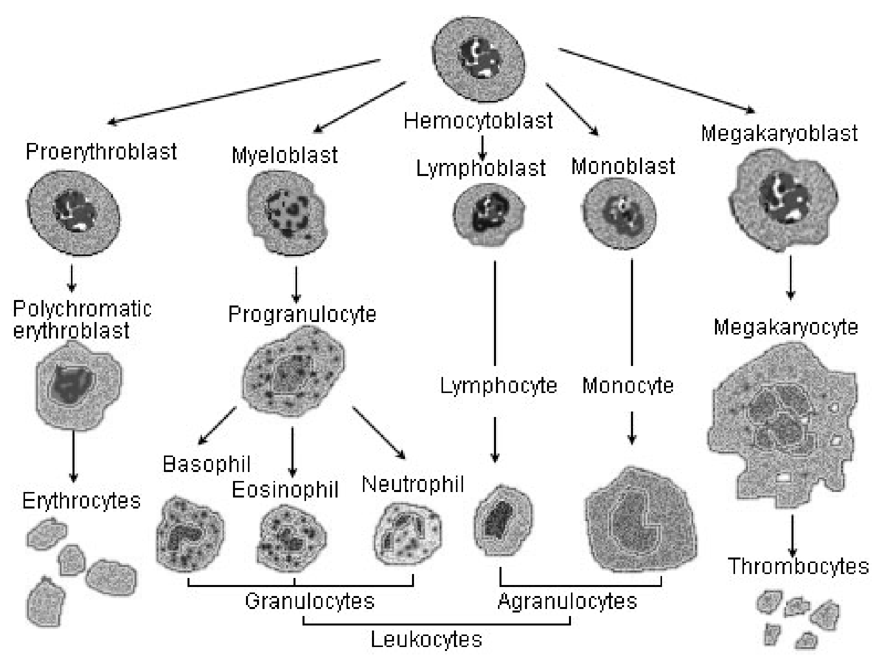
3) protection- Blood also protects the body. It holds specialized cells and chemicals that defend the body against diseases. Blood has the ability to clot, preventing the body from loosing large amounts of blood due to an injury.

The Components of the Blood - The liquid part of the blood is called plasma. Plasma takes up about 55% of the total volume of the blood. The remaining 45% of the blood is made up of formed elements (blood cells, ie, red blood cells, white blood cells, and platelets). An adult human has between four and six liters of blood in the body.

1) Plasma - Plasma is the clear liquid portion of the blood. 90% of plasma is water. The other 10% contains many types of molecules, including nutrients, glucose, vitamins, cellular wastes, salts and proteins. There are three major types of proteins which exist in plasma. These are albumin, fibrinogen, and globulins. Each protein has a specific function to perform. The albumin keeps water from leaving the blood and entering the surrounding cells by osmosis. It does this by helping to keep the concentration of the water within the blood the same as the concentration in the body tissues. The fibrinogen aids in the clotting of the blood. Some globulins transport proteins and other substances from one part of the body to the next. Other globulins are known as antibodies, which help to fight of infection. Antibodies are proteins that attach to and help destroy foreign substances in the body.

2) Formed elements:

2.2.1Red Blood Cells - These cells are red and carry oxygen and carbon dioxide. They are present in huge numbers within the blood. The human body contains 30 trillion red blood cells, or approximately 5 million cells per cubic millimeter of blood. The red blood cells transport oxygen from the lungs to the tissues in the body. They also carry carbon dioxide from the body tissues to the lungs. In humans, the matured red blood cells do not contain nuclei. Their cytoplasm is filled with an iron-containing protein called hemoglobin. Hemoglobin is the substance that gives the blood its red color. Human red blood cells are constructed by bone marrow and have and a average life span of up to 120 days. New cells are produced at the same rate red blood cells are destroyed. This occurs at pace of about 2 million per second. The old red cells are removed from the body by the spleen and liver and are then broken down. The iron from the hemoglobin is then collected and reused.



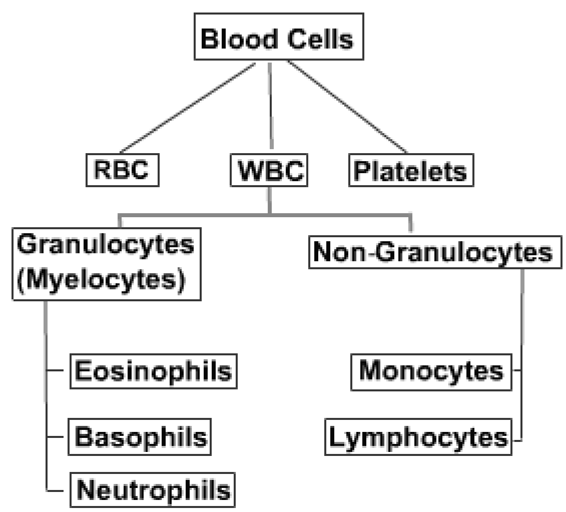
When a person has an insufficient amount of hemoglobin or too few red blood cells, this is referred to as anemia. Both of these conditions lower the amount of oxygen that can be carried throughout the blood. Anemia causes the cells not to receive the proper amount of oxygen. This is a hereditary disorder, and is caused by an abnormal form of hemoglobin.

2.2.2 White Blood Cells - There is a variety of colorless blood cells which make the white blood cells, or known as leukocytes. These white blood cells are defenders for the body. They protect the body from bacteria and viruses, which are disease-causing organisms. Unlike red blood cells, the white blood cells contain a nucleus and are larger than the red blood cells. There are fewer white blood cells than white, but there are still about 60 billion in an adult human body. The bone marrow and lymphatic tissue produce approximately 1 million white blood cells every second. The white bloods cells are distribute themselves throughout the body by moving through the circulatory system. When there is an infection within the body, the white blood cells collect in the infected area and attack the foreign organisms.

Diapedesis: white blood cells can move out of capillaries & into tissues, use amoeboid motion with flowing cytoplasmic extensions to move through tissue spaces positive chemotaxis: follow chemical trail of other WBCs to sites of infection

Leukocytosis: condition of increased WBC count during infection (normal response)

Two categories of WBC:



Granulocytes: WBCs with membrane-bound cytoplasmic granules

1. Neutrophils: most numerous WBCs (>50% of WBC volume),~ 2x size of RBCs. very fine, lightly staining granules containing enzymes or antibiotic-like proteins (defensins)

Nucleus has from **3-6 lobes** (also known as **PMNs** (polymorphonuclear Leukocytes))
Phagocytic cells (**kill** bacteria & fungi by **oxidation**), chemically attracted to sites of inflammation

2. Eosinophils: ~ 1-4% of WBC population; about size of Neutrophils
• **Nucleus** with **2 lobes** (like telephone receiver) large, **red-staining granules** with enzymes
• **digest** invading **parasitic flatworms & roundworms** with digestive enzymes
• **Phagocytic**; ingest immune complexes during allergic reactions

3. Basophiles: 0.5% of WBC population (rare); about size of Neutrophils large **purplish-black-staining granules** containing **histamine**-histamine: inflammatory chemical - vasodilator & chemo attractant –released by basophiles

Agranulocytes: WBCs without visible granules

1. Lymphocytes: small, medium & large sizes. Large spherical nucleus occupies most of cell volume. Most lymphocytes are in **lymphatic** organs
• **T lymphocytes:** fight virus-infected cells & tumor cells
• **B lymphocytes:** give rise to plasma cells that produce antibodies (immunoglobulin's)

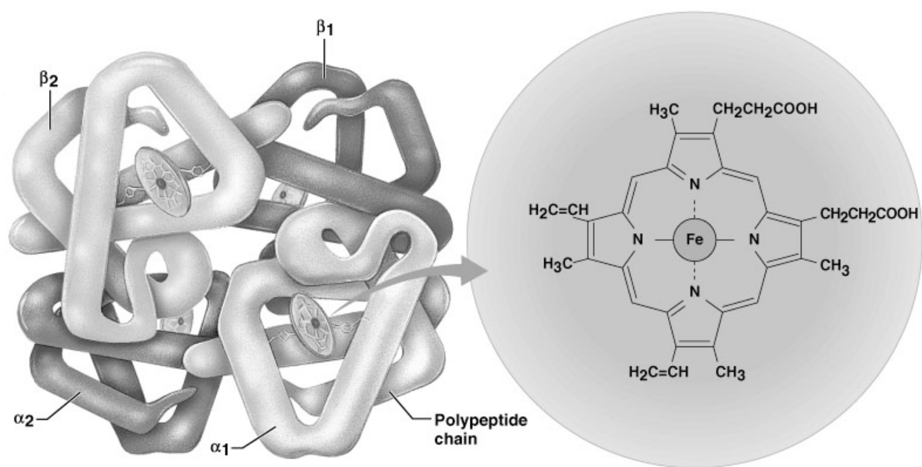
2. Monocytes: largest WBC's (2-3x size of RBCs).Large U or kidney-shaped nucleus. Differentiate into **macrophages** in tissues. Macrophages are phagocytic cells that destroy bacteria & help in immune response against viruses

The lymphocytes take care of the production of antibodies and the cells that destroy certain substances and uncommon cells. Usually, there are 7000 to 10 000 white blood cells present per cubic millimeter of blood. When an infection of the blood occurs, the numbers of white blood cells may increase to 30,000 or more per cubic millimeter.

2.2.3 PLATELETS - The part of the blood which is involved in the clotting of blood. Platelets are formed when bits of cytoplasm are pinched. Even though these bits of cytoplasm contain no nuclei, they surrounded by a membrane. There about a total of 1.5 trillion platelets in the blood of an adult human. There are about 300,000 platelets existing in a cubic millimeter of blood. Their life lasts for about seven days and is produced at about 200 billion per day.

2.2.4 HEMOGLOBIN:

Hemoglobin is the protein molecule in red blood cells that carries oxygen from the lungs to the body's tissues and returns carbon dioxide from the tissues to the lungs. Hemoglobin is made up of four protein molecules (globulin chains) that are connected together. The normal adult hemoglobin (Hbg) molecule contains 2 alpha-globulin chains and 2 beta-globulin chains. In fetuses and infants, there are only a few beta chains and the hemoglobin molecule is made up of 2 alpha chains and 2 gamma chains. As the infant grows, the gamma chains are gradually replaced by beta chains. Each globulin chain contains an important central structure called the heme molecule. Embedded within the heme molecule is iron that transports the oxygen and carbon dioxide in our blood. The iron contained in hemoglobin is also responsible for the red color of blood. Hemoglobin also plays an important role in maintaining the shape of the red blood cells. Abnormal hemoglobin structure can, therefore, disrupt the shape of red blood cells and impede its function and its flow through blood vessels.



(a) Hemoglobin **(b) Iron-containing heme group**

Hemoglobin is usually measured as a part of the complete blood count (CBC) from a blood sample. Several methods exist for measuring hemoglobin, most of which are done currently by automated machines designed to perform several different tests on blood. Within the machine, the red blood cells are broken down to get the hemoglobin into a solution. The free hemoglobin is exposed to a chemical containing cyanide which binds tightly with the hemoglobin molecule to form cyanmethemoglobin. By shining a light through the solution and measuring how much light is absorbed (specifically at a wavelength of 540 nanometers), the amount of hemoglobin can be determined.

Normal Hemoglobin Values

The hemoglobin level is expressed as the amount of hemoglobin in grams (gm) per deciliter (dl) of whole blood, a deciliter being 100 milliliters.

The normal ranges for hemoglobin depend on the age and, beginning in adolescence, the gender of the person. The normal ranges are:

Newborns: 17-22 gm/dl

One week of age: 15-20 gm/dl

One month of age: 11-15gm/dl

Children: 11-13 gm/dl

Adult males: 14-18 gm/dl

Adult women: 12-16 gm/dl

Men after middle age: 12.4-14.9 gm/dl

Women after middle age: 11.7-13.8 gm/dl

All of these values may vary slightly between laboratories. Some laboratories do not differentiate between adult and "after middle age" hemoglobin values.

Low hemoglobin level means-ANEMIA

Low hemoglobin is referred to as anemia. There are many reasons for anemia. Some of the more common causes are:

- loss of blood (traumatic injury, surgery, bleeding colon cancer or stomach ulcer),
- nutritional deficiency (iron, vitamin B12, folate),
- bone marrow problems (replacement of bone marrow by cancer,
- suppression by chemotherapy drugs,
- kidney failure), and
- Abnormal hemoglobin (sickle cell anemia).

High Hemoglobin Level

Higher than normal hemoglobin levels can be seen in people living at high altitudes and in people who smoker. Dehydration produces falsely high hemoglobin which disappears when proper fluid balance is restored.
Some other infrequent causes are:

- Advanced lung disease (for example, emphysema),
- Certain tumors,

- A disorder of the bone marrow known as polycythemia rubra vera, and
- Abuse of the drug erythropoietin (epogen) by athletes for blood doping purposes.

2.3 Coagulation of blood

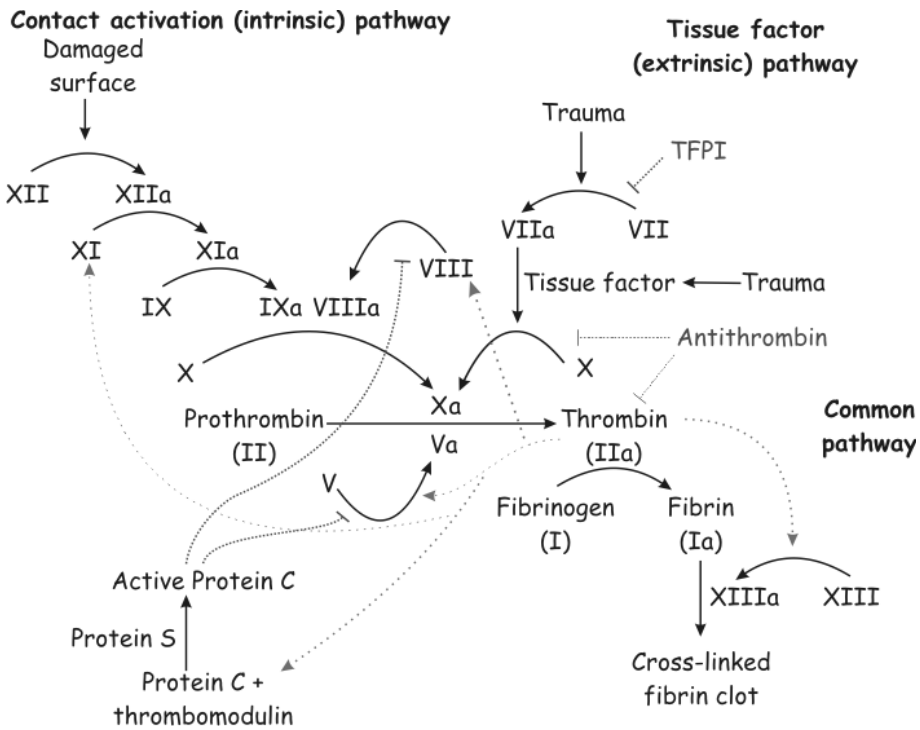
You must have, sometime or the other, got a cut on your finger and seen blood flowing out of it . You would have noticed that after a few minutes, the blood flow stops, as the blood thickens and forms a lump. This lump is called clot. The process of thickening of blood is called **coagulation or clotting of blood**. We are lucky that the blood clots and the bleeding stop. If it did not, a person with a very small wound would lose a lot of blood and die. When blood vessels are injured, a sequence of reactions takes place to prevent loss of blood. This problem is resolved by the complex mechanism of clotting. The clots form a temporary barrier to prevent blood loss until the vessel walls have healed.

The Clotting Process - When a blood vessel is injured, platelets begin to collect near the injury, which forms a barrier known as the platelet plug. When the platelets come in contact with an injured area, they swell up, become sticky, and release certain chemicals. Blood clotting requires many precise reactions to maintain a certain balance between quick and efficient clot formation. This balance has to be kept exact so that your blood will not clot at the wrong time.

Prothrombin and fibrinogen are two proteins that are produced by the liver that are always present in the plasma of the blood. The injured tissues and platelets release Prothrombin activator and calcium ions (Ca^{2+}) to change Prothrombin into the enzyme thrombin. Then the thrombin splits two short amino acid chains from each fibrinogen molecule. The ends of the fibrinogen then join together, forming threads of fibrin. These fibrins surround the platelet plug in the damaged area of the blood vessel and provide the shape for the clot. Red blood cells are present within the fibrin which makes the clot appear red. After this the clot stops the bleeding, gets smaller, and hardens. Over time the injury is repaired by the growth of new cells which will replace the cells lost because of the injury. When all the healing has finished an enzyme called plasmin in activated and dissolves the fibrin clot.

Thromboplastin + Prothrombin
(From blood platelets) (Plasma protein)
Ca++ions
Thrombin
Fibrinogen Fibrin
(Plasma protein) (Insoluble fibers)
FIBRIN + R.B.C CLOT (Scab) Prevents blood loss

Coagulation of blood takes place in two pathways intrinsic and extrinsic pathways as shown below,

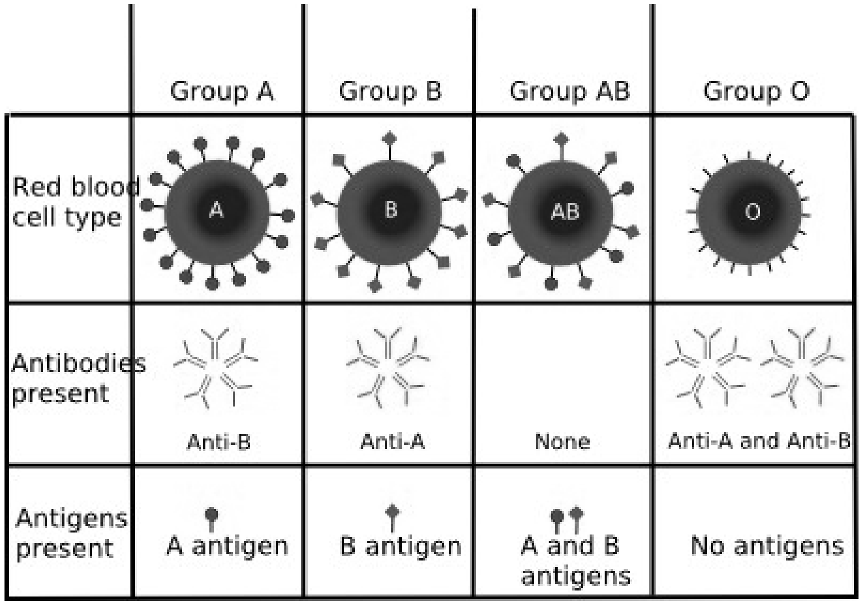


Some Clotting Problems - There are many conditions which can cause the clotting process to be disrupted. People, who have the hereditary disease hemophilia, lack the essential Factor VIII (Antihaemophilic Globulin, or AHG) of blood clotting. These people can receive certain injections which will enable their blood to clot properly. If you don't have enough platelets in the blood or lack vitamin K, this will reduce the ability to clot.

An **anticoagulant** is a substance that prevents coagulation; that is, it stops blood from clotting. A group of pharmaceuticals called anticoagulants can be used *in vivo* as a medication for thrombotic disorders. Some chemical compounds are used in medical equipment, such as test tubes, blood transfusion bags, and renal dialysis equipment.

2.4 Blood Groups

The ABO grouping and the Rh factor are the most often used to determine blood type. The physician Karl Landsteiner determined that there were four major blood groups among humans. He designated them as A, B, AB, and O. This same system is used today. It is now a known fact that blood type is based on a type of glycoprotein present in the red blood cells. Type A blood has A-type glycoprotein’s, type B blood has B-type glycoprotein’s, type AB blood has both of these glycoprotein’s, and type O blood has neither of them. The A and B glycoprotein’s function as antigens, and they combine specifically with antibody molecules. When this kind of reaction occurs, the red blood cells agglutinate (join together). People who have type O blood are called universal donors. It can be given to anyone without fear of agglutination because it does not contain any antigens that could combine with anti-a or anti-b antibodies.



The Rh factors are another group of antigens found on the surface of red blood cells. They are called Rh factors simply because they were first discovered in rhesus monkeys. About 85% of humans are Rh^+, which means they have Rh factors on their red blood cells. The remaining 15% of humans are Rh^-, which means that they do not contain the Rh factor. These Rh factors may present a problem when a mother is Rh^- and the baby is Rh^+. If their blood is to mix and some of the Rh^+ blood cells enter the mother's circulatory system, her immune system will from anti-Rh antibodies. In future pregnancies, these anti-Rh antibodies could enter the babies' blood stream. If these were to happen and the baby was Rh^-, the antibodies would destroy the baby's red blood cells. This problem can be eliminated if the mother is given an injection of anti-Rh antibodies to destroy the baby's Rh^+ cells shortly after the birth of each Rh^+ child. This will prevent the mother's immune system from forming its own antibodies.

2.4.1 Blood transfusion:

When excessive blood is lost from the body either due to an accident, hemorrhage or during surgery (operation), doctors transfer blood from a healthy person (Donor) to the patient (Recipient). This is called Blood **Transfusion.** When blood transfusion is needed, the red cells blood selected must belong to a group which will not be affected by any antibody in the patient's plasma. **Clumping** of donor's blood (Agglutination) may take place on transfusion if the blood group of donor does not match with that of the recipient. Clumping is a condition where the antibodies present in the plasma of recipient link donor's blood cells with each other. Agglutination is the process by which red blood cells clump together when the antigens on their surface react with complementary antibodies.

Matching of Blood Group, Safe and Unsafe Transfusion of Blood.

Those who can safely Receive blood of donor type	Donor	Blood group types who cannot
O, A, B, AB	Type O	
A, AB	Type A	O, B
B, AB	Type B	O, A
AB	Type AB	O, A, B,

Blood group of O type can be given to all groups. It is thus the **Universal** Donor. This is because there are no antigens in the blood of Group O. Blood groups AB can receive blood from all other groups and is thus called **Universal Recipient**. No Antibodies in the blood of Group AB, so no reaction with antigens of other blood groups.

2.5 summary

- Blood transports nutrients to cells and waste products from cells. It also defends against disease and regulates body temperature.
- Blood consists of plasma, the liquid matrix, and formed elements.
- There are three types of plasma proteins. Albumins aid in the balance of water flow between blood and cells. Globulins transport lipids and fat-soluble vitamins, and clotting proteins stop blood flow at the site of an injury.
- Formed elements of the blood are platelets, leukocytes (WBCs), and erythrocytes (RBCs). Undifferentiated cells called stem cells give rise to the formed elements.
- Leukocytes fight off disease and help remove wastes, toxins, and damaged or cancerous cells. The five types of leukocytes are specialized for different roles in the bodyís defense mechanism.
- Erythrocytes contain hemoglobin, an iron-containing protein that transports oxygen.
- Erythrocytes are formed in the red bone marrow under the control of the hormone erythropoietin. Worn and dead cells are broken down in the liver and spleen.
- Anemia is a reduction in the bloodís ability to carry oxygen. There are several forms of anemia including iron-deficiency anemia, pernicious anemia, and hemolytic anemias.

- Leukemia is a cancer of the WBCs that causes the production of large numbers of ineffective cells. Infectious mononucleosis is a highly contagious viral disease of lymphocytes.
- Blood types are determined by the presence of antigens on the cell surface. Oneís plasma contains antibodies against the antigens of foreign blood types causing agglutination. The major blood types are ABO and Rh.
- The prevention of blood loss involves three mechanisms: blood vessel spasm to restrict the loss of blood, platelet plug formation, and clotting. Clotting is a series of chemical changes in blood proteins resulting in the production of protein fibers that form a mesh that traps red blood cells and forms the clot.
- Hemophilia is an inherited condition of the blood resulting in a failure to clot properly.

Self assessment questions:

1. Add a note on composition of blood?
2. Name the plasma proteins and functions of blood?
3. Explain the extrinsic and intrinsic mechanism of blood clotting?
4. Name the blood group systems and explain ABO system of blood grouping?
5. Describe the two abnormal types of hemoglobin?
6. Name the clotting factors?
7. Describe the structure of hemoglobin?
8. What is blood transfusion and explain the basis of blood transfusion?
9. What are the normal hemoglobin levels and what is anemia?

3. THE CARDIOVASCULAR SYSTEM

3.1 Anatomy of Heart and blood vessels

3.2 Innervations of Heart

3.3 Properties of Cardiac muscles

3.4 Control of Cardiac cycle and circulation

3.5 Cardiac output

3.6 Blood Pressure

3.7 The Circulation

3.8 Key concepts

3.9 Summary

INTROIDUCTION:

The cardiovascular system is a wide network system that performs two major tasks: It delivers oxygen and nutrients to body organs and removes waste products of metabolism from tissue cells. Its major components are the heart—a muscular pump— and a circulatory system of large and small elastic vessels that transport blood throughout the body. In the course of one day, the amount of blood pumped through the heart of a normal healthy adult at rest reaches approximately 2,100 gallons.

3.1 ANATOMY OF HEART

Learning outcomes:

After studying this section, you should able to:

- **Describe the structure of heart and its position within the thorax**
- **Trace the circulation of the blood through the heart and the blood vessels in rest of the body**
- **Should outline the conducting system of heart.**

The heart, the central organ of the cardiovascular system, is located between the two lungs in the middle of the chest. Two-thirds of the heart lies to the left of the breastbone and one third to the right. Placing a hand on the chest, we can feel the heartbeat on the left side of the rib cage because in that spot, the bottom left corner of the heart, which is somewhat tilted forward, here it comes close to the surface of the body. The adult heart is about the size of two clenched fists. It is shaped like a cone and weighs about 7 to 15 ounces, depending on the size and weight of the individual.

3.1.1 THE CHAMBERS OF HEART :

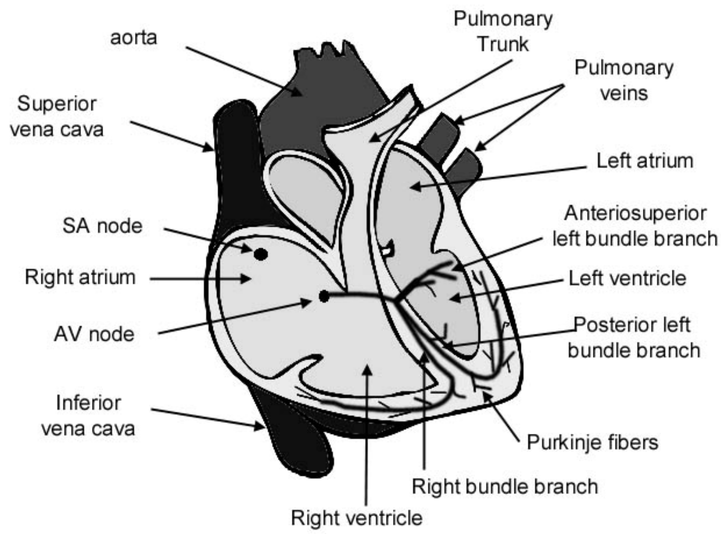
The human heart is divided into four chambers—

1. Right atrium
2. Right ventricle
3. Left atrium
4. Left ventricle.

The walls of the chambers are made of a special muscle, the myocardium that contracts rhythmically under the stimulation of electrical currents. The left and right atria and the left and right ventricles are separated from each other by a wall of muscle called the septum. Blood returning from the body through the venous system enters the heart through the right atrium, where it collects and is then pumped to the right ventricle. Each time the right ventricle contracts; it propels this blood, which is low in oxygen content, into the lungs, where it is enriched with oxygen. Pulmonary veins return the blood to the left atrium, which contracts and sends it to the left ventricle. The left ventricle, the main pumping chamber of the heart, ejects the blood through the aorta into the major circulatory network. Because it delivers blood to the entire body, this ventricle works harder than all other chambers; as a result, its walls are two to three times thicker than the walls of the right ventricle.

3.1.2 THE HEART VALVES :

Blood in the heart is kept flowing in a forward direction by a system of four one-way valves, each closing off one of the heart's chambers at the appropriate time in the cardiac cycle. The valves open to let the blood through when the chambers contract, and snap shut to prevent it from flowing backward as the chambers relax. The valve system also helps maintain different pressures on the right and left sides of the heart. The valves differ significantly in structure. The two valves separating the ventricles from the circulatory system are called semilunar valves. At the juncture of the right ventricle and the pulmonary artery lies the pulmonary valve. It consists of three cusps, or flaps of tissue, that open freely when the right ventricle contracts and blood is ejected into the lungs, and then fall back as the ventricle relaxes. The other semilunar valve, the aortic valve, lies between the left ventricle and the aorta and also has three cusps. It is flung open when the left ventricle squeezes down to propel blood into the main circulation. When the left ventricle relaxes, the pressure in the aorta pushes the valve closed. The ventricles are separated from the atria by valves that, in addition to the cusps, have thin but strong cords of fibrous tissue. When the ventricles contract, small muscles in their walls, called papillary muscles, pull the cords, which act as guide wires, and control the closure of the valve leaflets, preventing them from flapping too far backward. The valve located between the left ventricle and left atrium is a cone-shaped funnel called the mitral valve. It has two leaflets that are remarkably mobile and can open and close rapidly. The corresponding valve between the right ventricle and right atrium is called the tricuspid valve. As its name suggests, it has three cusps, or leaflets, that are thinner than those of the mitral valve.



3.1.2 ENDOCARDIUM AND PERICARDIUM OF HEART :

On the inside, the heart is lined with a protective layer of cells that form a smooth membrane called the endocardium. On the outside, the heart is encased in a two-layered fibrous sac called the pericardium, which extends to cover the roots of the major blood vessels. The inner layer of the pericardium is attached to the heart muscle, while the outer layer, connected by ligaments to the vertebral column, the diaphragm, and other body structures, holds the heart firmly in place. The layers are separated by a thin film of lubricating fluid that allows the heart to move freely within the outer pericardium.

3.1.3 CORONARY ARTERIES AND VEINS:

The heart supplies blood to itself through two coronary arteries, the right and the left, which leave the aorta about 1/2 inch above the aortic valve and run around the outside of the heart. Both arteries lie in grooves on the outside of the heart muscle and branch off into a system of smaller vessels and capillaries that supply the muscle fibers. After giving off its oxygen in the capillaries, the blood travels through coronary veins and drains directly into the right atrium, where it joins the venous blood from the rest of the body. When the heart is working harder than usual, the coronary arteries dilate to increase oxygen supply to the heart muscle. During extreme physical exertion, flow in these arteries may increase by five to six times. The better an individual’s physical condition, the more efficient is his or her heart in using the blood supply available. When blood supply is insufficient to meet the increased requirements in *oxygen* and nutrients and to wash away waste materials, the heart aches, just as other muscles might ache from an excessive workload. The lack of oxygen stimulates nerve cells, and chest pain, or angina pectoris, is noted. In contrast to other muscles of the body, however, the heart cannot stop for rest without devastating consequences.

3.1.4 THE CONDUCTION SYSTEM OF HEART:

Electrical currents that regulate the heart rhythm originate in cells of the heart muscle (myocardium) and travel through a network of specialized fibers referred to as the heart's conduction system. Its major elements include the sinus or sinoatrial node, the atrioventricular or AV node, the bundle of His, and the Purkinje fibers. The sinus node, known as the heart’s pacemaker, is a microscopic bundle of specialized cells located in the top right corner of the heart. Any portion of the heart muscle can generate electrical impulses, but in normal function, the impulses originate in this pacemaker. If the pacemaker’s function is disrupted, another part of the conduction system can take over the impulse-firing task. Impulses are transmitted through muscle fibers of the two atria to the atrioventricular node, located on the juncture between the right and left sides of the heart, in the area where the right atrium and right ventricle meet. From the atrioventricular node, they travel along the bundle of His and the Purkinje fibers-fibrous pathways named after the scientists who first described them — through the muscles of the right and left ventricles.

3.2 INNERVATION OF THE HEART:

The first development of the heart takes place independently of its innervation. Later, though, three differing sources for cardiac innervations can be found. The parasympathetic innervation (cholinergic system) arises from cardiac components of the cranial neural crest cells. The neurons of the cardiac ganglia, which represent parasympathetic neurons of the second order, migrate directly from the neural crest into the heart. Somewhat later, the axons of the first order nerves obtain access to the heart via the vagus nerve. The parasympathetic innervation slows the heartbeat.

The sympathetic nerve fibers (adrenergic system), which speed up the heartbeat as well as promote the positive inotropism of the cardiac musculature, arise from the thoracic sympathetic ganglia that in their turn come originally from the thoracic neural crest cells. The third component of the innervation comes directly from the vagus nerve. These are sensory nerves that arise from the ectodermal placode of the nodose ganglion.

3.3 PROPERTIES OF CARDIAC MUSCLES :

-Rhythmicity: capability of rhythmic self-excitation therefore no need for external control
-conductivity: conduction of action potential along specialized muscle cells.
-Excitability: ability of muscle fibers to get excited.
-Contractility; ability of cardiac muscle to contract.
It also has a long refractory period meaning it can’t tetanus

3.4 THE CARDIAC CYCLE

Learning outcomes:

After studying this section, you should able to:

- **Relate the cardiac electrical activity of the heart to the cardiac cycle**
- **Describe the main factors determining heart rate and cardiac output**

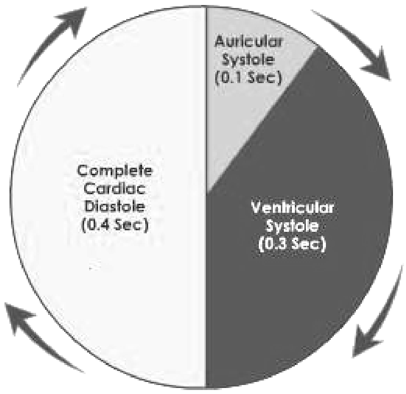
Electrical activity coordinates the rhythmic contraction and relaxation of the heart's chambers known as the cardiac cycle. Most currents in the heart are less than a millionth of an ampere (the current running through a 100-watt bulb is approximately 1 ampere), but they exert a powerful influence on the heart muscle.

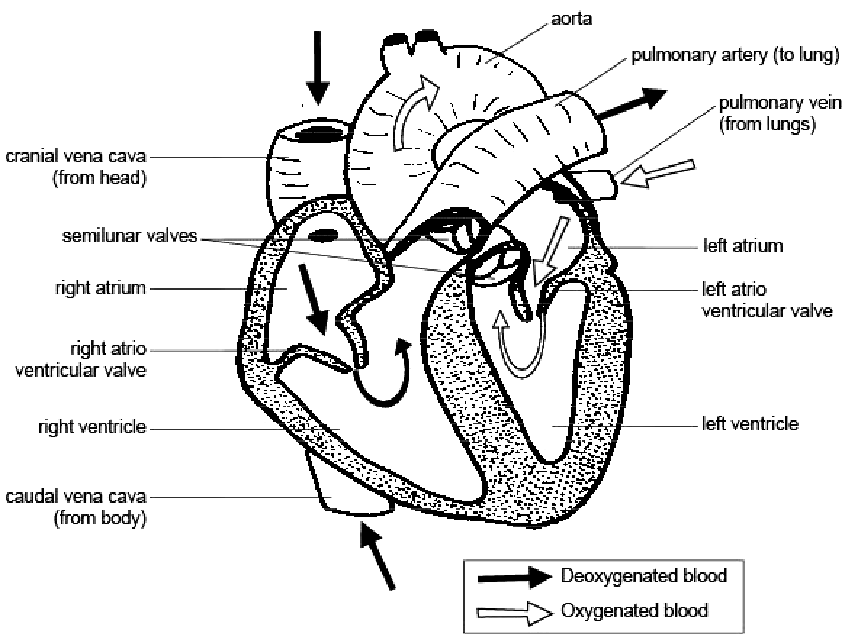
The cardiac cycle consists of two phases, called diastole and systole.
Diastole, during which the heart's ventricles are relaxed, is the longer phase, taking up approximately two-thirds of the cycle. The heart fills with blood under low pressure from the veins.

Systole, the phase during which blood is ejected from the ventricles, takes up the remaining one third. I.e., the chambers of the heart are emptying of blood.

During diastole, the sinus node generates an impulse that forces the two atria to contract. In this phase, the tricuspid and mitral valves are open, and blood is propelled from the atria into the relaxed ventricles. By the end of diastole, the electric impulse reaches the ventricles, causing them to contract. During systole, the contracting ventricles close the tricuspid and mitral valves. Shortly afterward, the pressure of the blood inside the ventricles rises sufficiently to force the pulmonary and aortic valves to open, and blood is ejected into the pulmonary artery and the aorta. As the ventricles relax again, blood backs up from the pulmonary artery and the aorta, closing down the pulmonary and aortic valves. The pressure in the relaxed ventricles is now lower than in the atria, the tricuspid and mitral valves open again, and the cardiac cycle starts as a new.

This seemingly lengthy sequence of events in fact takes approximately a second. The familiar double throb (lub dub) of the beating heart corresponds to the two sets of synchronized contractions that occur during the cardiac cycle: The throbbing sound we hear comes not only from the snapping of the valves, but also from the accompanying vibrations of other heart structures and from the turbulence produced by the flow of blood





3.4.1 Cardiac Output:

This term cardiac **output** is the amount of blood ejected by the left ventricle in one minute. The left ventricle seems to get the lion's share of attention perhaps because the body's blood flow and pulse are provided by the left ventricle. For an adult, an average cardiac output is about 5-8 liters of ejected blood per minute. With strenuous activity, an adult's cardiac output can increase to an amazing 25 liters per minute to satisfy the body's demands for oxygen and nutrients.

The cardiac output is calculated via the following formula:

Cardiac Output = Stroke Volume x Heart Rate

CO = SV x HR

Cardiac output is a product of **heart rate** (beats per minute) and stroke volume. **Stroke volume** is the amount of blood ejected by the left ventricle with each contraction. Sufficient cardiac output is necessary to deliver adequate supplies of oxygen and nutrients (glucose) to the tissues. This translates to the conclusion that cardiac output is directly related to energy production. Low cardiac output will reduce energy levels.

3.5 HEART RATE:

In an average adult, the pacemaker fires approximately 70 impulses a minute at rest, which means that in one minute the heart goes through a full cardiac cycle 70 times. The amount of blood pumped by the heart in one minute is called the cardiac output. When there is a need for an increased blood supply, as during physical exertion, the heart most commonly increases its output by beating faster—for example, up to 140 or 150 beats per minute. This mechanism, however, has its limits: Above a certain rate, the heart chambers do not have time to fill properly and fail to pump efficiently.

Factors affecting heart rate:

Since the heart can only pump **out** the blood that is returned to it, the primary cause of increased cardiac output when exercising is ↑ **blood to the heart** caused by the muscles squeezing the veins.

- **Increase**: exercise, increased body temperature, stress, mental excitement, infection.
- **Decrease**: increased physical fitness, sleep, and mental relaxation.

Coronary circulation

- The blood flowing through the heart **does not** supply the heart with blood
- **Coronary artery** supplies heart muscle with blood
- No coronary vein – directly drains back in diastole.

STROKE VOLUME

The cardiac output is determined not only by the heart rate but also by the amount of blood the ventricles eject or pump out with each contraction. This amount is called the stroke volume. Usually the ventricles expel about half the blood they contain, which corresponds to about 3 ounces in an average person at rest. A decrease in the stroke volume is one of the first signs of a failing heart. While both ventricles pump out, the same amount of blood in each stroke,it is usually measured only the stroke volume of the left ventricle, because it is the one that pumps blood to all of the body's organs except the lungs.

3.6 BLOOD PRESSURE

Learning outcomes:

After studying this section, you should able to:

- **Define blood pressure**
- **Factors responsible for Mechanism of regulation of blood pressure**
- **Test to find out BP**

Blood pressure is the force of blood moving through the arteries. Arteries are the blood vessels that carry blood from heart to the rest of our body. Blood pressure is measured in millimetres of mercury (shortened to 'mmHg'). Blood pressure gives 2 numbers. For example,
120\80. The top number measures the force of blood in your arteries when your heart contracts and forces blood round our body (beats). This is called *systolic* (sis-TA-lik) *pressure.*
The bottom number measures the force of blood in our arteries while our heart is relaxed (filling with blood between beats). This is called *diastolic* (die-a-STAH-lik) *pressure.* Heart is a pump that beats by contracting and then relaxing. The pressure of blood flowing through the arteries varies at different times in the heartbeat cycle.
However, the British Hypertension Society suggests that the
Ideal blood pressure is 120/80mmHg,
Normal is less than 130/80mmHg, and
'High-normal' is 130/80 to 139/89mmHg.

3.6.1 High blood pressure

In over 9 out of every 10 people there is no definite cause of high blood pressure. This condition is known as 'essential hypertension'.
Causes:

1. Not doing enough physical activity
2. Being overweight
3. Having too much salt in your diet
4. Drinking too much alcohol, and
5. Not eating enough fruit and vegetables.
6. Severe kidney disease
7. Medicines used to treat ulcers
8. Genes are another factor.

So, if one or both of your parents have (or had) hypertension, you have a greater chance of developing it too.

Test to find out high BP:
Doctor will probably examine chest and generally look for signs that show whether our circulation is healthy. This includes looking at eyes with an ophthalmoscope to see whether the high blood pressure has affected the blood vessels at the back of the eye. If already having hypertension, doctor will do simple blood and urine tests to find out more about the health of our heart and circulation.
The main tests are:
• An electrocardiogram (ECG) – a test to record the rhythm and electrical activity of your heart
• Blood tests to find out your cholesterol levels and blood sugar levels, and whether your high blood pressure has caused any damage to your kidneys, and
• A urine test to look for signs of blood or protein in the urine.

3.6.2 Low blood pressure:

People with low blood pressure tend to live longer than people with high or even 'normal' blood pressure. Low blood pressure is sometimes discovered during a routine examination. Most people with low blood pressure don't have any noticeable symptoms. However, in some people who have blood pressure below 90/60mmHg, it can cause dizziness or even fainting when they get up after bending over or lying down, especially in older people.

If you have low blood pressure, simple measures may help, such as making sure you are taking enough fluid and possibly using well-fitting cloths. Some people with low blood pressure may be encouraged to add more salt to their diet as this may help improve their blood pressure. (However, it is important to remember that having too much salt in the diet can lead to high blood pressure.) Low blood pressure can also be a side effect of drug treatment for high blood pressure, heart disease or depression. If so, doctor may need to adjust the dose of the drugs that are taken by patients, or give a different drug.

Sometimes low blood pressure can be the result of another illness or condition. So those having symptoms of dizziness, it is important to see doctor. If blood-pressure reading is unusually low, doctor should check to make sure there is not a medical cause. There is usually no need to treat low blood pressure. Only a very small number of people need to take medication for it.

3.7 THE CIRCULATION

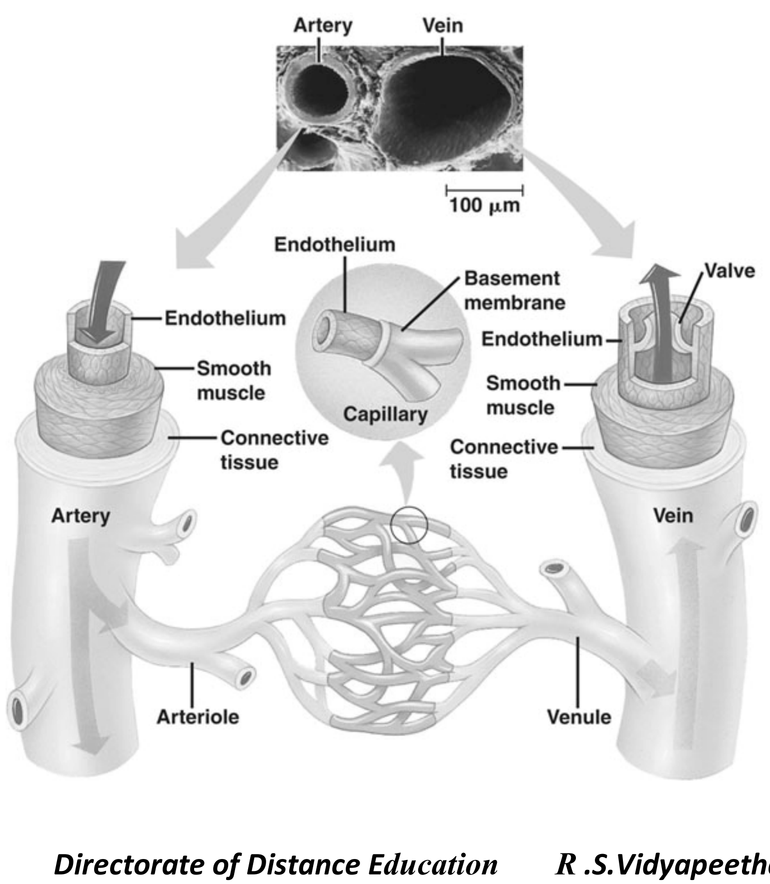
Learning outcomes:
After studying this section, you should able to:

- **Describe the structures and functions of arteries, veins and capillaries**
- **Explain relationship between the different types of blood vessels**
- **Explain the mechanism by which exchange of nutrients, gases and wastes takes place between the blood and tissues**

The circulatory system is an intricate network of vessels that supplies blood to all body organs and tissues. The part of the network that delivers blood to all parts of the body except the lungs is called the **systemic circulation**, while the flow of blood through the lungs is referred to as the **pulmonary circulation.** Placed end to end, all the blood vessels of the body would stretch some 60,000 miles in length.

3.7.1 THE SYSTEMIC CIRCULATION:

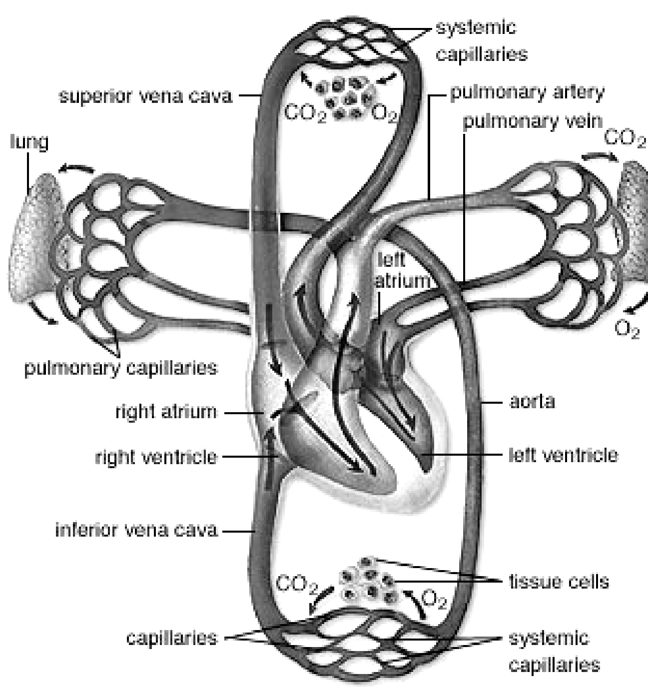
THE ARTERIES AND CAPILLARIES: Blood that has been oxygenated in the lungs (bright red in color) is pumped out of the heart through the aorta, the body's largest artery, which measures approximately 1 inch in diameter. The coronary arteries, which provide the heart's own blood supply, branch out from the aorta just above the aortic valve. The aorta arches upward from the left ventricle to the upper chest, then runs down the chest into the abdomen. It forms the main trunk of the arterial part of the circulation, which branches off into numerous arteries that deliver oxygen-rich blood to various tissues. The arteries are further subdivided into smaller tubes, the arterioles, which in turn branch off into even smaller vessels, the capillaries. While the walls of larger and medium-sized blood vessels are made of a layer of connective tissue and muscle cells with a very thin inner lining called the endothelium, the walls of the capillaries consist of endothelium alone. Most capillary walls are only one cell thick, and consist of a single red blood cell at a time. It is in the capillaries that the exchange of substances between the blood and the tissues takes place. Through the walls of the capillaries, the blood gives off its oxygen and nutrients and picks up carbon dioxide and waste products. A large part of the waste is extracted from blood as it flows through the kidneys, where the plasma— the fluid component of blood — seeps through the capillary walls of the kidneys excreting mechanism. Most of the fluid is reabsorbed into the bloodstream; a fraction of a percent, together with the waste, is removed from the body as urine, which accumulates at a rate of about a quart a day in a healthy adult. The blood pressure on the arterial side of the circulatory system is relatively high, but it decreases as the arteries branch off into arterioles and capillaries. On the venous side, the blood pressure is relatively low. The difference in pressure contributes to the driving force that propels the blood through the circulatory system.



THE VEINS: The capillaries carrying blood that now has lower oxygen content merge to form the venules, which in turn converge into successively larger veins. Venous blood, sometimes referred to as blue, is in fact a purplish or dark red color. Venous blood enters the right atrium through two major vessels: the superior vena cava, which brings blood from the upper part of the body, including the brain; and the inferior vena cava, which brings blood from the lower part, Since the pressure in the veins is normally significantly lower than in the arteries, the walls of the veins are considerably thinner than arterial walls. The larger veins have a system of internal one-way valves that prevents the blood from flowing downward under the pull of gravity when an individual stands up. When he or she moves, the veins are squeezed by the surrounding muscle, which helps propel more blood toward the heart. Without valves in the veins, blood would pool in the legs, leading to swelling in legs

3.7.2 THE PULMONARY CIRCULATION

The main function of the pulmonary circulation is to deliver oxygen to the blood and free it of carbon dioxide. This goal is accomplished as the blood flows through the lungs. The pressure in this part of the system is only about one-sixth as great as in the systemic circulation, and the walls of pulmonary arteries and veins are significantly thinner than the walls of corresponding vessels in the rest of the body. In the pulmonary circulation, the roles of arteries and veins are the opposite of what they are in the systemic circulation: Blood in the arteries has less oxygen, while blood in the veins is oxygen-rich. The circuit starts with the pulmonary artery, which extends from the right ventricle and carries blood with low oxygen content to the lungs.



In the lungs, it branches off into the two arteries, one for each lung, and then into arterioles and capillaries. The gas exchange between the air we breathe in and the blood takes place in the pulmonary capillaries. Their walls act like filters by allowing molecules of gas but not molecules of fluid to pass through. The total surface area of the capillaries in the lungs ranges from 500 to 1,000 square feet. The carbon dioxide and waste products are removed from the blood in the pulmonary arteries across capillary walls and leave the body through the mouth and nose. The blood that has picked up oxygen returns to the heart through four pulmonary veins and into the left atrium. and removing waste products from the tissues. Its cells are produced in the marrow of bones, primarily the flat bones such as the ribs and the breastbone. The volume of blood in an average adult amounts to approximately 10.5 pints.

3.8 Summary:

- The cardiovascular system consists of the blood vessels and the heart.
- The heart is a muscular pump that contracts rhythmically, providing the force that drives blood through the vessels.
- Blood flows in a continuous loop from the heart to branching network of arteries and arterioles to capillaries to venules to veins and then back to the heart.
- Arteries are elastic, muscular vessels that carry blood away from the heart.
- Each heartbeat sends a pressure wave down the artery called the pulse.
- Arteries have smooth muscles that result in vasoconstriction and vasodilation.
- Capillaries are one cell thick and allow for the exchange of materials between the blood and the tissues by diffusion, pressure-driven movement, endocytosis or exocytosis.
- Veins return blood to the heart. The lumen is larger in a vein than artery and the wall is less rigid.
- Veins contain valves that keep blood from flowing backward.
- The heart consists of two atria and two ventricles. The right and left halves of the heart function as separate pumps.
- The right side of the heart pumps blood through the pulmonary circuit transporting blood to and from the lungs. The left side of the heart pumps blood through the systemic circuit, which transports blood to and from the body tissues.
- The heart muscle is nourished by coronary circulation.
- The cardiac cycle is the sequence of heart muscle contraction (systole) and relaxation (diastole).

- Cardiac tissue has its own internal conduction system so that the cells contract in a coordinated manner.
- The sinoatrial node is the pacemaker, sending stimuli to the atrioventricular node down the atrioventricular bundle to the Purkinje fibers resulting in a contraction.
- The heartbeat is regulated by the autonomic nervous system and certain hormones. An electrocardiogram is a recording of the electrical activities of the heart.
- Blood pressure is the force blood exerts against the walls of the blood vessels.
- Systolic pressure is produced when the ventricles contract and diastolic pressure is produced when the ventricles relax.
- Cardiovascular disease is the single biggest killer of men and women in the US.
- High blood pressure can kill without symptoms, thus it is termed the silent killer.
- An inflammation process underlies the buildup of lipids in the artery walls called atherosclerosis. When this occurs in the coronary arteries, it is called coronary artery disease and is the major cause of heart attacks.
- The lymphatic system functions in the circulatory and immune systems to return excess interstitial fluid to the bloodstream, transport products of fat digestion from the small intestine to the blood stream, and help defend against disease-causing organisms.

Self assessment questions:

1. Explain the properties of cardiac muscle?
2. Draw a neat labeled diagram showing the structure and innervations of heart.
3. Define blood pressure. Give its normal values. Describe the factors regulating cardiac output?
4. Define cardiac output and cardiac index. Give its normal values?
5. Explain cardiac cycle?
6. Add a note on systemic and pulmonary circulation?
7. What is hypertension and hypotension?

4. THE LYMPHATIC SYSTEM

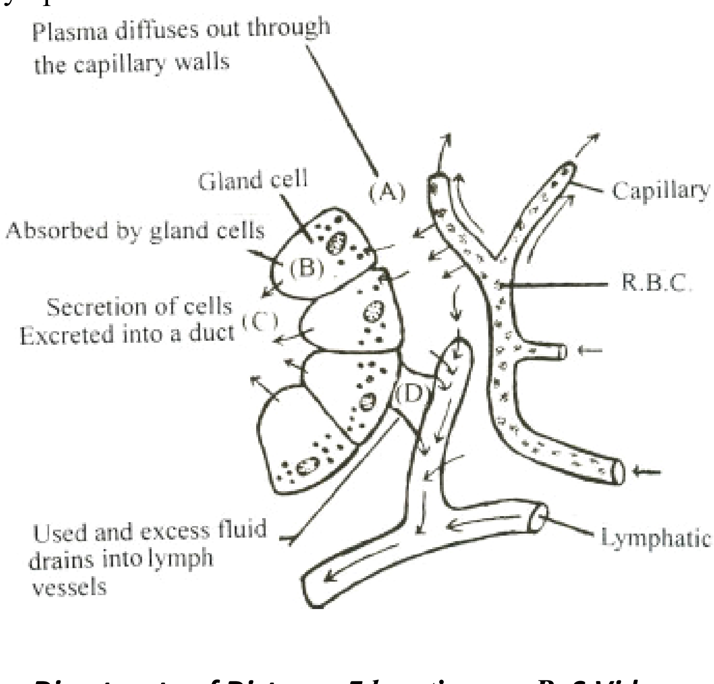
4.1 Functions of lymph
4.2 Differences between blood and lymph
4.3 Lymph nodes
4.4 summary

Learning outcomes:
After studying this section, you should able to:

- **Composition and functions of lymph**
- **Various lymph nodes of the body**
- **Differences between blood and lymph**

Introduction:

Our body has two kinds of circulating fluids – blood and lymph. Of these you have seen and felt the first (i.e. blood) in your own body, but lymph remains unnoticed even if it oozes out at any point of injury because it is colorless. This system consists of a series of branching vessels and a collection of lymphatic organs. A continuous exchange of materials between the blood capillary and the intercellular fluid (fluid present between cells of tissues) goes on. Some important components like proteins etc. that could not be returned back to blood capillaries from intercellular fluid, are taken up by the lymph capillaries as lymph and drained into veins in the lower neck portion of the body. Lymph should be regarded as modified tissue fluid. The clear, colorless liquid moving out of the capillary wall is called Lymph.
Lymph comes in to direct contact with body cells.



4.1 Functions of lymph

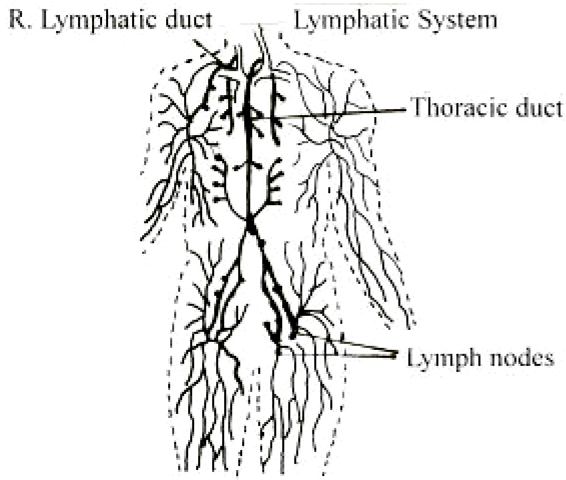
(i) Supplies nutrition and oxygen to those parts where blood cannot reach
(ii) Drains away, excess tissue fluid from extra-cellular spaces back into the blood.
(iii) Absorbs and transports fats absorbed from small intestine
(iv) Collects nitrogenous waste
(v) Lymphocytes and antibodies present in lymph help in removing bacteria

4.2 Differences between blood and lymph.

Blood differs from lymph in a number of ways as shown below

Blood	**Lymph**
1. Red in color due to presence of Hemoglobin	1. Color less fluid
2. Flows rapidly	2. Flow is very slow
3. Contains RBC, WBC, Platelets and Plasma	3. Contains plasma and WBC
4. Route of blood flow Heart Arteries Capillaires Viens Heart	4. Route of lymph flow Tissue Spaces Lymph Capillaries Lymphe Vessels Subclavian Vein Heart

The clear, colourless fluid that collects in a blister to provide protection to the underlying tissue is **lymph**.The lymphatic system consists of a large number of **lymph ducts, lymph nodes and lymph vessels as shown below.**It lacks a pumping mechanism. Fluid is pushed by muscle movement. The lymph nodes are scattered throughout the body. They are more concentrated in the neck, armpits and groins.



4.3 Lymph nodes:

Each node is a clump of tissue housing a number of lymphocytes. These nodes act as filters for bacteria, viral particles and cancerous cells. These resident lymphocytes then immediately attack the disease causing germs or pathogens

The spleen,thymus and tonsils are lymphoid organs.

Spleen

It is the largest lymphoid organ and has the following functions

(I) Haemopoiesis – Formation of Blood cells in the foetus
(ii) Destruction of old and worn out blood cells and hence termed as 'grave yard' of RBC.
(iii) Blood reservoir
(iv) Defensive action by engulfing bacteria

4.4 Summary :

The lymphatic system consists of organs, ducts, and nodes. It transports a watery clear fluid called lymph. This fluid distributes immune cells and other factors throughout the body. It also interacts with the blood circulatory system to drain fluid from cells and tissues. The lymphatic system contains immune cells called lymphocytes, which protect the body against antigens (viruses, bacteria, etc.) that invade the body.

Self assessment questions:

1. Describe the composition and functions of lymph?
2. What are lymph nodes?
3. Differences between blood and lymph fluid?

5. THE NERVOUS SYSTEM

Introduction:

The nervous system of human body is a **processing system**, and the system that keeps us in contact with the outside world. It tells us that we exist, and along with the muscles allows us to move and react to stimuli. Our **consciousness** resides in our nervous systems, as do our thoughts and emotions. In short, the roles of the nervous system are: responsible for coordination of movement, response to environmental stimuli, intelligence, **self-awareness**, **thought**, **and emotion**. **Composed** of nerve cells called **neurons**, which are specialized to carry nerve impulses. Otherwise it has three overlapping functions of **sensor input**, **integration**, and **motor output in simple**. This process is generally the same even at a very primitive level of nervous system, but we will focus here mostly on human nervous system.

In brief summary, The sensory input is sensing the environment and changes around an organism, and is carried out by **sensory organs** like eyes, ears, nose, tongue, and skin, some of them performing simultaneously. The integration involves processing of information, and is carried out by the **central nervous system** (CNS), which consists of brain and spinal cord. Motor neuron output is conduction of signals from the integration center, the CNS, and is carried out by a group of **effector cells**, the muscle cells or gland cells, which actually carry out body's responses to external stimuli. Both sensory input and motor output signals are carried through **nerves**, which are long ropelike structures made from nerve cells. Nerve cells are two types – **neurons** and **glia**.

Neurons are the cells which actually carry through signals

5.1 Neurons

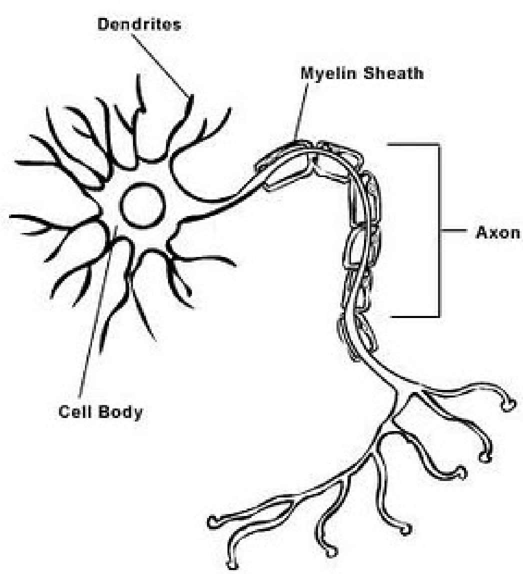
Learning outcomes:

After studying this section, you should able to:

- **Describe the structure of myelinated neuron**
- **Types of neurons**
- **Neuromuscular junction**

5.1.1 Structure of Nerve cell or "Neuron"

All neurons have three parts: i) **DENDRITE**(s) - conduct nerve impulses **towards** the cell body ii) **CELL BODY** and iii) **AXON** -conducts nerve impulses **away** from the cell body. Dendrites and axons are sometimes called **FIBERS**. Most long fibers are covered by a **MYELIN SHEATH**. The sheath has spaces in it exposing the axon called **NODES OF RANVIER**. The sheath is secreted by **SCHWANN CELLS**, each of which has a nucleus.



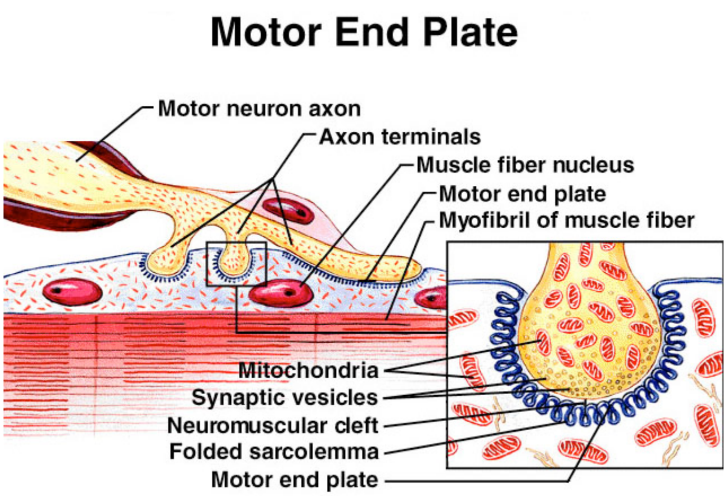
5.1.2 Three types of neurons:

1. SENSORY NEURON: (= afferent neuron) - takes a message from a sense organ to CNS. has **long** dendrite and short **axon**
2. **MOTOR NEURON**: (= efferent neuron) - takes message away from CNS to a muscle fiber or gland. **Short** dendrites, **long** axon.
3. **INTERNEURON**: (= association neuron or connector neuron): completely contained within CNS. Conveys messages between parts of the system. Dendrites, axons, may be long or short
Glia cells provide supporting structures and maintenance of neuronal cells. Glial cells outnumber neurons by 10 to 50-folds. Nerves are many times are made from end to end connection between neurons, supported by the glial cells. The nerves that communicate sensor and motor signals between the central nervous system and rest of the body are collectively referred to as **peripheral nervous system** (PNS). Sensory inputs are received by receptor cells located in sensory organs. For examples, light receptor cells are located in eyes, or chemical receptor cells are located on the surface of tongue. Signals from these receptors are carried through **sensory neurons** of the PNS into the CNS, and after processing in the CNS, instructions are communicated through the **motor neurons** of the PNS to effector cells, such as muscles. Communication from the receptor cells to effector cells is carried in two forms – chemical and electrical. Since communication of information involves more than one cell, the communication is through special chemicals called **neurotransmitters** or a specialized form of electric signal called **action potential**.

5.1.3 The Neuromuscular junction:

A nerve serving a muscle fiber has both motor and sensory neurons. Each motor neuron has an axon that extends from the CNS to a group of muscle fibers. Close to these skeletal muscle fibers the axon divides into branches called axon terminals. The axon terminals contact the sarcolemma of the muscle fiber by means of motor end plates. The area consisting of a motor end plate and the cell membrane of the muscle fiber is called the **neuromuscular junction.** Acetylcholine (ACH) is a neurotransmitter stored in the synaptic vesicles at the axon terminals. A nerve impulse reaching the axon terminal causes the release of ACH into the neuromuscular cleft. When this happens it causes a muscle contraction.

The Motor unit: a motor unit consists of a single motor neuron and the aggregation of muscle fibers innervated by the motor neuron. When a nerve impulse travels through a motor unit all of the fibers served by it contract simultaneously to their maximum. Most muscles have an innervation ratio of 1 motor neuron per 100-150 muscle fibers. Muscles capable of precise movements (ex. eye muscles) have a ratio of 1:10. Very large muscles such as in the thigh may have ratios of 1:500. Motor units vary in size. Neurons that innervate smaller numbers of fibers have smaller cell bodies and axon diameters than the neurons with large ratios. The smaller motor units are the ones that are used most often. The large motor units are activated only when large forceful contractions are needed. The magnitude of the task determines the number of motor units activated.



Length of neurons varies depending on their location. Neurons located in CNS could be a few millimeter long but some of the neurons in PNS could be more than a meter long. In a normal human body, there are about two billion neurons, approximately 1 billion in the brain, and another billion in rest of the body.

Organization of Nervous System
Structurally, the nervous system is organized in two parts – the **central nervous system** and the **peripheral nervous system.**

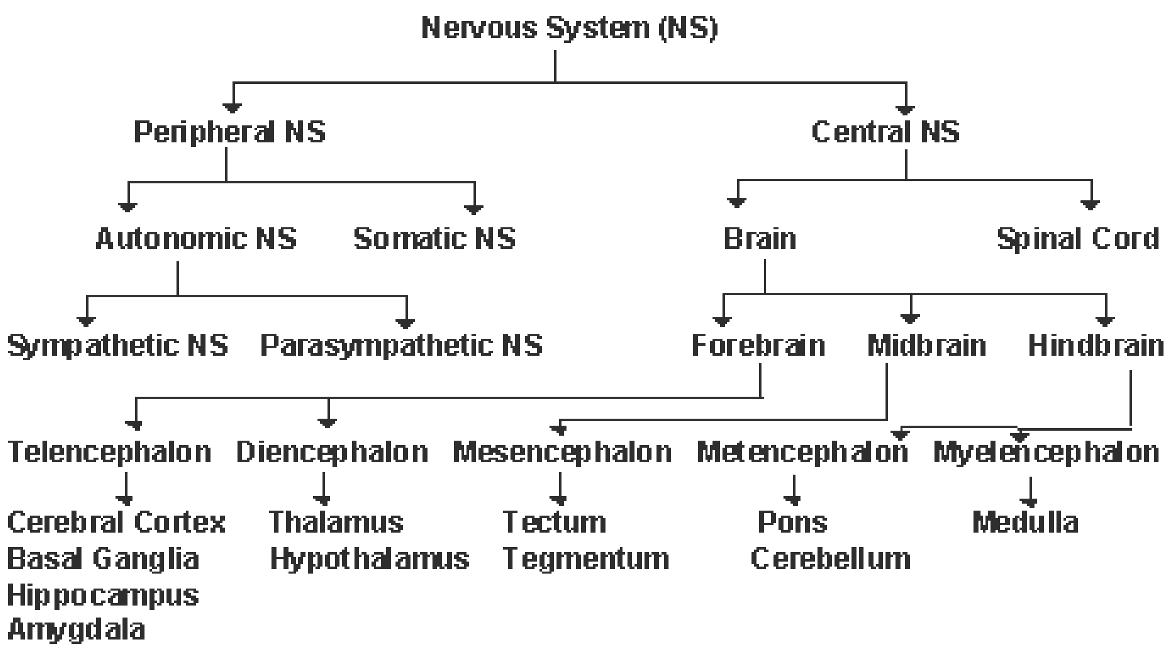
5.2 CENTRAL NERVOUS SYSTEM:

Learning outcomes:
After studying this section, you should able to:

- **Describe the structures of meninges**
- **Describe the flow of CSF in the brain**
- **Functions of CSF**

The CNS is made of brain and the spinal cord. The brain is divided into three parts – Forebrain, Midbrain, and Hindbrain.
The Forebrain develops into two parts – the telencephalon which consists of the cerebrum or the cerebral hemispheres, and includes cerebral cortex, white matter, and basal nuclei; and diencephalon which consists thalamus, hypothalamus, and epithalamus.

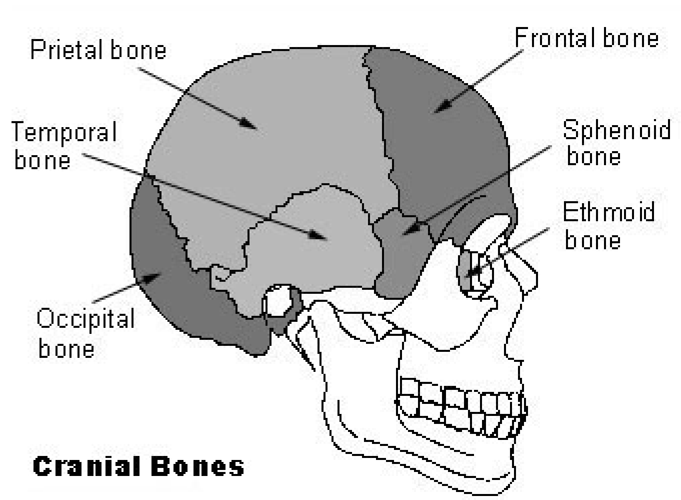
OVERVIEW ON NERVOUS SYSTEM IS GIVEN BELOW



5.2.1 Basic Anatomy and Physiology of the Human Brain

Skull :

The skull is a highly complex structure consisting of 22 bones altogether. These can be divided into two sets, the cranial bones (or cranium) and the facial bones. While the latter form the framework of the face, the cranial bones form the cranial cavity that encloses and protects the brain. All bones of the adult skull are firmly connected by sutures. The frontal bone forms the forehead and contains the frontal sinuses, which are air filled cells within the bone. Most superior and lateral aspects of the skull are formed by the parietal bones while the occipital bone forms the posterior aspects. The base of the occipital bone contains the foramen magnum, which is a large hole allowing the inferior part of the brain to connect to the spinal cord. The remaining bones of the cranium are the temporal, sphenoid and ethmoid bones.

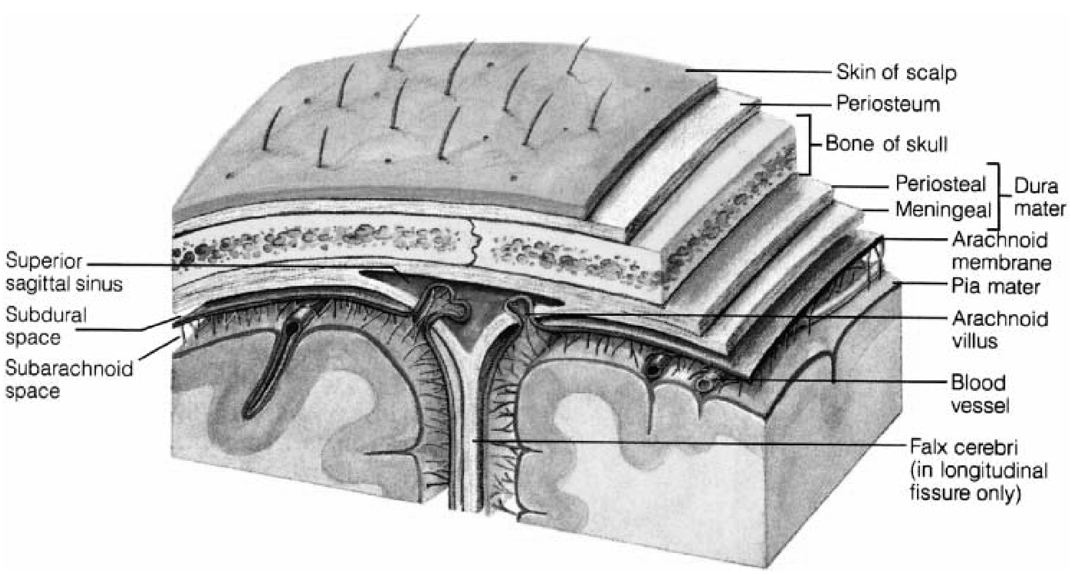


Meninges:

The meninges are three connective tissue membranes enclosing the brain and the spinal cord. Their functions are to protect the CNS and blood vessels, enclose the venous sinuses, retain the cerebrospinal fluid, and form partitions within the skull. The outermost meninges are the Dura mater, which encloses the arachnoid mater and the innermost pia mater.

Cerebrospinal fluid:

Cerebrospinal fluid (CSF) is a watery liquid similar in composition to blood plasma. It is formed in the choroid plexuses and circulates through the ventricles into the subarachnoid space, where it is returned to the dural venous sinuses by the arachnoid villi. The prime purpose of the CSF is to support and cushion the brain and help nourish it. Figure below illustrates the flow of CSF through the central nervous system.



BRAIN

Learning outcomes:

After studying this section, you should able to:

- **Describe the blood supply to brain**
- **Name the sulci and lobes of the brain**
- **Outline the functions of the cerebrum**
- **Describe the position and functions of the midbrain, Pons, medulla oblongata, thalamus and hypothalamus**
- **Describe the structure and functions of cerebellum.**

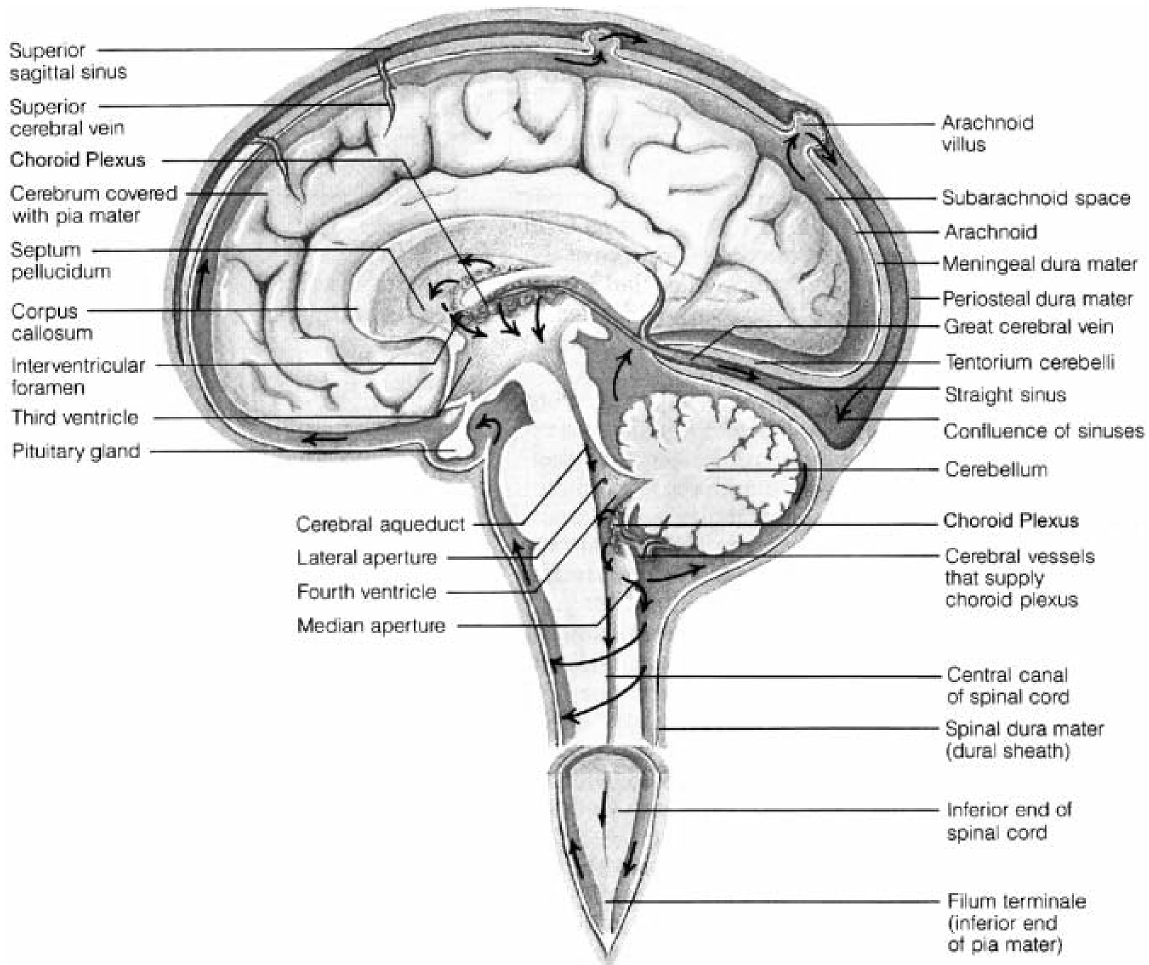
Brainstem:

The brain stem is similarly structured as the spinal cord: it consists of grey matter surrounded by white matter fiber tracts. Its major regions are the midbrain, Pons and medulla oblongata. The midbrain, which surrounds the cerebral aqueduct, provides fiber pathways between higher and lower brain centers, contains visual and auditory reflex and sub cortical motor centers. The Pons is mainly a conduction region, but its nuclei also contribute to the regulation of respiration and cranial nerves. The medulla oblongata takes an important role as an autonomic reflex centre involved in maintaining body homeostasis. In particular, nuclei in the medulla regulate respiratory rhythm, heart rate, blood pressure and several cranial nerves. Moreover, it provides conduction pathways between the inferior spinal cord and higher brain centers. The brainstem is a stalk along with cap like swellings located at the anterior end of the spinal cord. The brainstem has three parts – medulla oblongata, Pons, and the midbrain.

The **medulla oblongata** contains centers that control several visceral (autonomic, homeostatic) functions, including breathing, heart and blood vessel activities, swallowing, vomiting, and digestion. Most of the axons carrying instructions about movement from forebrain and midbrain to the spinal cord cross from one side of the CNS to the other as they pass through medulla. This leads to the control of movement in the left side of the body by the right side of the brain, and vice versa.

The **Pons** also participates in the functions described for medulla. All the bundles of axons Carrying sensory information to and motor instructions from higher brain regions pass through medulla and Pons.

The **midbrain** part of the brainstem contains centers for the receipt and integration of several types of sensory information, including those from auditory and visual systems. It also serves as a projection center, sending coded sensory information along neurons to specific regions of the forebrain



Diencephalon:

The diencephalon is located centrally within the forebrain. It consists of the thalamus, hypothalamus and epithalamus, which together enclose the third ventricle. The epithalamus consists of the pineal gland and the CSF producing choroid plexus.

Thalamus and Hypothalamus:

The **thalamus** acts as a major integrating center for sensory information going to the cerebrum and the main output center for motor information leaving the cerebrum. Incoming information from all the senses is sorted out in the thalamus and sent on to the appropriate higher brain centers for further interpretation and integration. The thalamus also receives information from cerebrum and from parts of brain that regulate emotion and arousal.

The **hypothalamus** is one of the most important brain regions for the homeostatic regulation of the body. It secretes two sets of hormones - the posterior pituitary hormones (oxytocin and antidiuretic hormones) and releasing hormones (e.g., growth hormones, prolactin, endorphins, etc.) that act on the anterior pituitary. The hypothalamus contains body's thermostat, centers for regulating hunger, thirst, and many of the body's survival mechanisms. Hypothalamus neurons also play a role in sexual response and mating behaviors, fight and flight response, and pleasure. The hypothalamus also controls the circadian rhythm in humans and animals.

Cerebellum :

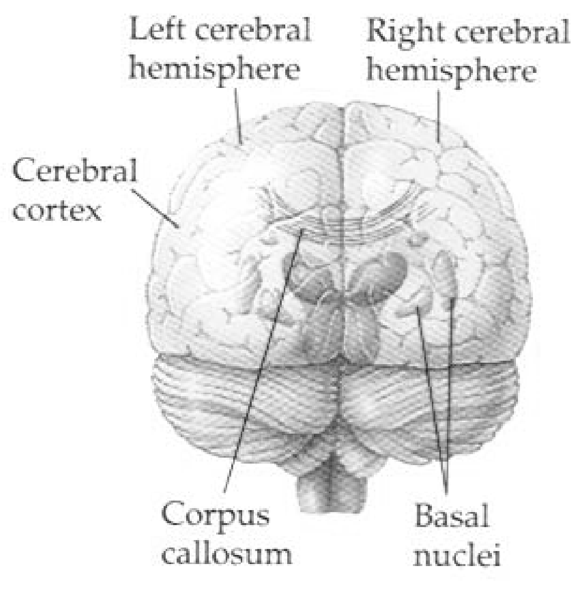
The cerebellum, which is located dorsal to the Pons and medulla, accounts for about 11% of total brain mass. Like the cerebrum, it has a thin outer cortex of grey matter, internal white matter, and small, deeply situated, paired masses (nuclei) of grey matter.

This part of brain's primary function is coordination of movement, thus it controls movement and balance by receiving sensory information about the position of the joints and the length of muscles, along with information from the auditory and visual systems. It also receives instructional motor inputs from the cerebrum for automatic coordination of movements and balance.

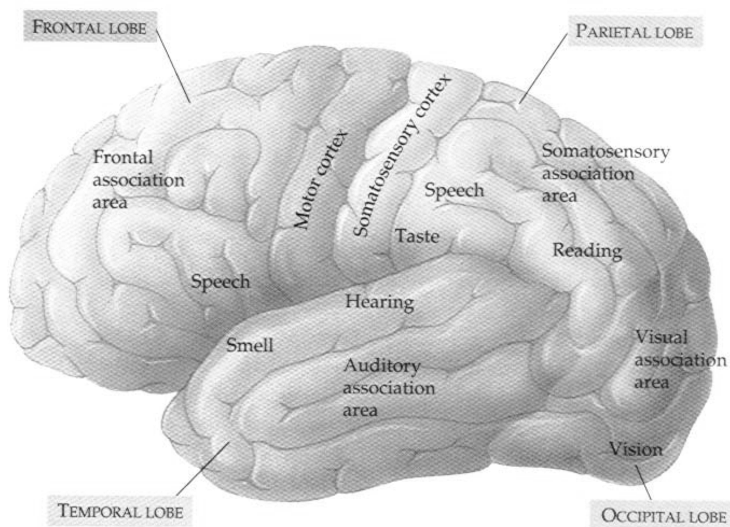
The Cerebrum:

The cerebrum, divided into left and right cerebral hemispheres, is the most complex integrating center in the CNS. Each hemisphere consists of gray matter or cerebral cortex, internal white matter, and a cluster of nuclei deep within the white matter, the basal nuclei or basal ganglia. The cerebral cortex is the largest and the most complex part of the human brain. Sophisticated behavior in mammals is associated with the relative size of the cerebral cortex and the presence of convolutions that increase its surface area. The cerebral cortex accounts for 80% of the total brain mass, and covers about 0.5 m2 surface area.

The thickness of the cerebral cortex layer is less than 5 mm Cerebral cortex is divided into right and left sides, which are connected through a thick band of fibers, the cerebral white matter known as corpus callosum.

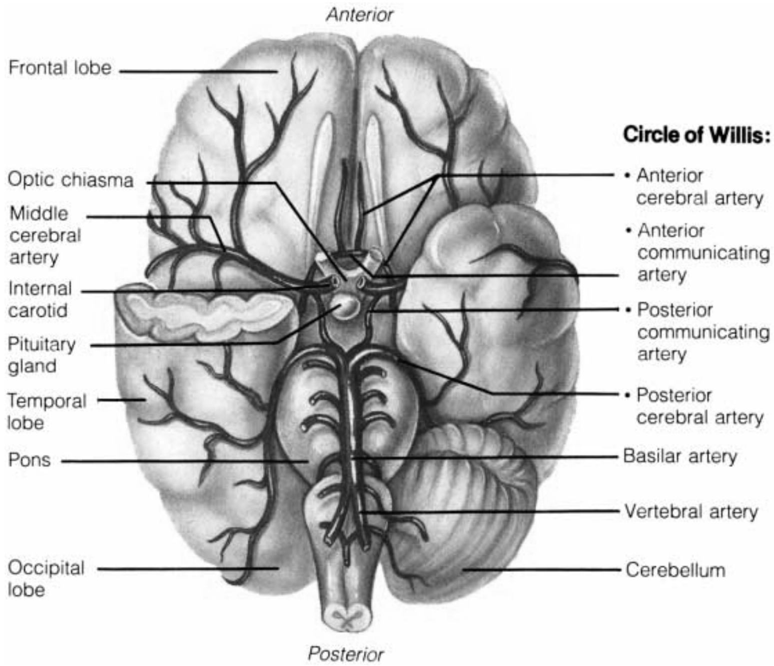


Each side has four discrete lobes – frontal lobe, temporal lobe, parietal lobe, and occipital lobe. A number of functional areas within each lobe have been identified. Two such areas, the primary motor cortex (PMC) and the primary somatosensory cortex (PSC), form the boundary between the frontal and parietal lobes The PMC region functions mainly in sending commands to skeletal muscles with appropriate response to sensory stimuli. The PSC region receives and partially integrates signals from touch, pain, pressure, and temperature perceptions throughout the body. The proportions of PMC and PSC regions devoted to a particular part of body is correlated with the importance of motor or sensory information for that part of the body, as shown in. Impulses transmitted from receptors to areas of somatosensory cortex enable people to associate pain, touch, pressure, heat, or cold with specific parts of the body receiving those stimuli. Notably, the special senses – vision, hearing, smell, and taste – are integrated by other cortical regions, although the functional regions obviously cooperate with respective association areas shown in.



Blood supply to the brain:

The major arteries are the vertebral and internal carotid arteries. The two posterior and single anterior communicating arteries form the circle of Willis, which equalizes blood pressures in the brain's anterior and posterior regions, and protects the brain from damage should one of the arteries become occluded. However, there is little communication between smaller arteries on the brain's surface. Hence occlusion of these arteries usually results in localized tissue damage. Figure below shows an overview of the arterial system supplying the brain



5.3 SPINAL CORD:

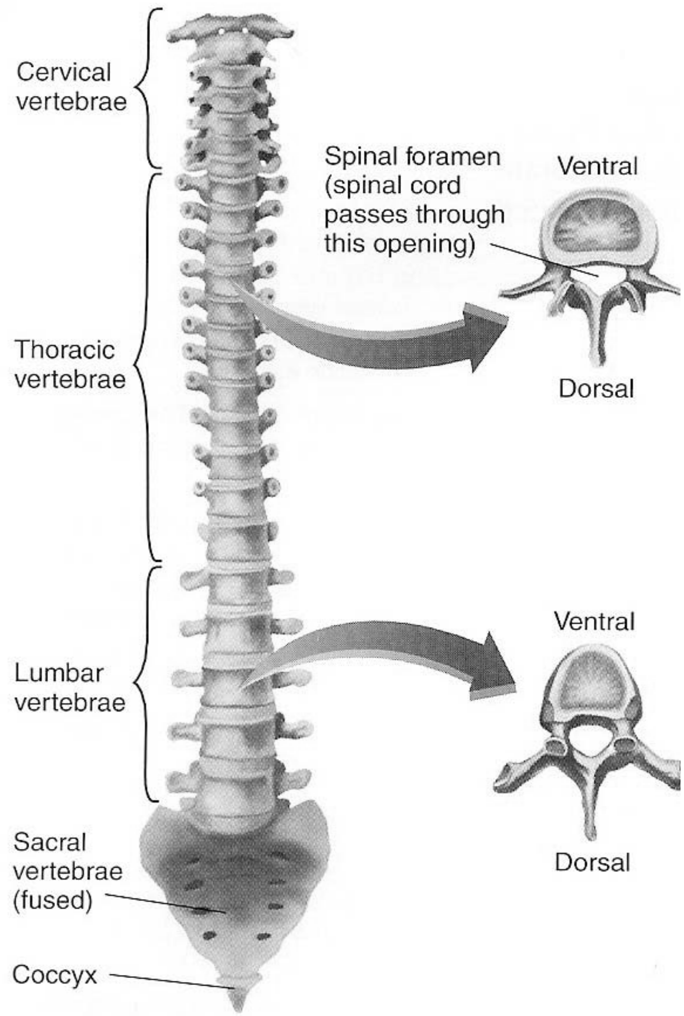
Learning outcomes:

After studying this section, you should able to:

- **Describe the gross structure of the spinal cord.**
- **State the functions of sensor (afferent) and motor (efferent) nerve tracts in the spinal cord.**

Begins from the brain stems and extends till the lowest end of backbone. The spinal cord containing bundle of nerves is protected by a series of vertebrae, **artificially** divided into five regions – cervical (7), thoracic (12), lumber (5), sacral (5), and coccygeal (1). The latter two are fused together. The spinal cord itself spans only about two-thirds of the vertebral column, but the rest of the space is filled with nerve fibers of spinal roots. Both the brain and spinal cord contain fluid filled spaces or cavities. The fluid in these spaces is called **cerebrospinal fluid** (CSF), and contains nutrients, hormones, white blood cells to maintain the CNS. Additionally, the fluid acts as shock absorber cushioning the brain. The CSF provides a direct link across the blood brain barrier for exchanging nutrients and other essential biomolecules. A typical human brain weighs about 1.4 kilogram, and contains 1 billion neurons. The CSF has a half-life of about 3.5 hours, and thus remains fresh for supporting the brain and spinal cord.

The spinal cord provides junction points for motor and sensory nerves, through **afferent** (ventral) and **efferent (dorsal)** roots, respectively. The cell body giving rise to afferent axon reside outside the spinal cord, in a cluster, called dorsal root ganglion (ganglion is where nerves form some sort of a knot). The afferent nerves bring the somatosensory information intended for the brain and efferent nerves take the information from brain to rest of the body.



A cross section of spinal cord shows a butterfly shape structure in which inside is the gray matter and outside the white matter. The gray matter is primarily made of cell bodies whereas white matter is made of axons.

5.4 PERIPHERAL NERVOUS SYSTEM

Learning outcomes:
After studying this section, you should able to:

- **List the spinal nerves**

The brain and spinal cord communicate with rest of the body through Cranial and Spinal nerves. These nerves are part of the peripheral nervous system, which conveys the sensory information to the brain either directly or through the spinal cord, and conveys instructional information to body's muscles and glands. There are 12 cranial nerves and 31 spinal nerves which form the part of PNS. Peripheral nervous system is complex and expansive in its structure and function. It is easier to classify it in its functional hierarchy. The sensory and motor systems of the peripheral nervous system are part of the cranial and spinal nerves. One of these cranial nerves, known as **vagus nerve**, regulates the functions of organs in the thoracic and abdominal cavities, and plays a major role in physiological function of cardiovascular system, hepatic system, and urinary system. Sensory information from head and neck region, including somatosensory inputs, and inputs related to taste, hearing, vision, and smell are received through cranial nerves. **Spinal nerves** sprouting from the spinal cord innervate the rest of the body for sending and receiving information related to external and internal environment. Functionally speaking the peripheral nervous system is divided into sensory and motor divisions. The s**ensory division** consisting of afferent or sensory neurons that convey information to the CNS from sensory receptors that monitor external and internal environment. The **motor division** is composed of efferent neurons that convey signals from the CNS to the effector cells, and is divided into two regions – the **somatic** nervous system and **autonomous** nervous system. The **somatic nervous system** carries signals to skeletal muscles mainly in response to ***external*** stimuli, thus being often referred to as voluntary nervous system. However, a substantial proportion of skeletal muscle movement is actually determined by reflexes mediated by the spinal cord or lower brain, without involving integration of information at the cerebral cortex level. The autonomous nervous system conveys signals that regulate the ***internal*** environment by controlling smooth and cardiac muscles and the organs of the gastrointestinal, cardiovascular, excretory, and endocrine systems. These controls are generally considered involuntary.

The three subdivisions of autonomous nervous system – the sympathetic division and the parasympathetic division– are distinguishable anatomically, physiologically, and chemically. The picture below gives the detail about the autonomic nervous system and their organs of target actions Somatic Nervous System. The somatic nervous system consists of peripheral nerve fibers that send sensory information to the central nervous system AND motor nerve fibers that project to skeletal muscle. The picture above shows the somatic motor system. The cell body is located in either the brain or spinal cord and projects directly to a skeletal muscle.

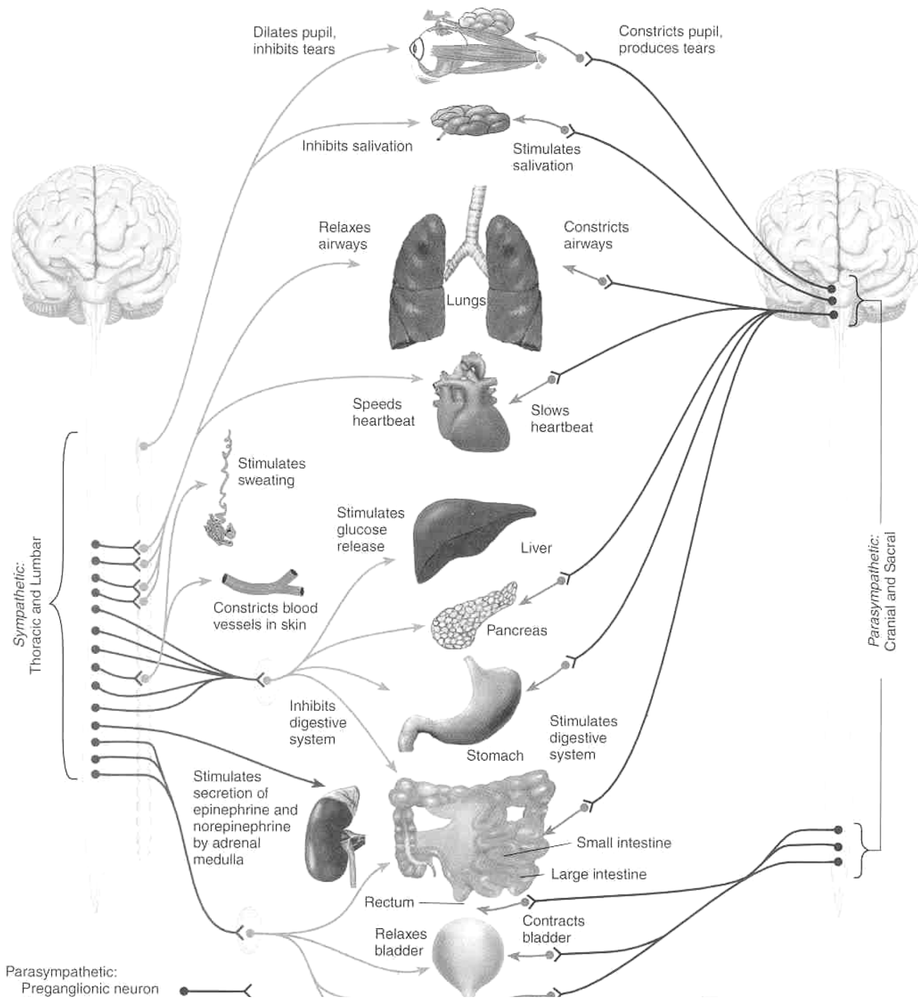
5.5 Autonomic Nervous System :

Learning outcomes:

After studying this section, you should able to:

- **Identify the two divisions of autonomic nervous system**
- **know what is "FIGHT OR FLIGHT" mechanism**
- **identify cranial nerves**

Is divided into three parts: the sympathetic nervous system, the parasympathetic nervous system and the enteric nervous system. The autonomic nervous system controls smooth muscle of the viscera (internal organs) and glands.



1) SYMPATHETIC NERVOUS SYSTEM: is especially important during **EMERGENCY SITUATIONS** and is associated with "**FIGHT OR FLIGHT**" reaction. For example, in an emergency, it causes the following:

1. Energy directed away from digestion
2. Pupils dilate,
3. Heart rate increases,
4. Perspiration increases,
5. Salivation decreases,
6. Breathing rate increases

The **neurotransmitter** released by the postganglionic axon of the Sympathetic nervous system is NORADRENALIN (which is closely related to adrenalin -- a known heart stimulant). **Noradrenalin** is released by postganglionic axon→heart rate accelerates, fibers for this system arise from middle part (thoracic-lumbar) of the spinal cord. Preganglionic fiber is short, postganglionic fiber (which contacts the organ) is long.

2) PARASYMPATHETIC NERVOUS SYSTEM:

The parasympathetic System promotes all the internal responses associated with a relaxed state. For example:

1. causes the pupils to contract
2. energy diverted for digestion of food
3. heart rate slows.

Important neurotransmitter in this system is **ACETYLCHOLINE**. Fibers for this system arise from **upper** and **lower part of spinal cord** (cranial and sacral nerves). Preganglionic fiber is **long**, postganglionic fiber is **short** because the ganglia lie near or within the organ.

3) ENTERIC NERVOUS SYSTEM:

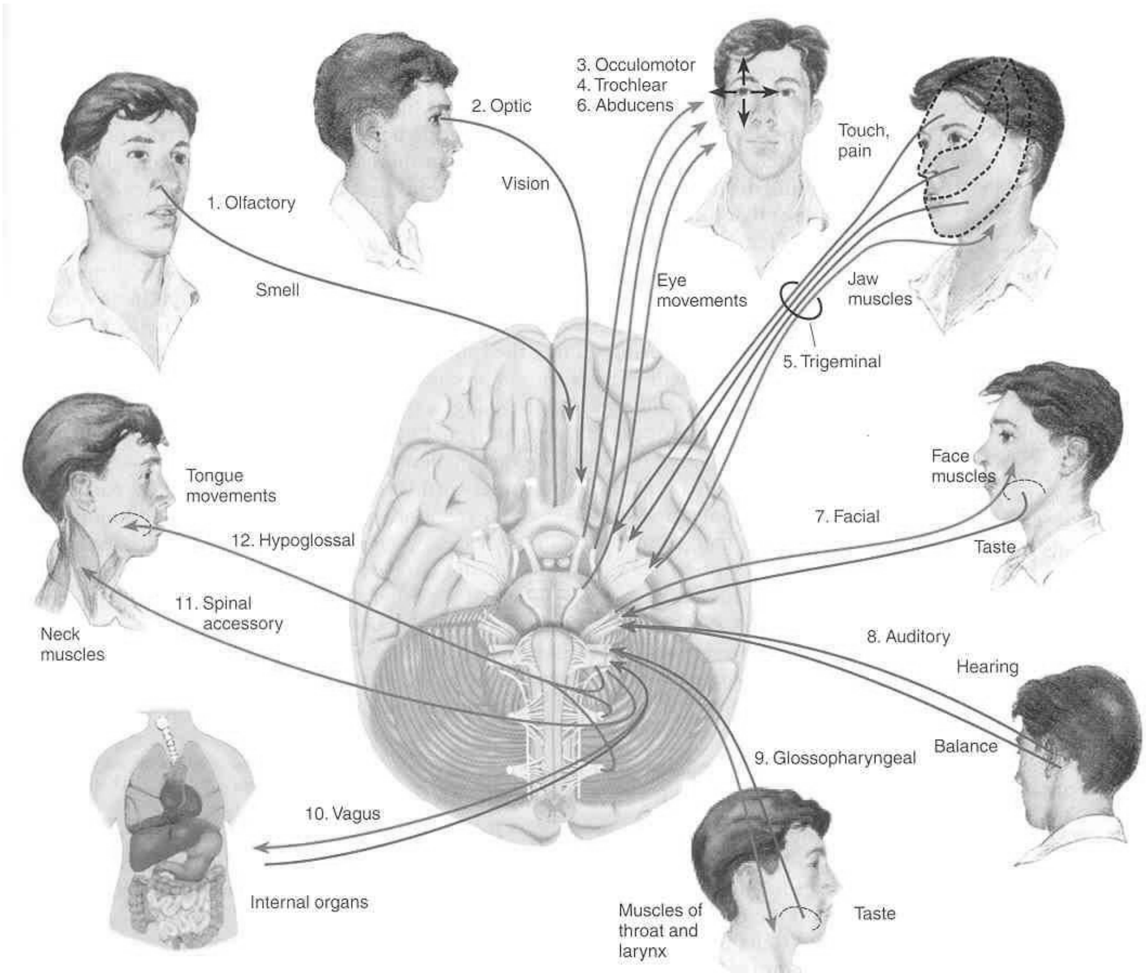
The enteric nervous system is a third division of the autonomic nervous system that you do not hear much about. The enteric nervous system is a meshwork of nerve fibers that innervate the viscera (gastrointestinal tract, pancreas, gall bladder). Contains approx. 100 million nerves.

5.5.1 Cranial Nerves

There are 12 pairs of cranial nerves emerging from the brain and radiating from its surface. They pass through skull foramina, fissures, or canals to exit the cranial vault and then distribute their innervation to their respective structures in the head and neck. One of the cranial nerves, the vagus (L., "wanderer") continues into the trunk where it innervates various thoracic and abdominal organs. In addition to being named, the cranial nerves are numbered sequentially with Roman numerals in the order in which they arise from the brain, rostrally to caudally. The following list includes their names and corresponding numbers.

I Olfactory nerve.
II Optic nerve.
III Oculomotor nerve.
IV Trochlear nerve.
V Trigeminal nerve.
VI Abducent nerve.
VII Facial nerve.
VIII Vestibulocochlear nerve.
IX Glossopharyngeal nerve.
X Vagus nerve.
XI Spinal accessory nerve.
XII Hypoglossal nerve.

CRANIAL NERVES AND THEIR TARGET OF ACTIONS



Yoga exercises and meditation could affect the cognitive and intrinsic systems and Sharpen their functions. Combined with yama and niyama, postures, Pranayama, pratyahara, and dharana, there is ample opportunity to train much of our nervous system to Make them help observe not only external but also internal signals within our bodies. This could be helpful both in physical health of body and mental perception of the world.

5.5 summary

- The nervous system is divided into the central nervous system and the peripheral nervous system.
- The central nervous system consists of the brain and spinal cord and is responsible for integrating incoming information and coordinating all voluntary and involuntary responses.

- The peripheral nervous system consists of all neural tissue outside the central nervous system including ganglia.
- Bone, membranes, and cerebrospinal fluid protect the central nervous system.
- The brain is the primary organ of the nervous system and consists of many parts with specific functions.
    - The cerebrum is the largest and most prominent part of the brain and is responsible for consciousness.
    - The thalamus receives sensory input, sorts information, and relays it to the appropriate regions of the brain for processing.
    - The hypothalamus maintains homeostasis and is the bridge to the endocrine system.
    - The cerebellum is responsible for coordination of sensory input and motor output.
    - The medulla oblongata contains the reflex centers that keep us alive.
    - The pons connects the brain to the medulla oblongata, and thus to the spinal cord.
- The limbic system allows us to experience emotions and to maintain short and long term memory.
- The reticular activating system filters sensory input and stimulates the cerebral cortex to maintain consciousness.
- The spinal cord transmits messages to and from the brain and is a reflex center.
- The peripheral nervous system consists of the somatic nervous system and the autonomic nervous system.
- The somatic nervous system carries information to and from the CNS resulting in sensations and voluntary movement.
- The autonomic nervous system governs involuntary, unconscious activities and maintains homeostasis.
- The autonomic nervous system consists of the sympathetic nervous system that takes over during emergency conditions and the parasympathetic nervous system that conserves energy during non-stressful times.
- Health issues and injuries of the nervous system vary in seriousness depending upon the nature of the problem and the location.

Self assessment questions:

1. Explain the mechanism of synaptic transmission?
2. List the nuclei; describe the connections and functions of thalamus and hypothalamus
3. Explain the divisions of nervous system
4. Draw a neat label diagram of neuron
5. What are the types of neurons?
6. What are the functions of cerebrospinal fluid (CSF)?

6. SPECIAL SENSES

6.1 EYE (Vision)
6.1.1 Structure of eye
- Extra ocular muscles of the eye
- Accessory organs of eye

6.1.2 Normal Action of the Eyes
6.1.3 Physiology of sight and accommodation
6.1.4 Visual pathway

6.2 HEARING AND EAR
6.2.1 Structure
6.2.2 Physiology of hearing
6.2.3 Physiology of balance

6.3 SMELL (Nose)
6.3.1 Structure of nose
6.3.2 Physiology of smell

6.4 TASTE (Tongue)
6.4.1 Structure of tongue
6.4.2 Physiology of taste

6.5 summary

Introduction:

We receive information about our environment through sensory nerves located in a number of organs – the skin, eyes, ears, taste buds and olfactory organs. In order for us to perceive a sensation in our brain, energy must first stimulate a nerve causing it to depolarize. This is called a transduction. Different sensory nerves respond to different forms of energy – light, chemicals, vibration (mechanical), etc. Certain sensory organs have evolved for these nerves to better respond to the sources of energy. Organs of the Special senses are structurally more Complex than the structures that make up the general senses.

• **SPECIAL SENSES CLASSIFICATION:**

a. Vision(eye)
b. Equilibrium(ears)
c. Hearing?(ears)
d. Olfactory(nose)
e. Gustation(tongue)

6.1 EYE:

Learning out comes:
After studying this section you should be able to:

- **Describe the gross structure of the eye.**
- **Describe the route taken by a nerve impulse from the retina to the cerebrum.**
- **Describe how light entering the eye is focused on the retina.**
- **Describe the extraocculra and accessory organs of eye**
- **Describe Normal Action of the Eyes**

Introduction:
The human eye is a complex structure designed to gather a significant amount of information about the environment around us.

BASIC ANATOMY AND PHYSIOLOGY OF THE HUMAN EYE

This chapter provides a brief overview of the visual system, beginning at the front surface of the eye and progressing to the primary visual cortex at the back of the brain.
Topics include:

• The Protective Structures of the Eye
- The Orbit
- The Lids
- The Sclera

• The Anterior Segment of the Eye
- The Cornea
- The Aqueous Humor
- The Iris
- The Crystalline Lens and Ciliary Muscle

• The Posterior Segment of the Eye
- The Retina
- The Vitreous Humor

• The Visual System Pathways to the Brain
- The Optic Nerves and Optic Tracts
- The Lateral Geniculate Nucleus
- The Visual Cortex

6.1.1 STRUCTURES OF THE EYES

a) Adnexa of the Eyes :

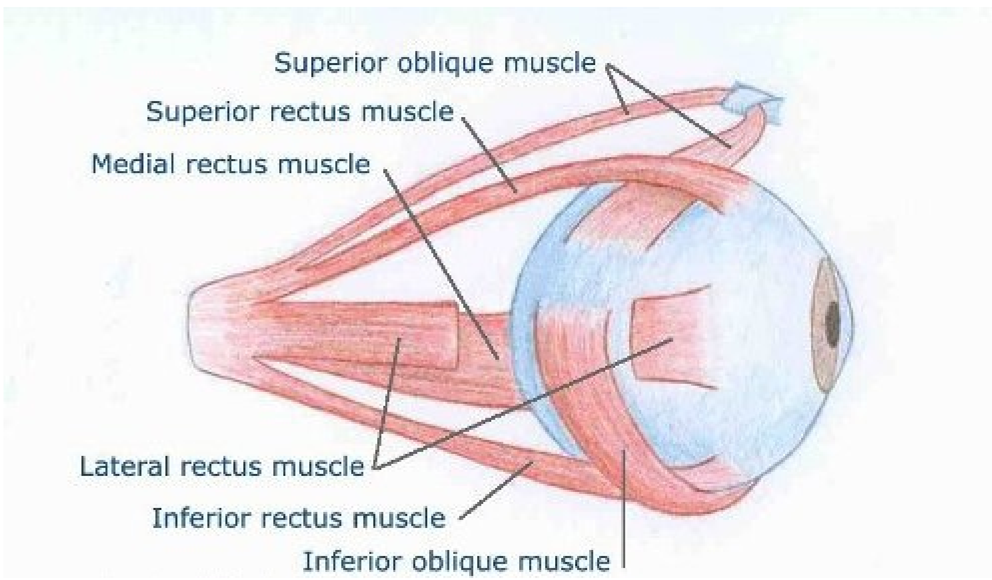
The **Adnexa** of the eyes**,** also known as **Adnexa oculi**, are the structures outside the eyeball: they are as follows, the orbit, eye muscles, eyelids, eyelashes, conjunctiva, and lacrimal apparatus. The term *Adnexa,* means the appendages or accessory structures of an organ.

b) The Orbit

The **orbit,** also known as the **eye socket,** is the bony cavity of the skull that contains and protects the eyeball and its associated muscles, blood vessels, and nerves.

c) The Eye Muscles

Six major muscles are attached to each eye and arranged into three pairs. These muscles make possible a wide range of very precise eye movements.The muscles of both eyes work together in coordinated movements that enable normal binocular vision. *Binocular* refers to the use of both eyes working together



d) The Eyelids

The **upper** and **lower eyelids** of each eye protect the eyeball from foreign matter, excessive light, and impact.

c) The canthus

The **canthus** is the angle where the upper and lower eyelids meet.The **inner canthus** is where the eyelids meet *nearest* the nose. The **epicanthus** is a vertical fold of skin on either side of the nose.The **outer canthus** is where the eyelids meet *farthestfrom* the nose.The **tarsus** also known as the **tarsal plate**, is the platelike framework within the upper and lower eyelids that provides stiffness and shape

e) The Eyebrows and Eyelashes

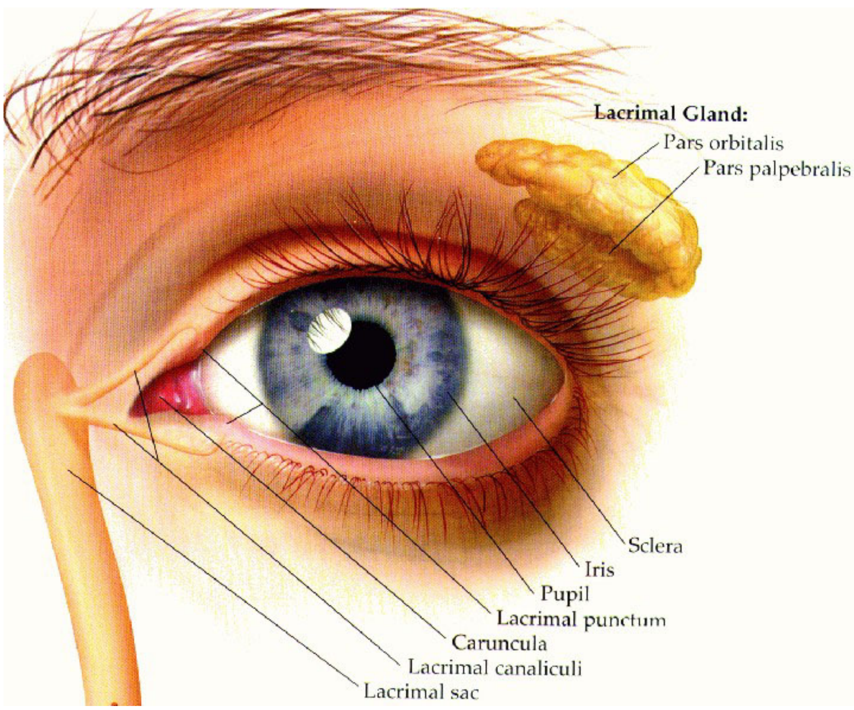
The **eyebrows** and **eyelashes** prevent foreign matter from reaching the eyes. The edges of the eyelids contain small hairs called **cilia** also known as **eyelashes**, and oil producing sebaceous glands.

f) The Conjunctiva

The **conjunctiva** is the transparent mucous membrane that lines the underside of each eyelid and continues to form a protective covering over the exposed surface of the eyeball

g) The Lacrimal Apparatus

The **lacrimal apparatus** also known as the **tear apparatus** consists of the structures that produce, store, and remove tears. The **lacrimal glands** are located above the outer corner of each eye. These glands secrete **lacrimal fluid**, which is also known as **tears**. The function of this fluid is to maintain moisture on the anterior surface of the eyeball. Blinking distributes the lacrimal fluid across the eye. The **lacrimal canal** is made up of two ducts at the inner corner of each eye. These ducts collect tears and empty them into the lacrimal sacs. Crying is the overflowing of tears from the lacrimal canals. The **lacrimal sac**, also known the **tear sac**, is an enlargement of the upper portion of the lacrimal duct. The **lacrimal duct**, also known as the **nasolacrimal duct**, is the passageway that drains excess tears into the nose.
Lacrimation is the secretion of tears, especially in excess.

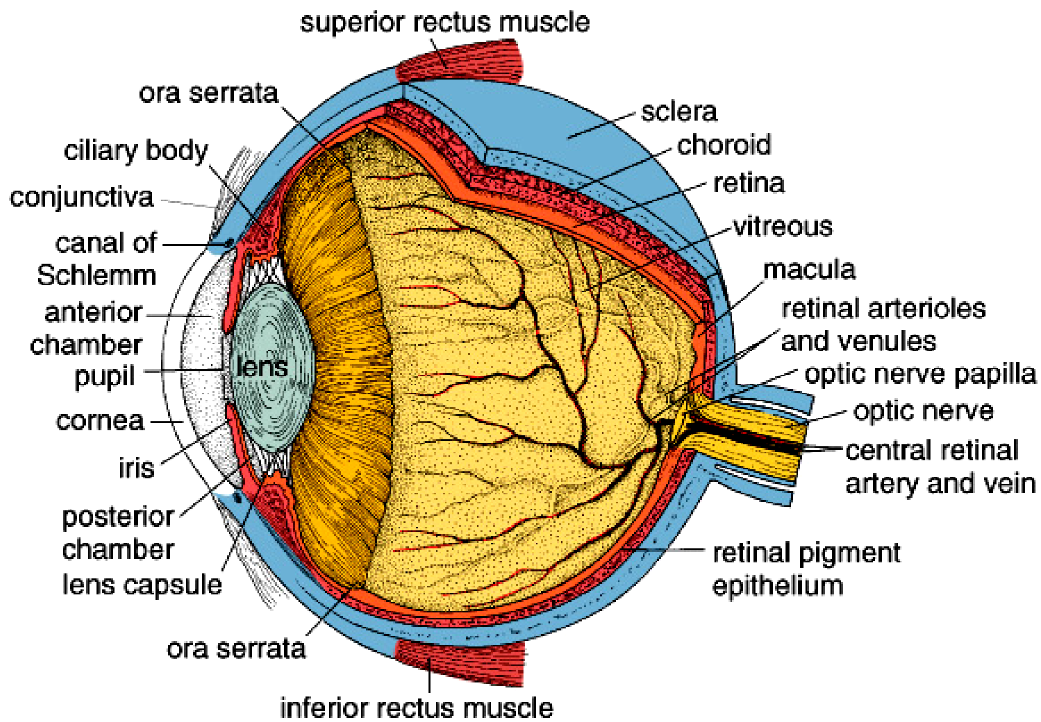


h) The Eyeball

The eyeball, also known as the **globe**, is a one-inch sphere with only about one-sixth of its surface showing on the outside. The walls of the eyeball are made up of three layers: the sclera, choroid, and retina. The interior of the eye is divided into anterior and posterior segments.

i) The Sclera and Cornea

The **sclera** also known as the **white of the eye**, is the tough, fibrous tissue that forms the outer layer of the eye, except for the part covered by the cornea. It maintains the shape of the eye and protects the delicate inner layers of tissue. The **cornea** is the transparent outer surface of the eye covering the iris and pupil. It is the primary structure focusing light rays entering the eye.



j) The Uveal Tract

The **uveal tract** also known as the **uvea** is the vascular layer of the eye. The iris is in the front, and behind it are the choroid and the ciliary body

k) The Iris, Pupil, and Lens

1) The **iris** is the pigmented (colored) muscular layer that surrounds the pupil. The color of the iris is determined by the amount of melanin that is present. *Melanin* is the pigment that also determines the color of the skin.
2) The **pupil** is the black circular opening in the center of the iris that permits light to enter the eye.

Muscles within the iris control the amount of light that is allowed to enter. To *decrease* the amount of light, these circular muscles contract and make the pupil smaller. To *increase* the amount of light, the muscles dilate (relax) and make the pupil larger.

3) The **lens,** also known as the **crystalline lens**, is the clear, flexible, curved structure that focuses images on the retina. The lens is contained within a clear capsule located behind the iris and pupil.

I) The Choroid

The **choroid** also known as the **choroid coat**, is the opaque middle layer of the eyeball that contains many blood vessels and provides the blood supply for the entire eye. *Opaque* means that light cannot pass through this substance.

1) The Ciliary Body

The **ciliary body** which is located within the choroid is a set of muscles and suspensory ligaments that adjust the thickness of the lens to refine the focus of light rays on the retina. To focus on nearby objects, these muscles adjust the lens to make it *thicker.* To focus on distant objects, these muscles stretch the lens so it is *thinner.*

J) The Retina

The **retina** is the sensitive innermost layer that lines the posterior segment of the eye. The retina contains specialized light-sensitive cells called **rods** (black and white receptors) and **cones**
(Color receptors). These rods and cones receive images and convert them into nerve impulses, which are sent to the brain via the optic nerve.

- **Histology of retina**

Photoreceptors- Are Inner and outer segments of cone and rod cells.
Rods (visual pigment **rhodopsin**) most numerous (120 million).

- Rods are sensitive to light for low illumination vision.

Cones (visual pigment **iodopsin**) 6 million.

- Cones concentrated in **fovea** for highest visual acuity.
- Cones' outer segment disks are folds of plasma membrane. Rod disks are separate stacks.
- Cones are responsible for color vision.

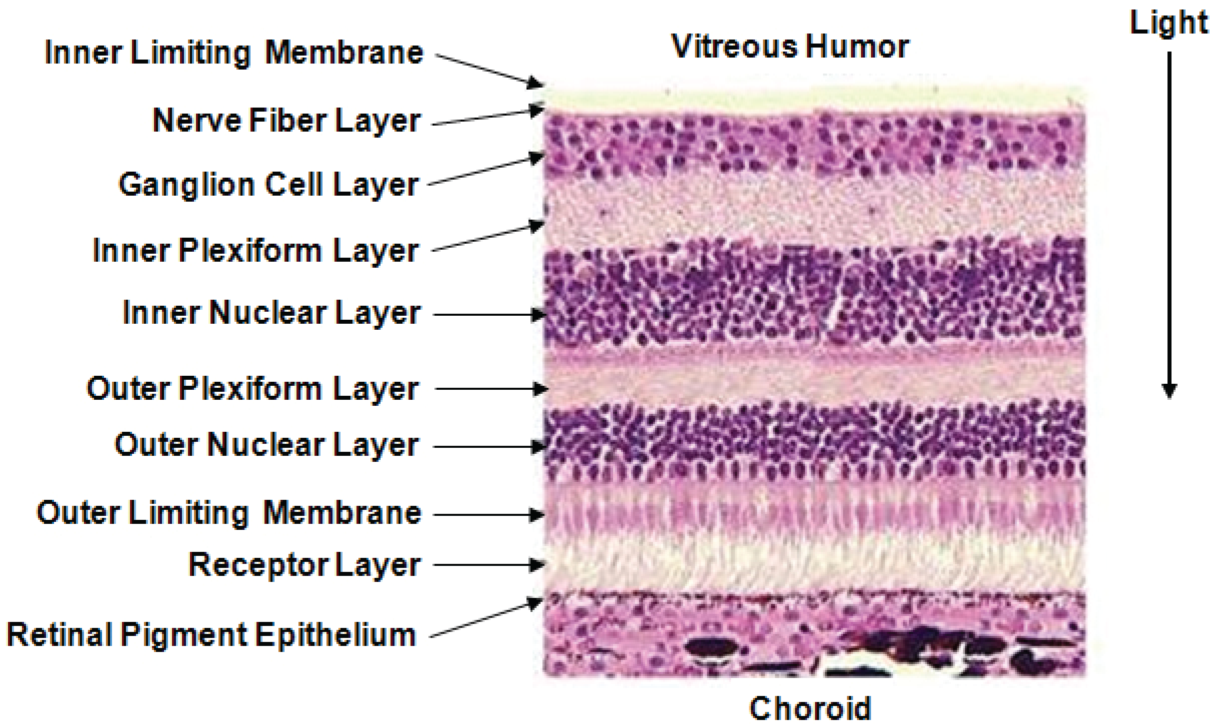
Outer limiting membrane- Junctional complexes between **Muller cells** and photoreceptor cells. **Outer nuclear layer**- Nuclei of photoreceptors.
Outer plexiform layer-Synapses of photoreceptor axons and dendrites of bipolar cells and horizontal cells.
Inner nuclear layer- Nuclei of bipolar, amacrine, horizontal and Muller cells.
Inner plexiform layer-Synapses between bipolar, ganglion and amacrine cells.
anglion cell layer-Ganglion cells of the neural retina.
Nerve fiber layer-Axons of ganglion cells
Inner limiting membrane-Basal lamina of the connected Muller cells.

The Macula and Fovea Centralis

The **macula** also known as the **macula lutea**, is a clearly defined yellow area in the center of the retina This is the area of sharpest central vision.
The **fovea centralis** is a pit in the middle of the macula. Color vision is best in this area because it contains a high concentration of cones and no rods.

The Optic Disk and Nerve

The **optic disk**, also known as the **blind spot**, is a small region in the eye where the nerve endings of the retina enter the optic nerve. It is called the blind spot because it does not contain any rods or cones to convert images into nerve impulses.The **second cranial nerve**, also known as the **optic nerve**, transmits the nerve impulses from the retina to the brain.



Segments of the Eye

The interior of the eye is divided into the anterior and posterior segments. Both segments are filled with fluid that is produced by the ciliary body .

1. **Anterior Segment of the Eye**

The front one-third of the eyeball, known as the **anterior segment**, is divided into anterior and posterior chambers. The **anterior chamber** is located behind the cornea and in front of the iris. The **posterior chamber** is located behind the iris and in front of the ligaments holding the lens in place. *Note:* Don't confuse the posterior chamber with the posterior segment.

These chambers are filled with **aqueous fluid**, also known as **aqueous humor**. As used here, a *humor* is any clear body liquid or semifluid substance. Aqueous fluid helps the eye maintain its shape and nourishes the intraocular structures. This fluid is constantly filtered and drained through the **trabecular meshwork** and the **canal of Schlemm**. This constant drainage regulates **intraocular pressure (IOP)**.

2. **Posterior Segment of the Eye**

The posterior two-thirds of the eyeball is known as the **posterior segment**. **Vitreous humor** also known as **vitreous gel**, is the soft, clear, jellylike mass that fills this segment to aid the eye in maintaining its shape. The posterior segment is lined with the retina and its related structures.

6.1.2 Normal Action of the Eyes

- The two eyes are the receptor organs of sight.
- The letter *O* stands for *oculus*, the Latin word for eye.
- The functions of the eyes are to receive images and transmit them to the brain.

1. **Accommodation** is the process whereby the eyes make adjustments for seeing objects at various distances. These adjustments include constriction (narrowing) and dila dilation (widening) of the pupil, movement of the eyes, and changes in the shape of the lens.
2. **Convergence** is the simultaneous inward movement of the eyes toward each other in an effort to maintain single binocular vision as an object comes nearer.
3. **Emmetropia** is the normal relationship between the refractive power of the eye and the shape of the eye that enables light rays to focus correctly on the retina
4. **Refraction** is the ability of the lens to bend light rays to help them focus on the retina

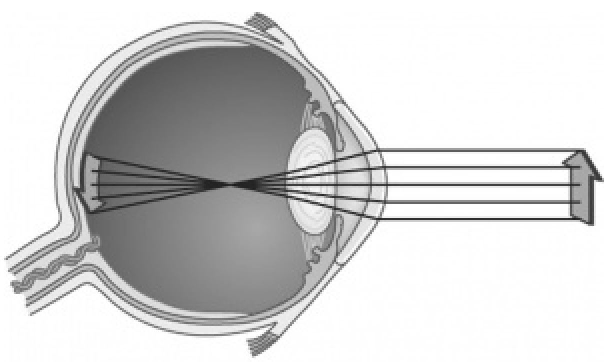
6.1.3 Accommodation

The mechanism by which the eye changes focus from distant to near images is called accommodation. Accommodation is produced by a change in lens shape as a result of the action of the ciliary muscle on the zonular fibers. The lens substance is most malleable during childhood and the young adult years, and it progressively loses its ability to change shape with age. After approximately 40 years, the rigidity of the lens nucleus clinically reduces accommodation.

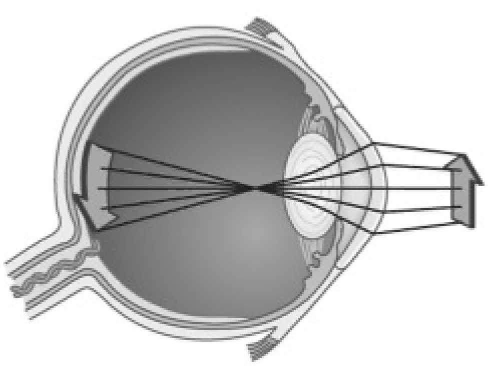
Most of the change in lens shape that takes place during accommodation occurs at the central anterior lens surface. The central anterior capsule is thinner than the peripheral capsule, and the anterior zonular fibers insert slightly closer to the visual axis than do the posterior zonular fibers, resulting in a central anterior bulge with accommodation. The central posterior capsule is the thinnest area of the capsule and tends to bulge posterior to the same extent regardless of zonular tension.

The ciliary muscle is a ring that, upon contraction, has the opposite effect from that intuitively expected of a sphincter. When a sphincter muscle contracts, it usually tightens its grip. However, when the ciliary muscle contracts, the diameter of the muscle ring is reduced, thereby relaxing the tension on the zonular fibers and allowing the lens to become more spherical. Thus, when the ciliary muscle contracts, the axial thickness of the lens increases, its diameter decreases, and its dioptric power increases, producing accommodation. When the ciliary muscle relaxes, the zonular tension increases, the lens flattens, and its dioptric power decreases. The accommodative response may be stimulated by the known or apparent size and distance of an object, or by blur, chromatic aberration, or a continual oscillation of ciliary tone. Accommodation is mediated by the parasympathetic fibers of cranial nerve III (oculomotor). Parasympathomimetic drugs (e.g. pilocarpine) induce accommodation, while parasympatholytic medications (e.g. atropine) block accommodation. Drugs that cause relaxation of the ciliary muscle are called cycloplegics.

The amplitude of accommodation is the amount of change in the eye's refractive power that is produced by accommodation. It diminishes with age and may be affected by some medications and diseases. Adolescents generally have 12-16 diopters of accommodation, while adults at age 40 have 4-8 diopters. After age 50 accommodation decreases to less than 2 diopters. Hardening of the lens with age is the principal cause of accommodation, which is called presbyopia.



Distant image: lens is flattened



Close image: lens is rounded

6.1.4 The Visual Pathway

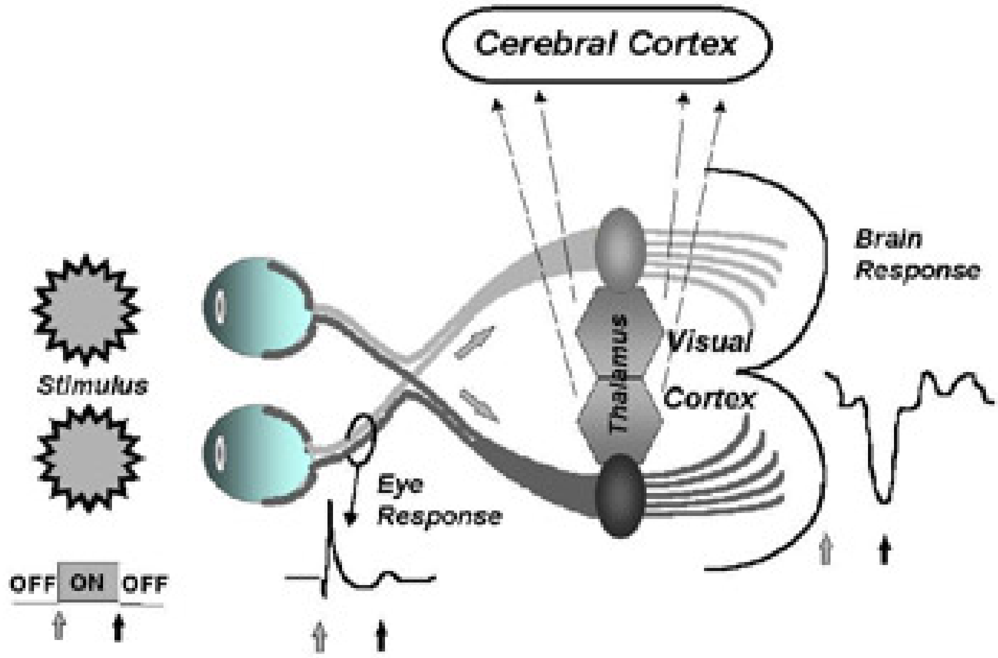
The neural signals initially processed by the retina travel via the axons of the ganglion cells through the optic nerves, dividing and partially crossing over into the optic chiasm and then travelling via the optic tracts to the lateral

geniculate nucleus (LGN). From the LGN, the signals continue to the primary visual cortex, where further visual processing takes place (Figure 6-5).
When both eyes are open, the blind spot of each eye is “filled in” by the visual field of the other eye. The optic nerves of each eye continue posteriorly and then meet at the optic chiasm. It is here that axons of neurons from the nasal retina (temporal visual field) cross to the opposite or “contralateral” optic tract. From the right eye temporal visual field cross to the optic tract on the left side of the brain). Axons of neurons from the temporal retina continue along the same side or “ipsilateral” optic tract (same side of the brain). This means that visual signals from the right side of the visual field are traveling to the brain via the left optic tract and signals from the left visual field are traveling via the right optic tract. Each optic tract terminates at its LGN.

The lateral geniculate nucleus (LGN)
The LGN is a paired structure located at the dorsal thalamus. It is here that visual information to the brain, specifically the visual cortex, appears to be regulated and the first stage of coordinating vision from both eyes begins. Each LGN has six layers, three receiving input from the right eye and three receiving input from the left eye. The LGN then sends forward neurons via the *optic radiations* to the p*rimary visual cortex*.

- The Visual Cortex

The visual cortex in the occipital lobe of the brain is where the final processing of the neural signals from the retina takes place and “vision” occurs. The occipital lobe is at the most posterior portion of the brain. There are a total of six separate areas in the visual cortex, known as the V1, V2, V3, V3a, V4 and V5. The primary visual cortex or V1 is the first structure in the visual cortex where the neurons from the LGN synapse. In V1, the neural signals are interpreted in terms of visual space, including the form, color and orientation of objects. V1 dedicates most of its area to the interpretation of information from the fovea. This mapping is known as “cortical magnification” and is typical in primates and animals that rely on information from the fovea for survival. The signals then pass through to V2 where color perception occurs and form is further interpreted. As the neural signals continue further into other areas of the visual cortex, more associative processes take place. In the portions of the visual cortex that make up the parietal visual cortical areas, motion of objects, motion of self through the world and spatial reasoning occur. In the temporal visual cortical areas, including the middle temporal (V5) area, recognition of objects through interpretation of complex forms and patterns occurs. The final psychological and perceptual experience of vision also includes aspects of memory, expectation/prediction and interpolation sub served by other apparently non-visual areas of the brain.


Cerebral Cortex
Brain
Response
Stimulus
Thalamus
Visual
Cortex
Eye
Response
OFF ON OFF

6.2 HEARING AND EAR

6.2.1 Structure

6.2.2Functions of ears

6.2.3 Physiology of hearing

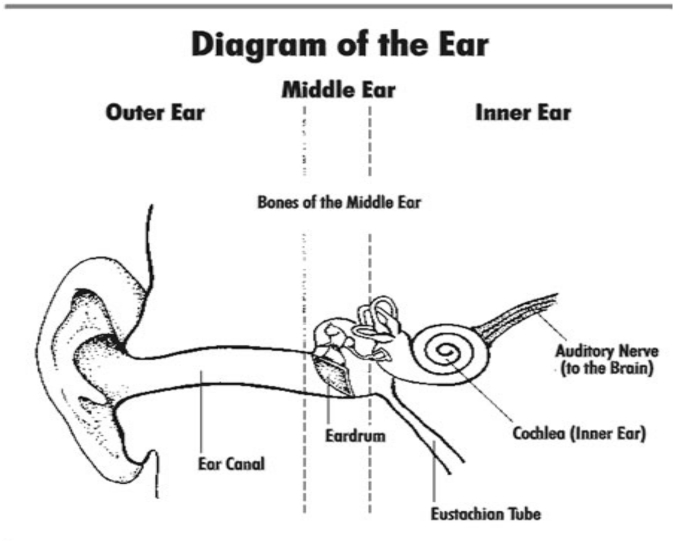
6.2.4 Physiology of balance

Learning outcomes
After studying this section you should be able to**:**
- **Describe the structure of the outer, middle and inner ear.**
- **Explain the physiology of hearing.**
- **Describe the normal actions of ears.**

Introduction:
Hearing is one of the major senses and like vision is important for distant warning and communication. It can be used to alert, to communicate pleasure and fear. The function of the ear is to convert physical vibration into an encoded nervous impulse. It can be thought of as a biological microphone.
The ears are paired organs, one on each side of the head with the sense organ itself, which is technically known as the cochlea, deeply buried within the temporal bones. Part of the ear is concerned with conducting sound to the cochlea; the cochlea is concerned with transducing vibration. The transduction is performed by delicate hair cells which, when stimulated, initiate a nervous impulse.

6.2.1 STRUCTURE OF THE EARS
The ear is divided into three separate regions: the outer ear, the middle ear, and the inner ear

a) The Outer Ear
The pinna (PIN-nah), also known as the auricle, is the external portion of the ear. This structure catches sound waves and transmits them into the external auditory canal. The external auditory canal transmits sound waves from the pinna to the middle ear. Cerumen also known as ear wax is secreted by ceruminous glands that line the auditory canal. This sticky yellow-brown substance has protective functions as it traps small insects, dust, debris, and certain bacteria to prevent them from entering the middle ear.



b) The Middle Ear

The tympanic membrane, also known as the eardrum, is located between the outer and middle ear. The eardrum seals the inner end of the ear canal. When sound waves reach the eardrum, this membrane transmits the sound by vibrating. The middle ear is surrounded by the mastoid bone cells, which are hollow air spaces located in the mastoid process of the temporal bone. An infection in the middle ear can rapidly spread to these cells.

The auditory ossicles are three small bones found in the middle ear. These bones transmit the sound waves from the eardrum to the inner ear by vibration. These bones, which are named for the Latin terms that describe their shapes, are the:

- **Malleus** also known as the **hammer**
- **Incus,** also known as the **anvil**
- **Stapes,** also known as the **stirrup**

The Eustachian tubes, also known as the auditory tubes, are narrow tubes that lead from the middle ear to the nasal cavity and the throat. The purpose of the tubes is to equalize the air pressure in the middle ear with that of the outside atmosphere.

c) The Inner Ear

The inner ear, also known as the labyrinth, contains the sensory receptors for hearing and Balance. The oval window, which is located under the base of the stapes, is the membrane that separates the middle ear from the inner ear. Vibrations enter the inner ear through this passage. The cochlea is the spiral passage that leads from the oval window. The cochlear duct, located within the cochlea, is filled with fluid that vibrates when the sound waves strike it. The organ of Corti, also located within the cochlea, is the receptor site that receives these vibrations and relays them to the auditory nerve fibers, which transmit them to the auditory center of the brain's cerebral cortex, where they are heard and interpreted.

The three semicircular canals, also located within the inner ear, contain endolymph (a liquid) and sensitive hair like cells. The bending of this hair like cells in response to the movements of the head sets up impulses in nerve fibers to help maintain equilibrium. *Equilibrium* is the state of balance. The acoustic nerves (cranial nerve VIII) transmit this information to the brain, and the brain sends messages to muscles in all parts of the body to ensure that equilibrium is maintained.

6.2.2 **Normal Action/functions of the Ears**

1)Air conduction is the process by which sound waves enter the ear through the pinna. These waves then travel down the external auditory canal and strike the tympanic membrane between the outer and middle ear.

2)Bone conduction occurs as the eardrum vibrates and moves the auditory ossicles. These bones then conduct the sound waves through the middle ear to the inner ear.

3)Sensorineural conduction occurs when sound vibrations reach the inner ear via the oval window. From here the structures of the inner ear receive the sound waves and relay them to auditory nerve for transmission to the brain.

6.2.3 THE PHYSIOLOGY OF HEARING:

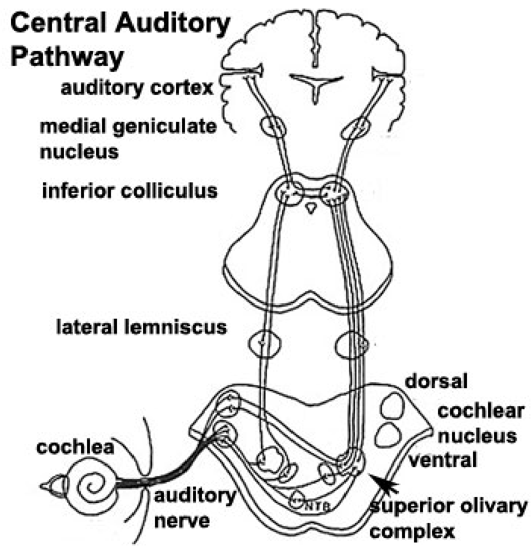
Let us deal first with the sound conducting mechanism. The range of audible sound is approximately 10 octaves from somewhere between 16 and 32 Hz (cycles per second) to somewhere between 16,000 and 20,000 Hz. The ear canal acts as a resonating tube and actually amplifies sounds at between 3000 and 4,000 Hz adding to the sensitivity (and susceptibility to damage) of the ear at these frequencies.

The ear is very sensitive and responds to sounds of very low intensity, to vibrations which are hardly greater than the natural random movement of molecules of air. The Eustachian tube provides the means of the pressure equalization. It does this by opening for short periods, with every 3rd or 4th swallow; if it were open all the time one would hear one's own every breath.

The outer and middle ears serve to amplify the sound signal. The pinna presents a fairly large surface area and funnels sound to the smaller tympanic membrane; in turn the surface of the tympanic membrane is itself much larger than that of the stapes foot plate, so there is a hydraulic amplification: a small movement over a large area is converted to a larger movement of a smaller area. In addition, the ossicular chain is a system of levers which serve to amplify the sound. The outer and middle ears amplify sound on its passage from the exterior to the inner ear. This amplified movement is transmitted to the inner hair cells which then respond. The function of the inner ear is to transduce vibration into nervous impulses.

Central Auditory Processing :

The nervous impulses are carried along the 8th (statico-acoustic nerve) nerve from the cochlea to the brain stem. Here the nerve fibers reach nuclei where they relay with other nerve fibers. The fibers from each auditory nerve split, some passing to one side of the brain, others remaining on the same side. Thus, as auditory stimuli pass up each side of the brain from both ears. The fibers pass up the hind brain to the mid brain and the cerebral cortex.



6.3 SENSE OF SMELL (OLFACTION)

6.3.1 Structure of nose
6.3.2 Physiology of smell

<u>Learning outcomes</u>

After studying this section you should be able to:

- **Describe the physiology of smell.**
- **Describe the structure of nose.**

Introduction:

Our senses of smell (olfaction) depend on chemoreceptor's that respond to chemicals in an aqueous solution.

Olfactory Sensation

• The reception of the sense of smell is provided by a pair of olfactory organs. Olfactory organs are located in the nasal cavity. The olfactory organs are made up of two layers.

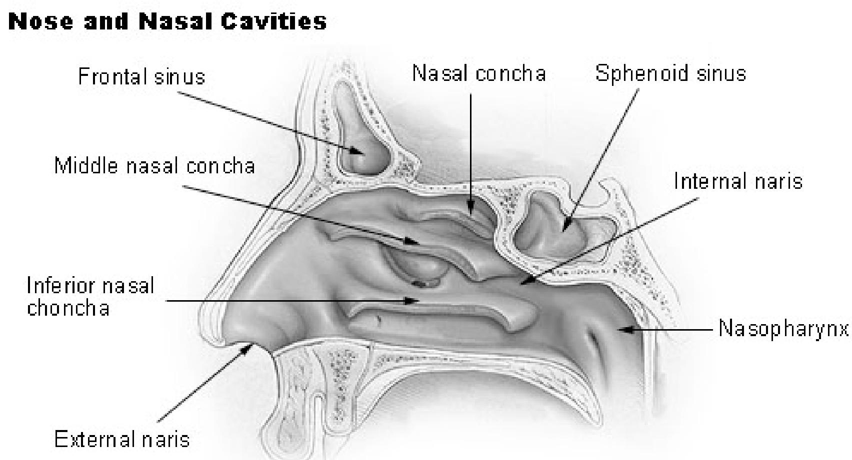
Olfactory epithelium contains
– Olfactory receptors
– Supporting cells
– Basal cells

• It covers certain areas of the ethmoid bone, the inferior surface of the cribiform plate, Superior aspect of perpendicular plate, Superior nasal conchae

-Olfactory Sensation

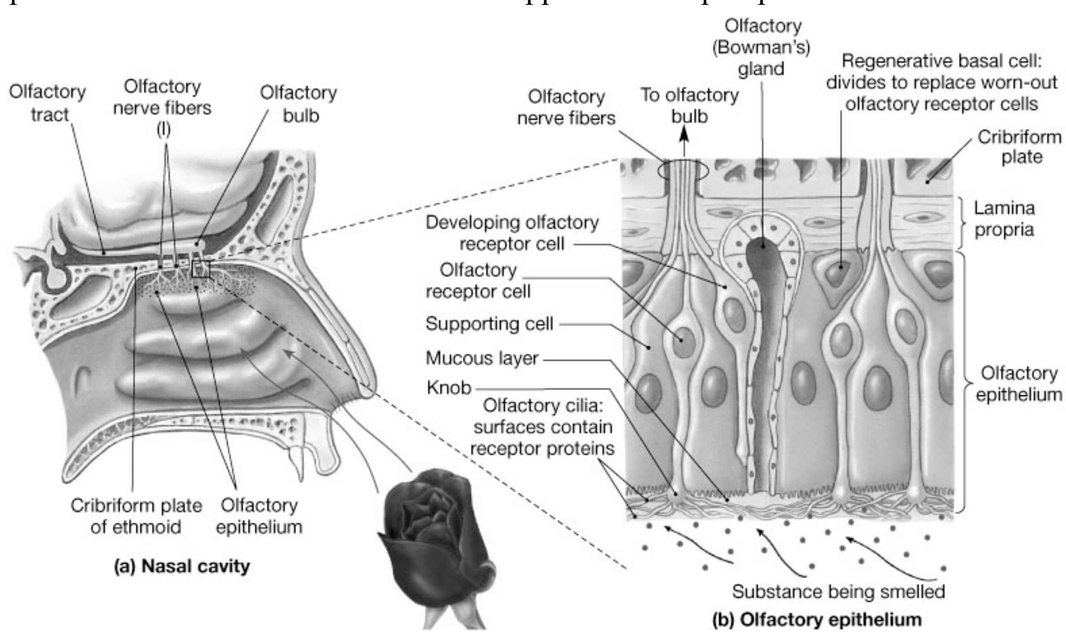
• Breathing in air through the nose circulates the air around within the nasal cavities. The nasal concha helps in the swirling motion of the air. Molecules in the air need to be trapped into a liquid mucus phase before the receptors can be stimulated by them

6.3.1 Structure of nose



-Lamina Propria

• Lamina propria is located under the olfactory epithelium and contains, numerous blood vessels, Nerves; Olfactory Glands (Bowman's Glands).Bowman's glands provide the mucus via ducts to the surface of the epithelium such that molecules can be trapped into a liquid phase.



6.3.2 Physiology of smell:

- Olfactory Receptors

Olfactory Receptors are located in the Olfactory mucosa. They are specialized neurons that contain numerous cilia that extend into the surface, surrounded by mucus. Dissolved chemicals interact with the cilia and result in binding to receptors that are coupled to G-proteins. This results in production of cAMP, which in turn opens Na+ channels and Depolarization occurs. If sufficient depolarization's occur (graded potentials), an action potentials is triggered.

- Olfactory Pathways

The olfactory neurons pass through the holes of the cribiform plate and synapse with the Olfactory bulb. From here, the olfactory nerve has axons synapsing with the olfactory cortex, the hypothalamus and portions of the limbic system. No connections are made with the Thalamus. Extensive convergence occurs within the olfactory epithelium before reaching the olfactory bulb. This allows for possible inhibition of facilitation. Similarly, other neurons synapse with the olfactory bulb allowing an additional level of facilitation or inhibition. At least 50 primary "smells" have been identified and we can identify 2000 - 4000 chemical stimuli. Many odorants are detected at an amazing small quantity (beta- mercaptane).Our olfactory sensation is very under-developed compared to other animals (Dogs have olfactory surface area 70 times greater than humans)

6.4 SENSE OF TASTE- GUSTATION (Tongue)

6.4.1 Structure of tongue

6.4.2 Physiology of taste

Learning outcomes

After studying this section you should be able to:

- **Describe the physiology of taste**
- **Describe structure of tongue.**

Introduction:

The receptor organs for taste are called taste buds and are concentrated on the tongue though a few may be found on the soft palate, the inside of the cheeks, and even the epiglottis. Taste buds on the tongue are found on papillae, minute "bumps" on the tongue that give the tongue a rough texture. There may be many taste buds on a papilla.

The taste bud consists of several dozen epithelium cells of two types:

- Gustatory cells which are arranged like sections of an orange. From the ends of these project long microvilli called gustatory hairs which extend through a taste pore to the surface.

- Deep to the gustatory cells are basal cells which divide into new gustatory cells. Because gustatory cells are subjected to so much erosion, these cells divide rapidly, replacing gustatory cells about every week or so. In order for the sensation of taste to occur certain chemicals bind to the gustatory hairs. This causes a depolarization of the cell membrane which then synapses with sensory nerve dendrites of cranial nerves VII and IX, attached to the gustatory cell. For a chemical to bind to the gustatory hairs, it must first be in an aqueous solution (dissolved in saliva).

There are five basic taste sensations:

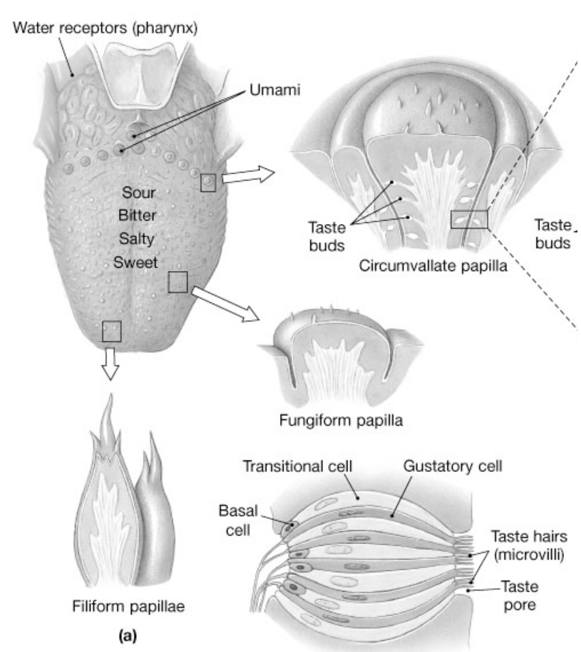
1. **Sweet.** The sweet sensation is triggered by a number of organic molecules, mostly sugars but some alcohols and amino acids, and by some lead compounds.
2. **Sour.** This taste is produced by the H+ ions in acids.
3. **Salt.** The taste of salt is produced by certain metal ions such as Na+.
4. **Bitter.** The bitter taste comes from plant alkaloids such as caffeine and nicotine and some other Nonalkaloid chemicals.
5. **Umami.** This "beefy" taste comes from a few amino acids.

Most taste buds respond to more than one of these and our taste sensation is usually a mixture of several of these. All of the other rich sensations we have while eating (e.g. chocolate) are really perceived through olfaction. Gustation provides the information for the foods and liquids we consume.

• the taste buds are located in epithelial projections called the lingual papillae. Human tongue has 3 different kinds of papillae.

1. Filiform : do not contain taste buds but provide friction for moving food around
2. Fungiform : contain around 5 taste buds
3. Circumvallate : contain around 100 taste buds and are located in back of the tongue in a V-shape

6.4.1 Structure of tongue



Tastebuds :

Each taste bud contains about 50 -100 cells. There are 4 different kinds of cells. Two important ones are

• Basal cells
• Gustatory cells

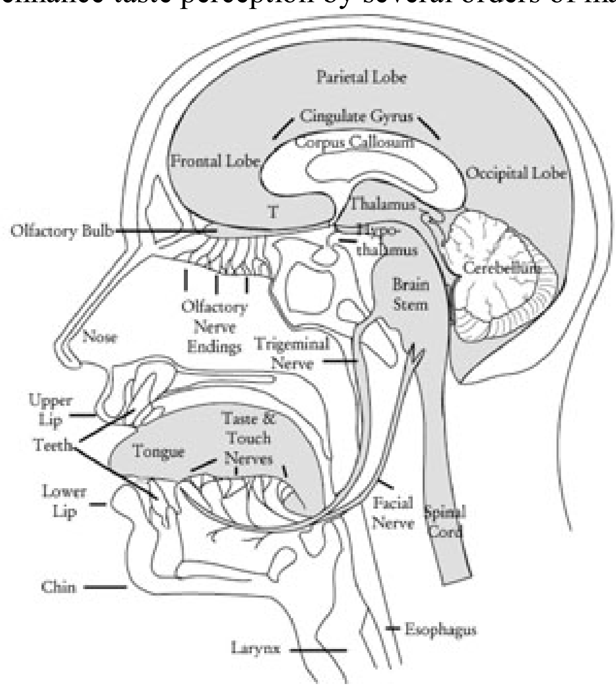
Taste sensitivity shows significant individual differences, some of which are inherited. The number of taste buds declines with age.

• Typical gustatory cells lasts for about 10 days Each taste receptor cell is connected, through an ATP-releasing synapse, to a sensory neuron leading back to the brain. However, a single sensory neuron can be connected to several taste cells in each of several different taste buds. The sensation of taste — like all sensations —resides in the brain

6.4.2 Physiology of taste :

Gustation Pathways:

• The Taste buds are monitored by cranial nerves: VII, IX and X.Sensory afferent nerves synapse within the solitary nucleus of the medulla oblongata. Then on to the thalamus and the primary sensory cortex. Information about Texture is provided via the Trigeminal nerve. In addition, olfactory receptors enhance taste perception by several orders of magnitude



6.5 Summary:

The special senses of hearing, sight, smell, and taste all have specialised sensory receptors(nerve endings) Outside the brain.

In the brain the incoming nerve impulses undergo complex process Of integration and coordination that result in perception of sensory information and a variety of responses inside and out side the body

Self assessment questions:

1. Trace the visual pathway?
2. What are the contents and functions of the middle ear?
3. Explain the mechanism of appreciation of sounds? trace the auditory pathway with the help of a neat labeled diagram.
4. Trace the taste pathway.
5. Trace the olfactory pathway.
6. List the functions of lacrimal secretions?
7. Discuss the location and types of visual cortex.
8. Mention the extraocculra muscles and movements produced by them.
9. Name the primary taste sensations.
10. Draw the diagram of a taste bud.

7. THE ENDOCRINE SYSTEM

7.1 Pituitary gland and hypothalamus
  Anterior Pituitary
  Posterior Pituitary
7.2 Thyroid gland
7.3 Parathyroid glands
7.4 Adrenal(suprarenal)glands
  Adrenal cortex
  Adrenal medulla
7.5 Pancreatic islets
7.6 Pineal gland or body
7.7 Thymus gland
7.8 Gonads and their hormones
7.9 Local hormones
7.10 summary

Introduction:

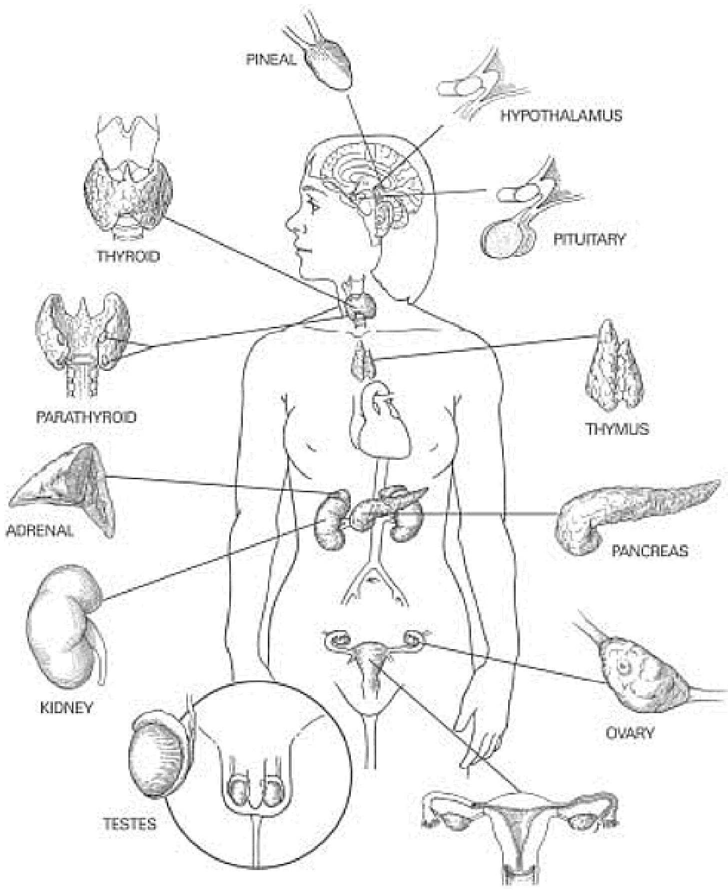
For the body to function properly, its various parts and organs must communicate with each other to ensure that a constant internal environment (i.e., homeostasis) is maintained. Communication among various regions of the body also is essential for enabling the organism to respond appropriately to any changes in the internal and external environments. Two systems help ensure communication: the nervous system and the hormonal (i.e., neuroendocrine) system. Hormonal communication, which relies on the production and release of hormones from various glands and on the transport of those hormones via the bloodstream, is better suited for situations that require more widespread and longer lasting regulatory actions.

Generally speaking, hormones control the growth, development, and metabolism of the body; the electrolyte composition of bodily fluids; and reproduction. The endocrine system accomplishes these tasks via a network of glands and organs that produce, store, and secrete certain hormones.

Endocrine glands lack ducts and are hence, called ductless glands. Their secretions are called hormones. Hormones are molecules that are produced by endocrine glands, including the hypothalamus, pituitary gland, adrenal glands, gonads, (i.e., testes and ovaries), thyroid gland, parathyroid glands, and pancreas. In addition to these, some other organs, e.g., gastrointestinal tract, liver, kidney, heart also produce hormones.

Hormones are non-nutrient chemicals which act as intercellular messengers and are produced in trace amounts. The term “endocrine” implies that in response to specific stimuli, the products of those glands are released into the bloodstream. The hormones then are carried via the blood to their target cells. Some hormones have only a few specific target cells, whereas other hormones affect numerous cell types throughout the body. The target cells for each hormone are characterized by the presence of certain docking molecules (i.e., receptors) for the hormone that are located either on the cell surface or inside the cell. The interaction between the hormone and its receptor triggers a cascade of biochemical reactions in the target cell that eventually modify the cell's function or activity.

The endocrine glands are:
1 pituitary gland
1 thyroid gland
4 parathyroid glands
2 adrenal (suprarenal) glands
The pancreatic islets (islets of langerhans)
1 pineal gland or body
1 thymus gland
2ovaries in the female
2 testes in the male.



7.1 PITUITARY GLAND AND HYPOTHALAMUS

Learning outcomes

After studying this section you should be able to:

- **Describe the structure of hypothalamus and the pituitary gland**
- **Explain the influence of hypothalamus on pituitary lobes**
- **Outline the actions of the hormones secreted by the anterior and posterior lobes of pituitary gland.**

7.1.1 Hypothalamic-Pituitary adrenal Axis

The hypothalamus is the control center for most of the body's hormonal systems. Located deep within the brain, the hypothalamus receives nerve impulses stemming from both physical and psychological stimuli and releases hormones in response to those signals. Hypothalamic activity thus governs numerous body functions including reproduction, metabolism, use of nutrients, and growth.

7.1.2 The Hypothalamus and Its Hormones

The hypothalamus is a small region located within the brain that controls many bodily functions, including eating and drinking, sexual functions and behaviors, blood pressure and heart rate, body temperature maintenance, the sleep-wake cycle, and emotional states (e.g., fear, pain, anger, and pleasure). Hypothalamic hormones play pivotal roles in the regulation of many of those functions. Because the hypothalamus is part of the central nervous system, the hypothalamic hormones actually are produced by nerve cells (i.e., neurons). The hypothalamus serves as the major link between the nervous and endocrine systems. Hypothalamic function is influenced by both the external and internal environments as well as by hormone feedback. The communication between other brain areas and the hypothalamus, which conveys information about the internal environment, involves electrochemical signal transmission through molecules called neurotransmitters (e.g., aspartate, dopamine, gammaaminobutyric acid, glutamate, norepinephrine, and serotonin). The complex interplay of the actions of various neurotransmitters regulates the production and release of hormones from the hypothalamus.

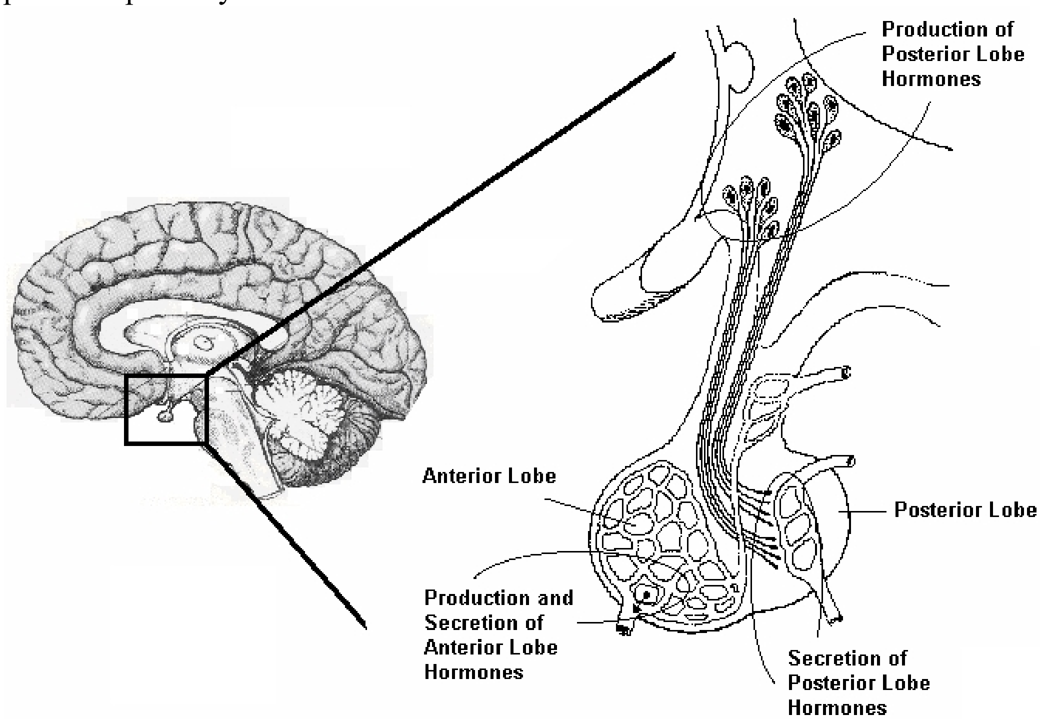
The hypothalamic hormones are released into blood vessels that connect the hypothalamus and the pituitary gland (i.e., the hypothalamichypophyseal portal system). Because they generally promote or inhibit the release of hormones from the pituitary gland, hypothalamic hormones are commonly called releasing or inhibiting hormones.

The major releasing and inhibiting hormones include the following:

• **Corticotropin-releasing hormone (CRH),** which is part of the hormone system regulating carbohydrate, protein, and fat metabolism as well as sodium and water balance in the body
• **Gonadotropin-releasing hormone (GnRH**), which helps control sexual and reproductive functions, including pregnancy and lactation (i.e., milk production)
• **Thyrotropin-releasing hormone (TRH),** which is part of the hormone system controlling the metabolic processes of all cells and which contributes to the hormonal regulation of lactation
• **Growth hormone-releasing hormone (GHRH**), which is an essential component of the system promoting the organism's growth
• **Somatostatin**, which also affects bone and muscle growth but has the opposite effect as that of GHRH
• **Dopamine,** a substance that functions primarily as a neurotransmitter but also has some hormonal effects, such as repressing lactation until it is needed after childbirth.

7.1.3 The Pituitary gland and Its Major Hormones

The pituitary (also sometimes called the hypophysis) is a gland about the size of a small marble and is located in the brain directly below the hypothalamus. The pituitary gland consists of two parts: the anterior pituitary and the posterior pituitary.



7.1.3a The Anterior Pituitary(adenohypophysis)

The anterior pituitary produces several important hormones that either stimulate target glands (e.g., the adrenal glands, gonads, or thyroid gland) to produce target gland hormones or directly affect target organs. The pituitary hormones include

1. Adrenocorticotropic hormone (ACTH)
2. Gonadotropin
3. Thyroid-stimulating hormone (TSH), also called Thyrotropin
4. Growth hormone (GH) and
5. Prolactin.

The first three of those hormones— ACTH, gonadotropins, and TSH— act on other glands.

1. ACTH stimulates the adrenal cortex to produce corticosteroid hormones—primarily cortisol—as well as small amounts of female and male sex hormones.

2. Gonadotropins comprise two hormones.
   a. Luteinizing hormone (LH) and
   b. Follicle-stimulating hormone (FSH).

These two hormones regulate the production of female and male sex hormones in the ovaries and testes as well as the production of the germ cells—that is, the egg cells (i.e., ova) and sperm cells (i.e., spermatozoa).
3. TSH stimulates the thyroid gland to produce and release thyroid hormone.
The remaining two pituitary hormones, GH and Prolactin, directly affect their target organs.

4. Growth Hormone*:* GH is the most abundant of the pituitary hormones. As the name implies, it plays a pivotal role in controlling the body's growth and development. For example, it stimulates the linear growth of the bones; promotes the growth of internal organs, fat (i.e., adipose) tissue, connective tissue, endocrine glands, and muscle; and controls the development of the reproductive organs. Accordingly, the GH levels in the blood are highest during early childhood and puberty and decline thereafter. Nevertheless, even relatively low GH levels still may be important later in life, and GH
Deficiency may contribute to some symptoms of aging. In addition to its growth-promoting role, GH affects carbohydrate, protein, and fat (i.e., lipid) metabolism. Thus, GH increases the levels of the sugar glucose in the blood by reducing glucose uptake by muscle cells and adipose tissue and by promoting glucose production (i.e., gluconeogenesis) from precursor molecules in them liver.GH also enhances the uptake of amino acids from the blood into cells, as well as their incorporation into proteins, and stimulates the breakdown of lipids in adipose tissue. To elicit these various effects, GH modulates the activities of numerous target organs, including the liver, kidneys, bone, cartilage, skeletal muscle, and adipose cells. Two hypothalamic hormones control GH release: (1) GHRH, which stimulates GH release, and

(2) Somatostatin, which inhibits GH release. This regulatory mechanism also involves a short-loop feedback component, by which GH acts on the hypothalamus to stimulate somatostatin release. In addition, GH release is enhanced by stress, such as low blood sugar levels (i.e., hypoglycemia) or severe exercise, and by the onset of deep sleep.

5. Prolactin. Together with other hormones, prolactin plays a central role in the development of the female breast and in the initiation and maintenance of lactation after childbirth. Prolactin's function in men, however, is not well understood, although excessive prolactin release can lead to reduced sex drive (i.e., libido) and impotence. Several factors control prolactin release from the anterior pituitary. For example, Prolactin is released in increasing amounts in response to the rise in estrogen levels in the blood that occurs during pregnancy. In nursing women, prolactin is released in response to suckling by the infant. Several releasing and inhibitory factors from the hypothalamus also control Prolactin release. The most important of those factors is dopamine, which has an inhibitory effect.

Disorders of The anterior pituitary:

a. Hyperpituitarism

Hyperpituitarism is defined as excessive secretion of one or more of the pituitary hormones. Its most common causes are functioning (hormone-secreting) adenomas of the anterior lobe.

Effects of pituitary adenomas

Pituitary adenomas cause problems because of a combination of endocrine effects (excessive secretion of a particular hormone) and compressive effects, caused by an increase in local pressure of the following:

• Remainder of the pituitary →hypopituitarism.

• Optic chiasm →visual field defects, notably bitemporal haemianopia. The endocrine effects depend on which hormone is being excessively secreted.

b. hypopituitarism

Hypopituitarism is defined as insufficient secretion of the pituitary hormones. The clinical features depend on the patient's age and on the type and severity of the hormone deficiencies Hypopituitarism can be caused by either hypothalamic lesions or pituitary lesions. Hypothalamic lesions are:

• Idiopathic deficiency of one or more of the releasing factors, e.g. gonadotrophin-releasing hormone (GnRH; Kallmann's syndrome), growth-hormone releasing factor (GHRH) or, more rarely, thyrotrophin-releasing hormone (TRH) or corticotrophin-releasing factor (CRF).

• Infarction.

• Inflammation, e.g. sarcoidosis, tuberculous meningitis.

• Suprasellar tumors, e.g. craniopharyngioma or, more rarely, pinealoma, teratoma or a secondary tumor from another site.

7.1.3b The Posterior Pituitary(neurohypophysis)

The posterior pituitary does not produce its own hormones; instead, it stores two hormones:

1. Vasopressin
2. Oxytocin.

Those are produced by neurons in the hypothalamus. Both hormones collect at the ends of the neurons, which are located in the hypothalamus and extend to the posterior pituitary. Vasopressin, also called arginine vasopressin (AVP), plays an important role in the body's water and electrolyte economy. Thus, AVP release promotes the reabsorption of water from the urine in the kidneys. Through this mechanism, the body reduces urine volume and conserves water.

AVP release from the pituitary is controlled by the concentration of sodium in the blood as well as by blood volume and blood pressure. For example, high blood pressure or increased blood volume results in the inhibition of AVP release. Consequently, more water is released with the urine, and both blood pressure and blood volume are reduced. Oxytocin, the second hormone stored in the posterior pituitary, stimulates the contractions of the uterus during childbirth. In nursing women, the hormone activates milk ejection in response to suckling by the infant (i.e., the so-called let-down reflex).

Disorders of The posterior pituitary:

Diseases of the posterior pituitary are much less common than those of the anterior pituitary and are usually the result of damage to the hypothalamus by tumor invasion or infarction. Posterior pituitary diseases typically cause disorders of abnormal ADH secretion. There are no known effects of abnormal Oxytocin secretion.

Diabetes insipidus

Diabetes insipidus (DI) is a rare condition characterized by the persistent excretion of excessive quantities of dilute urine (polyuria) and by constant thirst (polydipsia).

There are two types

1. Cranial DI—caused by the failure of ADH production.
2. Nephrogenic DI—distal tubules are refractory to the water reabsorptive action of ADH.

7.2 THE THYROID GLAND AND ITS HORMONES

Learning outcomes

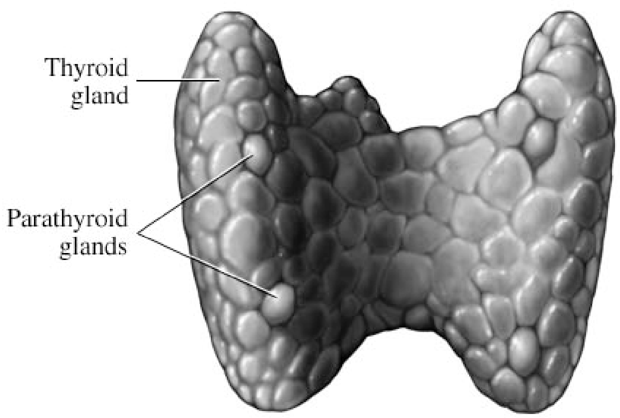
After studying this section you should be able to:

- **Describe the position of the thyroid gland and its related structure**
- **Outline the actions of thyroid gland**

The thyroid gland, which consists of two lobes, is located in front of the windpipe (i.e., trachea), just below the voice box (i.e., larynx). The gland produces two structurally related hormones,

1. Thyroxin (T4)
2. Triiodothyronine (T3),

Those are iodinated derivatives of the amino acid tyrosine. Both hormones are collectively referred to as “thyroid hormone.” T4 constitutes approximately 90 percent of the hormone produced in the thyroid gland. However, T3 is a much more active hormone, and most of the T4 produced by the thyroid is converted into T3 in the liver and kidneys.



Thyroid hormone in general serves to increase the metabolism of almost all body tissues. For example, thyroid hormone stimulates the production of certain proteins involved in heat generation in the body, a function that is essential for maintaining body temperature in cold climates. Moreover, thyroid hormone promotes several other metabolic processes involving carbohydrates, proteins, and lipids that help generate the energy required for the body’s functions. In addition to those metabolic effects, thyroid hormone plays an essential role in the development of the central nervous system during late fetal and early postnatal developmental stages. Furthermore, thyroid hormone exerts an effect similar to that of GH on normal bone growth and maturation. Finally, thyroid hormone is required for the normal development of teeth, skin, and hair follicles as well as for the functioning of the nervous, cardiovascular, and gastrointestinal systems. In addition to thyroid hormone, certain cells (i.e., parafollicular C cells) in the thyroid gland produce calcitonin, a hormone that helps maintain normal calcium levels in the blood. Specifically, calcitonin lowers calcium levels in the blood by reducing the release of calcium from the bones; inhibiting the constant erosion of bones (i.e., bone resorption), which also releases calcium; and inhibiting the reabsorption of calcium in the kidneys. Those effects are opposite to those of parathyroid hormone (PTH), which is discussed in the following section.

Thyroid Gland Disorders

a. Thyrotoxicosis (hyperthyroidism) this syndrome is caused by the excessive secretion of thyroid hormones—typically both thyroxin (T4) and tri-iodothyronine (T3)—in the bloodstream. Symptoms include tachycardia, sweating, tremor, anxiety, increased appetite, loss of weight and intolerance of heat.

Hyperthyroidism can be classified on the basis of aetiology into:

• Primary hyperthyroidism (↑ thyroid hormones, ↓ TSH)—hypersecretion of thyroid hormones, which is not secondary to increased levels of TSH (the rise in thyroid hormones actually suppresses TSH).

• Secondary hyperthyroidism (↑ thyroid hormones, ↑ TSH)—overstimulation of the thyroid gland caused by excess TSH produced by a tumor in the pituitary or elsewhere (rare).

The most important symptoms diagnostically are:

• Heat intolerance and excessive sweating (hyperhidrosis).
• Nervousness and irritability.
• Weight loss with normal or increased appetite.
• Goiter (an enlargement of the thyroid gland).

b. Hypothyroidism

Decreased activity of the thyroid gland results in decreased production of thyroid hormones. There are two forms:

1. Hypothyroidism present at birth →cretinism or congenital hypothyroidism.
2. Hypothyroidism in adult's →myxoedema.

- Cretinism (congenital hypothyroidism) Hypothyroidism in children

This condition occurs as a result of extreme hypothyroidism during fetal life, infancy or childhood. It has the following types and aetiology:

• Endemic cretinism—occurs in iodine-deficient countries where goiter is common. The mother almost always has a goiter and the thyroid of the affected infant is usually enlarged and nodular.

• Sporadic cretinism—caused by congenital hypoplasia or absence of the thyroid gland and often associated with deaf mutism.

• Dyshormonogenesis—a congenital familial recessive enzyme defects causing an inability to complete the formation of thyroid hormones. TSH is increased, and the thyroid gland is enlarged and shows epithelial hyperplasia.

The clinical features of cretinism are:

• Mental retardation.
• Retarded growth—skeletal growth is inhibited more than soft tissue growth, resulting in an obese, stocky, short child.

• Coarse, dry skin.
• Lack of hair and teeth.
• Pot belly (often with umbilical hernia).
• Protruding tongue.

- Hypothyroidism in adults (myxoedema)
This common clinical condition is associated with decreased function of the thyroid gland and a decrease in the circulating level of thyroid hormones.
Hypothyroidism can be classified according to aetiology:
• Primary (↓ thyroid hormones, ↑ TSH)—failure of the thyroid gland itself. This is much more common than secondary hypothyroidism. Note that subclinical hypothyroidism describes an increase in TSH but with normal thyroid hormone levels, and is increasingly being treated with the aim of reducing progression to full disease.
• Secondary (↓ thyroid hormones, ↓TSH)—failure of TSH production due to pituitary disease.

7.3 THE PARATHYROID GLANDS AND THEIR HORMONES

Learning outcomes

After studying this section you should be able to:

- **Describe the position and gross structure of parathyroid glands**
- **Outline the functions of parathyroid hormone and calcitonin**

The parathyroid glands are four pea sized bodies located behind the thyroid gland that produce PTH. This hormone increases calcium levels in the blood, helping to maintain bone quality and an adequate supply of calcium, which is needed for numerous functions throughout the body (e.g., muscle movement and signal transmission within cells). Specifically, PTH causes reabsorption of calcium from and excretion of phosphate in the urine. PTH also promotes the release of stored calcium from the bones as well as bone resorption, both of which increase calcium levels in the blood. Finally, PTH stimulates the absorption of calcium from the food in the gastrointestinal tract. Consistent with PTH's central role in calcium metabolism, the release of this hormone is not controlled by pituitary hormones but by the calcium levels in the blood. Thus, low calcium levels stimulate PTH release, whereas high calcium levels suppress it. Many of the functions of PTH require or are facilitated by a substance called 1,25-dihydroxycholecalciferol, a derivative of vitamin D. In addition, numerous other hormones are involved in regulating the body's calcium levels and bone metabolism, including estrogens, glucocorticoids, and growth hormone.

Parathyroid Gland Disorders:

a. Hyperparathyroidism

Hyperparathyroidism is defined as an elevated secretion of PTH, of which there are three main types:

1. Primary—hypersecretion of PTH by adenoma or hyperplasia of the gland.
2. Secondary—physiological increase in PTH secretions in response to hypocalcaemia of any cause.
3. Tertiary—supervention of an autonomous hypersecreting adenoma in long-standing

Secondary hyperparathyroidism.

Effects of hyperparathyroidism:

The clinical effects are the result of hypercalcaemia and bone resorption.

Effects of hypercalcaemia:

• Renal stones due to hypercalcuria.
• Excessive calcification of blood vessels.
• Corneal calcification.
• General muscle weakness and tiredness.
• Exacerbation of hypertension and potential shortening of the QT interval.
• Thirst and polyuria (may be dehydrated due to impaired concentrating ability of kidney).
• Anorexia and constipation.

Effects of bone resorption:

• Osteitis fibrosa—increased bone resorption with fibrous replacement in the lacunae.
• 'Brown tumours'—haemorrhagic and cystic tumor-like areas in the bone, containing large masses of giant osteoclastic cells.
• Osteitis fibrosa cystica (von Recklinghausen disease of bone)—multiple brown tumors combined with osteitis fibrosa.
• Changes may present clinically as bone pain, fracture or deformity.

Secondary hyperparathyroidism

This is compensatory hyperplasia of the parathyroid glands, occurring in response to diseases of chronic low serum calcium or increased serum phosphate.

Its causes are:

• Chronic renal failure and some renal tubular disorders (most common cause).
• Steatorrhoea and other malabsorption syndromes.
• Osteomalacia and rickets.
• Pregnancy and lactation.

Tertiary hyperparathyroidism

This condition, resulting from chronic overstimulation of the parathyroid glands in renal failure, causes one or more of the glands to become an autonomous hypersecreting adenoma with resultant hypercalcaemia.

b. Hypoparathyroidism

Hypoparathyroidism is a condition of reduced or absent PTH secretion, resulting in hypocalcaemia and hyperphosphataemia. It is far less common than hyperparathyroidism.

The effects of hypoparathyroidism are:

• ↓ release of Ca2+ from bones.

• ↓ Ca2+ reabsorption but ↑ PO4

− re absorption by kidney.

• ↓ 1-hydroxylation of 25-hydroxyvitamin D by kidney.

Most symptoms of hypoparathyroidism are those of hypocalcaemia:

• Tetany—muscular spasm provoked by lowered plasma Ca2+.

• Convulsions.

• Paraesthesiae.

• Psychiatric disturbances, e.g. depression, confusional state and even psychosis.

• Rarely—cataracts, parkinsonian-like movement disorders, alopecia, brittle nails.

7.4 THE ADRENAL GLANDS AND THEIR HORMONES

Learning outcomes

After studying this section you should be able to:

- **Describe the structure of adrenal glands**
- **Describe the actions of each of the three groups of adrencorticoid hormones**

The adrenal glands are small structures located on top of the kidneys. Structurally, they consist of an outer layer (i.e., the cortex) and an inner layer (i.e., the medulla).

The **adrenal cortex** produces numerous hormones, primarily Corticosteroids-

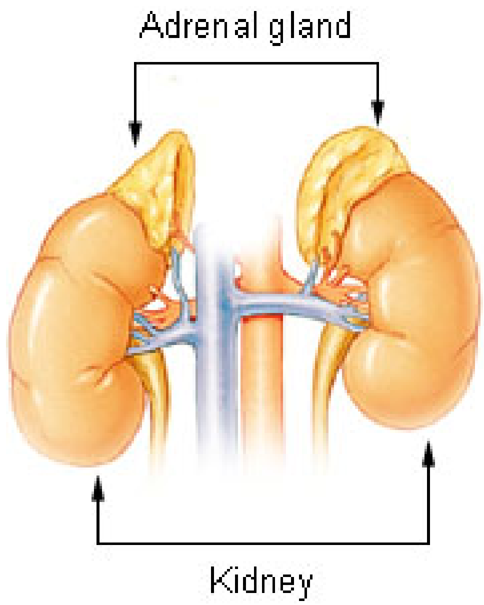
1. glucocorticoids -cortisol
2. mineralocorticoids- aldosterone

The cortex is also the source of small amounts of sex hormones.

The **adrenal medulla** generates two substances—

1. Adrenaline
2. Noradrenalin

Those are released as part of the **fight-or-flight response** to various stress factors. The primary glucocorticoids in humans is cortisol (also called hydrocortisone), which helps control carbohydrate, protein, and lipid metabolism. For example, cortisol increases glucose levels in the blood by stimulating gluconeogenesis in the liver and promotes the formation of glycogen (i.e., a molecule that serves as the storage form of glucose) in the liver.



Cortisol also reduces glucose uptake into muscle and adipose tissue, thereby opposing the effects of insulin. Furthermore, in various tissues, cortisol promotes protein and lipid breakdown into products (i.e., amino acids and glycerol, respectively) that can be used for gluconeogenesis. In addition to those metabolic activities, cortisol appears to protect the body against the deleterious effects of various stress factors, including acute trauma, major surgery, severe infections, pain, blood loss, hypoglycemia, and emotional stress. All of these stress factors lead to drastic increases in the cortisol levels in the blood. For people in whom cortisol levels cannot increase (e.g., because they had their adrenal glands removed), even mild stress can be fatal. Finally, high doses of cortisol and other corticosteroids can be used medically to suppress tissue inflammation in response to injuries and to reduce the immune response to foreign molecules. The primary mineralocorticoid in humans is aldosterone, which also helps regulate the body's water and electrolyte balance. Its principal functions are to conserve sodium and to excrete potassium from the body. For example, aldosterone promotes the reabsorption of sodium in the kidney, thereby reducing water excretion and increasing blood volume. Similarly, aldosterone decreases the ratio of sodium to potassium concentrations in sweat and saliva, thereby preventing sodium loss via those routes. The effect can be highly beneficial in hot climates, where much sweating occurs. In contrast to the glucocorticoids, pituitary, or hypothalamic, hormones do not regulate aldosterone release. Instead, it is controlled primarily by another hormone system, the reninangiotensin system, which also controls kidney function.

Adrenal Gland Disorders

a. Hyperfunction of the adrenal cortex:

Cushing's syndrome

The symptoms and signs of Cushing's syndrome are associated with prolonged inappropriate elevation of free corticosteroid levels

Clinical features—the main effects of sustained elevation of glucocorticoid secretion are:

• Central obesity and moon face.
• Plethora and acne.
• Menstrual irregularity.
• Hirsutism and hair thinning.
• Hypertension.
• Diabetes.
• Osteoporosis—may cause collapse of vertebrae, rib fractures.
• Muscle wasting and weakness.
• Atrophy of skin and dermis—paper thin skin with bruising tendency, purple striae.

b. Hypofunction of the adrenal cortex

Addison's disease:

This rare condition of chronic adrenal insufficiency is due to a lack of glucocorticoids and mineralocorticoids.

7.5 THE PANCREAS AND ITS HORMONES

Learning outcomes

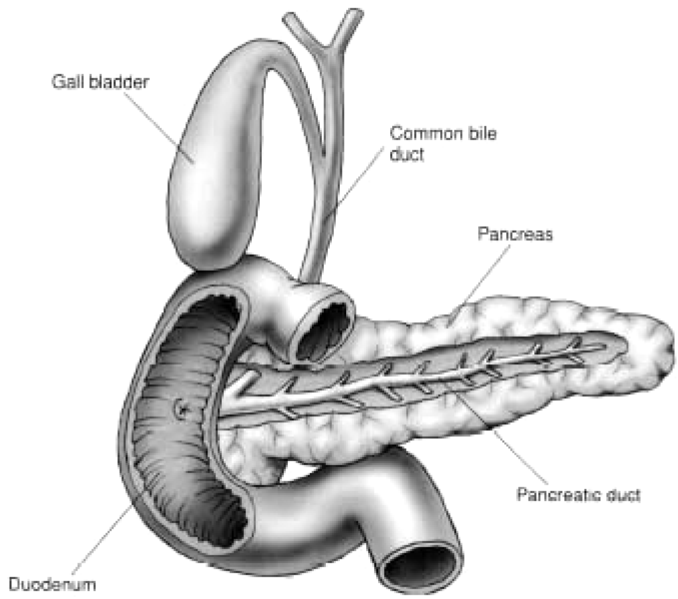
After studying this section you should be able to:

- **List the hormones secreted by the endocrine pancreas**
- **Describe the actions of insulin and glucagon**

The pancreas is located in the abdomen, behind the stomach, and serves two distinctly different functions. First, it acts as an exocrine organ, because the majority of pancreatic cells produce various digestive enzymes that are secreted into the gut and which are essential for the effective digestion of food. Second, the pancreas serves as an endocrine organ, because certain cell clusters (i.e., the Islets of Langerhans) produce two hormones—

1. insulin
2. glucagon

Those are released into the blood and play pivotal roles in blood glucose regulation.



Insulin

Insulin is produced in the beta cells of the Islets of Langerhans. Its primary purpose is to lower blood glucose levels; in fact, insulin is the only blood sugar-lowering hormone in the body. To this end, insulin promotes the formation of storage forms of energy (e.g., glycogen, proteins, and lipids) and suppresses the breakdown of those stored nutrients. Accordingly, the target organs of insulin are primarily those that are specialized for energy storage, such as the liver, muscles, and adipose tissue. Specifically, insulin has the following metabolic effects:

• Promotes glucose uptake into cells and its conversion into glycogen, stimulates the breakdown of glucose, and inhibits gluconeogenesis.

• Stimulates the transport of amino acids into cells and protein synthesis in muscle cells, thereby lowering the levels of amino acids available for gluconeogenesis in the liver.

• Increases fat synthesis in the liver and adipose tissue, thereby lowering the levels of glycerol, which also can serve as a starting material for gluconeogenesis. The release of insulin is controlled by various factors, including blood glucose levels; other islet hormones (e.g., glucagon); and, indirectly, other hormones that alter blood glucose levels (e.g., GH, glucocorticoids, and thyroid hormone).

Glucagon

The second blood-sugar–regulating pancreatic hormone is glucagon, which is produced in the alpha cells of the Islets of Langerhans. Glucagon increases blood glucose levels; accordingly, its main actions generally are opposite to those of insulin. For example, glucagon increases glycogen breakdown and gluconeogenesis in the liver as well as the breakdown of lipids and proteins.

The release of glucagon is regulated by many of the same factors as is insulin's release, but sometimes with the opposite effect. Thus, an increase in blood glucose levels stimulates insulin release but inhibits glucagon release.
A finely tuned balance between the activities of insulin and glucagon is essential for maintaining blood sugar levels. Accordingly, disturbances of that balance, such as an insulin deficiency or an inability of the body to respond adequately to insulin, result in serious disorders, such as diabetes mellitus.

Disorders of Pancreas:

a. Diabetes mellitus:

Diabetes mellitus (DM) is a multisystem disease of an abnormal metabolic state characterised by hyperglycemia due to inadequate insulin action/production. It can be classified into primary and secondary. Primary DM is a disorder of insulin production/ action. Primary DM is by far the most important cause of diabetes and it is further classified into:
• Type I, also known as insulin-dependent DM (IDDM) or juvenile-onset diabetes.
• Type II, also known as non-insulin-dependent DM (NIDDM) or mature-onset diabetes.

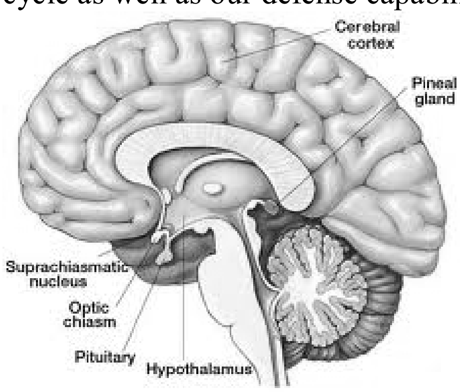
7.6 THE PINEAL GLAND

Learning outcomes

After studying this section you should be able to:

- **State the position of pineal gland**
- **Outline the actions of melatonin.**

The pineal gland is located on the dorsal side of forebrain. Pineal secretes a hormone called **melatonin**. Melatonin plays a very important role in the regulation of a 24-hour (diurnal) rhythm of our body. For example, it helps in maintaining the normal rhythms of sleep-wake cycle, body temperature. In addition, melatonin also influences metabolism, pigmentation, the menstrual cycle as well as our defense capability.



Disorders of the pineal gland

Pinealomas (germinomas)

These tumors of young adults and children are often called germinomas.
• Pressure on the midbrain may produce Parinaud's syndrome (paralysis of the conjugate upward gaze without paralysis of convergence).
• Pressure on the hypothalamus can produce symptoms of DI, emaciation or precocious puberty.

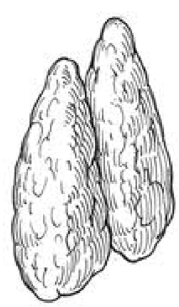
7.7 Thymus gland

Learning outcomes

After studying this section you should be able to:

- **State the position of thymus gland**
- **Outline the actions of thymosin**

The thymus gland is a lobular structure located on the dorsal side of the heart and the aorta. The thymus plays a major role in the development of the immune system. This gland secretes the peptide hormones called **thymosin**. Thymosin plays a major role in the differentiation of **Tlymphocytes**, which provide **cell-mediated immunity**. In addition, thymosin also promotes production of antibodies to provide **humoral immunity**. Thymus is degenerated in old individuals resulting in a decreased production of thymosin. As a result, the immune responses of old persons become weak.



7.8 THE GONADS AND THEIR HORMONES

Learning outcomes

After studying this section you should be able to:

- **Outline the gonadal hormones and their functions**

The gonads (i.e., the ovaries and testes) serve two major functions.
1) They produce the germ cells (i.e., ova in the ovaries and spermatozoa in the testes). 2)the gonads synthesize steroid sex hormones that are necessary for the development and function of both female and male reproductive organs and secondary sex characteristics (e.g., the adult distribution of body hair,

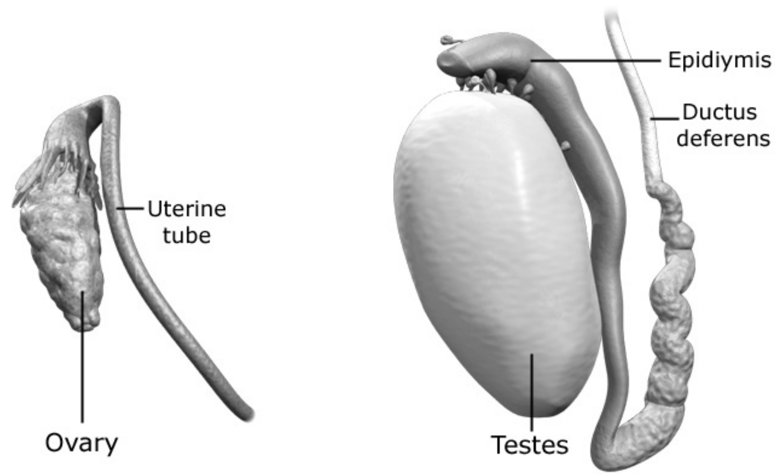
such as facial hair in men) as well as for pregnancy, childbirth, and lactation. Three types of sex hormones exist; each with different functions:

(1) Estrogens (e.g., estradiol), which exert feminizing effects

(2) Progestogens (e.g., progesterone), which affect the uterus in preparation for and during pregnancy; and

(3) Androgens (e.g., testosterone), which exert masculinizing effects.

In addition to the reproductive functions, sex hormones play numerous essential roles throughout the body. For example, they affect the metabolism of carbohydrates and lipids, the cardiovascular system, and bone growth and development.



Estrogens

The major estrogen is estradiol, which, in addition to small amounts of estrogen and estriol, is produced primarily in the ovaries. Other production sites of estrogens include the corpus luteum, the placenta, and the adrenal glands. In men and postmenopausal women, most estrogens present in the circulation are derived from the conversion of testicular, adrenal, and ovarian androgens. The conversion occurs in peripheral tissues, primarily adipose tissue and skin. The main role of estrogens is to coordinate the normal development and functioning of the female genitalia and breasts. During puberty, estrogens promote the growth of the uterus, breasts, and vagina; determine the pattern of fat deposition and distribution in the body that results in the typical female shape; regulate the pubertal growth spurt and cessation of growth at adult height; and control the development of secondary sexual characteristics. In adult women, the primary function of estrogens includes regulating the menstrual cycle, contributing to the hormonal regulation of pregnancy and lactation, and maintaining female libido. During menopause, estrogen production in the ovaries ceases. The resulting reduction in estrogen levels leads to symptoms such as hot flashes, sweating, pounding of the heart (i.e., palpitations), increased irritability, anxiety, depression, and brittle bones (i.e., osteoporosis). The administration of estrogens (i.e., hormone replacement therapy) can alleviate those symptoms and reduce the risk of osteoporosis and coronary heart disease in postmenopausal women. At the same time, however, hormone replacement therapy may increase the risk of certain types of cancer (e.g., breast cancer and uterine [i.e., endometrial] cancer).

Progestogens

The ovaries produce progestogens during a certain phase of the menstrual cycle and in the placenta for most of pregnancy. Progestogens cause changes in the uterine lining in preparation for pregnancy and—together with estrogens—stimulate the development of the mammary glands in the breasts in preparation for lactation. The primary progestogen is progesterone.

Androgens

The principal androgenic steroid is testosterone, which is secreted primarily from the testes but also, in small amounts, from the adrenal glands (both in men and women) and from the ovaries. Its main function is to stimulate the development and growth of the male genital tract. In addition, testosterone has strong protein anabolic activities— that is, it promotes protein generation, which leads to increased muscle mass. The specific functions of testosterone vary during different developmental stages, as follows:

• In the fetus, testosterone primarily ensures the development of the internal and external male genitalia.
• During puberty, testosterone promotes the growth of the male sex organs and is responsible for other male developmental characteristics, such as the pubertal growth spurt and eventual cessation of growth at adult height; deepening of the voice; growth of facial, pubic, axillary, and body hair; and increase in muscularity and strength.
• In the adult male, testosterone primarily serves to maintain masculinity, libido, and sexual potency as well as regulate sperm production. Testosterone levels decline slightly with age, although the drop is not as drastic as the reduction in estrogen levels in women during menopause.

7.9 LOCAL HORMONES

Learning outcomes

After studying this section you should be able to:

- **Name substances that act as local hormones.**

Hormones of Heart, Kidney and Gastrointestinal Tract

As mentioned earlier, hormones are also secreted by some tissues which are not endocrine glands. For example,
1. The atrial wall of our heart secretes a very important peptide hormone called **atrial natriuretic factor** (ANF), which decreases blood pressure. When blood pressure is increased, ANF is secreted which causes dilation of the blood vessels. This reduces the blood pressure.

2. The juxtaglomerular cells of kidney produce a peptide hormone called **erythropoietin** which stimulates erythropoiesis (formation of RBC).

3. Endocrine cells present in different parts of the gastro-intestinal tract secrete four major peptide hormones, namely

1. **Gastrin**,
2. **Secretin**,
3. **cholecystokinin** (CCK) and
4. **Gastric inhibitory peptide** (GIP).

Gastrin acts on the gastric glands and stimulates the secretion of hydrochloric acid and pepsinogen. Secretin acts on the exocrine pancreas and stimulates secretion of water and bicarbonate ions. CCK acts on both pancreas and gall bladder and stimulates the secretion of pancreatic enzymes and bile juice, respectively. GIP inhibits gastric secretion and motility. Several other non-endocrine tissues secrete hormones called **growth factors.** These factors are essential for the normal growth of tissues and their repairing/regeneration.

7.10 Summary:

- The endocrine system communicates via chemical messengers called hormones.
- Endocrine glands secrete hormones directly into the fluid just outside the cells where they diffuse directly into the bloodstream to be transported throughout the body.
- Lipid-soluble hormones move through the plasma membrane and combine with receptor molecules in the cytoplasm.
- Water-soluble hormones are modified amino acids. They cannot enter the cells and instead bind to receptors on the surface of the target cell.
- Feedback mechanisms regulate the secretion of hormones. In a negative feedback mechanism, the outcome of a process causes the system to shut down. In a positive feedback mechanism the outcome of a process stimulates the process.
- Nervous control sometimes overrides feedback mechanisms.
- Hormones influence growth, development, metabolism, and behavior.
- The hypothalamus produces releasing hormones and inhibiting hormones that control secretions of the anterior pituitary gland.
- The pituitary gland consists of two lobes. The anterior pituitary produces growth hormone (GH), prolactin (PRL), thyroid-stimulating hormone (TSH), adrenocorticotropic hormone (ACTH), follicle-stimulating hormone (FSH), and luteinizing hormone (LH). The posterior pituitary releases oxytocin (OT) and antidiuretic hormone (ADH) produced in the hypothalamus.
- Thyroid hormones regulate metabolism by thyroid hormone (TH) and decrease blood calcium by calcitonin (CT).
- Parathyroid hormone increases blood calcium levels.

- The adrenal gland consists of the adrenal cortex, which secretes gonadocorticoids, mineralocorticoids, and glucocorticoids, and the adrenal medulla which secretes epinephrine and norephinephrine effective in our fight-or-flight response.
- Hormones of the pancreas, glucagon and insulin, regulate blood glucose.
- Hormones of the thymus gland promote maturation of white blood cells involved in our defense response.
- The pineal gland secretes melatonin, which influences our daily rhythms.
- Prostaglandins are lipid molecules released by the plasma membranes of most cells that are chemical messengers with only local effects.

Self assessment questions:

1. Name the anterior pituitary hormones.describe the secretion regulation and functions of growth hormone.
2. What is normal blood sugar level?how is it regulated?add a note on diabetes mellitus.
3. Classify hormones.explain the mechanism of actions of hormones.
4. Describe the hypothalamo-hypophyseal axis.
5. Explain the role of hypothalamus as an endocrine gland.
6. Name the posterior pituitary hormones.explain their actions.
7. Enumerate the actions of thyroxin.
8. Glucose metabolism.
9. Name the hormones secreated by pancreas and their functions.
10. List the functions of pineal gland.
11. What are the functions of thyroid and parathyroid glands?
12. What are the effects of hyper and hypo secretion of thyroid glands?

SECTION III

INTAKE OF FOOD AND ELIMINATION OF METABOLIC WASTE PRODUCTS

- **The respiratory system**
- **Food nutrition, enzymes**
- **Digestive system**
- **Excretory system**

8. THE RESPIRATORY SYSTEM

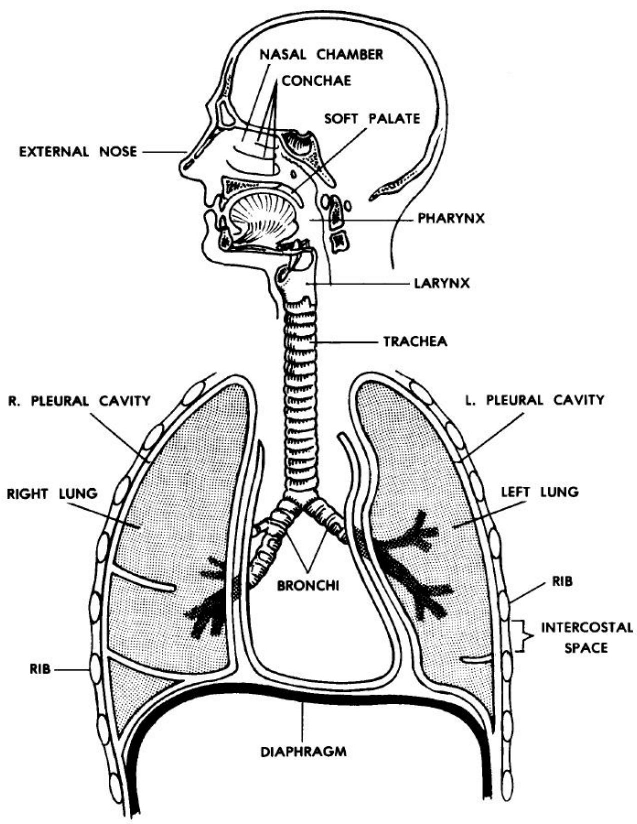
Introduction:

The respiratory system consists of organs that deliver oxygen to the circulatory system for transport to all body cells. Oxygen is essential for cells, which use this vital substance to liberate the energy needed for cellular activities. In addition to supplying oxygen, the respiratory system aids in removing of carbon dioxide, preventing the lethal buildup of this waste product in body tissues. Day-in and day-out, without the prompt of conscious thought, the respiratory system carries out its life-sustaining activities. If the respiratory system's tasks are interrupted for more than a few minutes, serious, irreversible damage to tissues occurs, followed by the failure of all body systems, and ultimately, death. While the intake of oxygen and removal of carbon dioxide are the primary functions of the respiratory system, it plays other important roles in the body. The respiratory system helps regulate the balance of acid and base in tissues, a process crucial for the normal functioning of cells. It protects the body against disease-causing organisms and toxic substances inhaled with air. The respiratory system also houses the cells that detect smell, and assists in the production of sounds for speech. The respiratory and circulatory systems work together to deliver oxygen to cells and remove carbon dioxide in a two-phase process called respiration.

The first phase of respiration begins with breathing in, or inhalation. Inhalation brings air from outside the body into the lungs. Oxygen in the air moves from the lungs through blood vessels to the heart, which pumps the oxygen-rich blood to all parts of the body. Oxygen then moves from the bloodstream into cells, which completes the first phase of respiration. In the cells, oxygen is used in a separate energy-producing process called cellular respiration, which produces carbon dioxide as a byproduct. The second phase of respiration begins with the movement of carbon dioxide from the cells to the bloodstream. The bloodstream carries carbon dioxide to the heart, which pumps the carbon dioxide-laden blood to the lungs. In the lungs, breathing out, or exhalation, removes carbon dioxide from the body, thus completing the respiration cycle.

Structure:

The organs of the respiratory system extend from the nose to the lungs and are divided into the upper and lower respiratory tracts. The upper respiratory tract consists of the nose and the pharynx, or throat. The lower respiratory tract includes the larynx, or voice box; the trachea, or windpipe, which splits into two main branches called bronchi; tiny branches of the bronchi called bronchioles; and the lungs, a pair of saclike, spongy organs. The nose, pharynx, larynx, trachea, bronchi, and bronchioles conduct air to and from the lungs. The lungs interact with the circulatory system to deliver oxygen and remove carbon dioxide.



Anatomy of the Respiratory system

1. **Upper respiratory:** nasal cavity, pharynx & larynx
2. **Lower respiratory:** trachea & lungs including bronchi, bronchioles and pulmonary alveoli.
3. **Conducting division :** includes all structures except for the pulmonary alveoli
4. **Respiratory division:** the pulmonary alveoli where gas exchange occurs between air and blood.

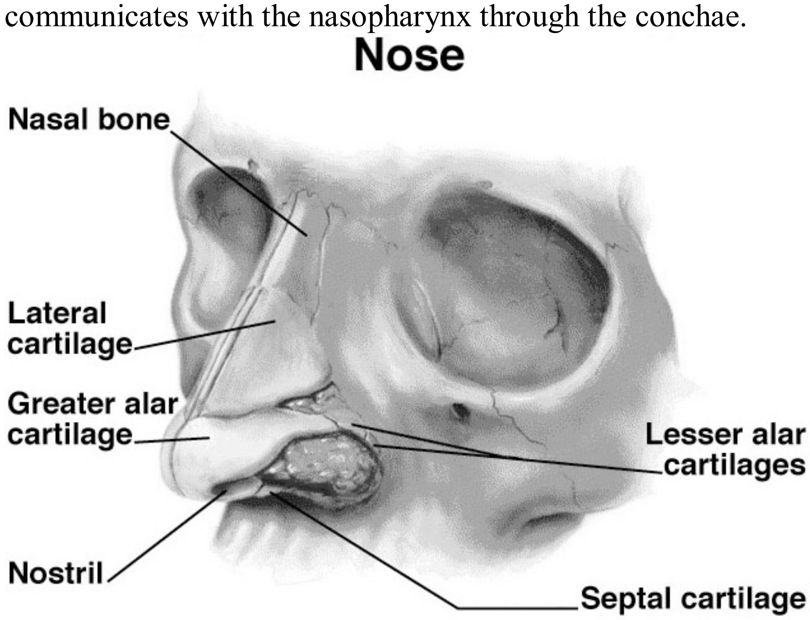
8.1 THE NOSE AND NASAL PASSAGES:

Learning outcomes

After studying this section you should be able to:

- **Describe the location of nasal cavities**
- **Describe the functions of nasal cavities and par nasal sinuses**

The external portion of the nose is made up of the nasal bones which make up the bridge and the pliable lateral and greater alar cartilage which is covered by skin. The septal cartilage forms the anterior portion of the nasal septum and the paired lateral and alar cartilage form the framework of the nostrils. The vomer and the perpendicular plate of the ethmoid bone together with the septal cartilage form the nasal septum which divides the interior of the nose into 2 lateral halves. Each half is referred to as a nasal fossa. The nasal vestibule is the anterior expanded portion of the nasal fossa. Each nasal fossa opens anteriorly through the nostril (nares or external nares) and communicates with the nasopharynx through the conchae.



The roof of the nasal cavity is formed anteriorly by the frontal bone and paired nasal bones, medially by the cribriform plate of the ethmoid and posteriorly by the sphenoid bone. The palatine and maxillary bones form the floor of the cavity. On the lateral walls of the cavity are three bony projections, the superior, middle and inferior nasal conchae or turbinates.

Air passages between the conchae are called nasal meatuses. The walls of the nasal conchae are lined with pseudo stratified ciliated epithelial cells and mucous secreting goblet cells. The function of the ciliated epithelium is to help move the mucus throughout the cavity and lubricate the lining, preventing drying of the nasal passages.

The functions of the nasal cavity and its structures are threefold:

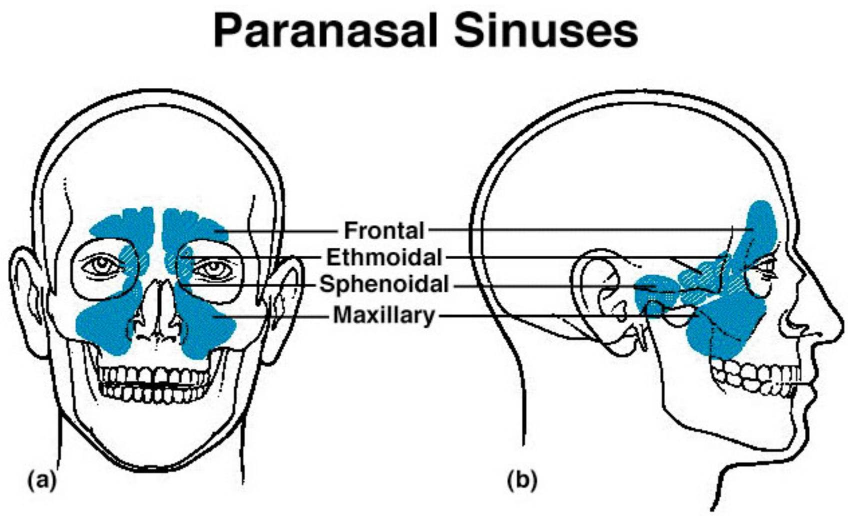
1. Warm, moisten and cleanse the inspired air.
2. The olfactory epithelium in the upper medial portion of the nasal cavity is concerned with smell.
3. The nasal cavity affects the voice by acting as a resonating chamber.

Para nasal Sinuses

Paired air spaces in the skull bones are called **par nasal sinuses.** These sinuses are named for the bones in which they are found. There are the **maxillary, frontal, sphenoid and ethmoid sinuses.** Each sinus communicates via drainage ducts within the nasal cavity on its own side.

Function of the Sinuses:

1. Decrease the weight of the skull while providing structural strength
2. Warm and moisten air
3. Sound resonance



8.2 THE PHARYNX

Learning outcomes

After studying this section you should be able to:

- **Describe the location of the pharynx**
- **Relate the structure of the pharynx to its function**

The pharynx is a funnel shaped organ about 5 "(13 cm) long that connects the nasal and oral cavities to the larynx and to the esophagus. It is made up of skeletal muscle and is lined with a mucous membrane. There are paired lymphoid organs called **tonsils** located on each side. The pharynx has both respiratory and digestive functions as it has openings to both systems. It also provides a resonating chamber for certain sounds. The pharynx is divided according to location and function.

1. **The Nasopharynx** serves as a passageway for air as it is located above the point of entry for food (mouth). It is the uppermost portion of the pharynx directly behind the nasal cavity and above the soft palate. A pendulous **uvula** hangs from the middle lower portion of the soft palate. The paired auditory (Eustachian) tubes connect the nasopharynx to the tympanic cavities. The pharyngeal tonsils (adenoids) are situated in the posterior wall of the nasal cavity. During the act of swallowing the soft palate and uvula are elevated so that the nasal cavity is blocked and food is prevented from entering that area. Occasionally this fails to close when a person exhales air while swallowing fluid. If this occurs, the fluid may be expelled through the nasal cavity.

2. The **oropharynx** is the middle portion of the pharynx between the soft palate and t he level of the hyoid bone. Both swallowed food and inhaled air pass through it. The base of the tongue forms the anterior wall of the oropharynx. Paired **palatine tonsils** are located on the posterior wall and the **lingual tonsils** are found at the base of the tongue.

3. The **laryngopharynx** is the lowermost portion of the pharynx. It extends inferiorly from the hyoid bone to the larynx and opens into the larynx and the esophagus. It is in the lower portion that the digestive and respiratory systems become distinct. Swallowed food goes to the esophagus and inhaled air goes to the larynx.

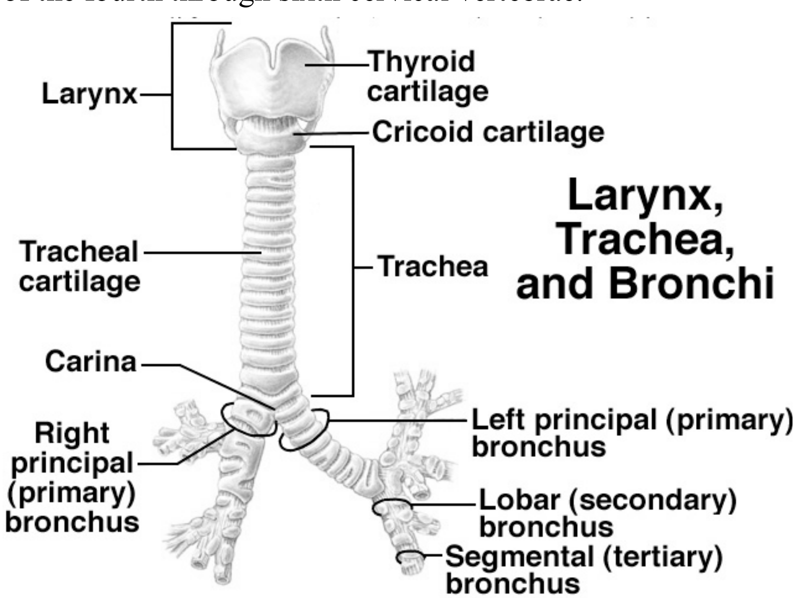
8.3 LARYNX

Learning outcomes

After studying this section you should be able to:

- **Describe the structure and function of larynx**
- **Outline the physiology of speech generation**

The **larynx** or voice box is a continuation of the laryngopharynx that connects to the trachea. It is positioned in the anterior mid line of the neck at the level of the fourth through sixth cervical vertebrae.



The larynx is shaped like a triangular box. it is composed of a framework of 9 cartilages: three are large unpaired structures and six are smaller and paired. The largest of the unpaired structures is the anterior **Thyroid cartilage.** The **laryngeal prominence** of thyroid cartilage is also referred to as the **Adam's apple**. It is an anterior vertical ridge that can be palpitated on the mid line of the neck. This structure is larger and more prominent in adult males due to the effect of testosterone during puberty. Women also have this structure also- it is much smaller. The spoon shaped **epiglottis** has a framework of hyaline cartilage, referred to as the **epiglottic cartilage.** The epiglottis is located behind the root of the tongue where it aids in closing the **glottis or laryngeal opening** during swallowing. The entire larynx elevates during swallowing to close the glottis against the epiglottis. If this does not close during swallowing food may become lodged within the glottis. The lower end of the larynx is formed by the ring shaped **cricoid cartilage**. This third unpaired cartilage connects the thyroid cartilage to the trachea. The **arytenoid cartilages** located above the cricoid and behind the thyroid are the posterior attachments of the **vocal folds.** The other paired **cuneiform cartilages** and the **corniculate cartilages** are small accessory cartilages that are closely associated with the **arytenoids cartilages.**

Two pairs of strong connective tissue bands are stretched across the upper opening of the larynx from the thyroid cartilage anteriorly to the paired **arytenoid cartilages** posteriorly. These are the **vocal folds (true vocal chords)** and the **vestibular folds (false vocal chords).** The **vestibular folds** support the **vocal chords (vocal folds)** and produce mucus to keep the vestibular folds from drying out. The vestibular folds are not used in making sounds. Sound results from the vocal chords vibrating. The laryngeal muscles are important in closing the glottis during speech and during swallowing The muscles of the larynx consist of **extrinsic muscles,** responsible for elevating the larynx during swallowing, and **intrinsic muscles** that when contracted change the length, position and tension of the vocal chords. Various pitches are produced as air passes over the altered vocal chords. If the vocal chords are taut, vibration is more rapid and produces a higher pitch. Less tension on the vocal chords produce slower sounds.

Function of the Larynx:

1. Prevent food or fluid from entering the trachea and lungs during swallowing and to permit the passage of air while breathing.
2. Produce sounds and speech

8.4 TRACHEA

Learning outcomes

After studying this section you should be able to:

- **Describe the location of trachea**
- **Outline the structure of trachea**
- **Explain the functions of trachea**

The **trachea (wind pipe)** is a semi rigid tubular organ approximately 4” (12 cm) long and 1” (2.5 cm) in diameter, connecting the larynx to the primary bronchi. It is positioned anterior to the esophagus as it extends into the thoracic cavity. A series of 16 to 20 C shaped hyaline cartilages form the supporting walls of the trachea. These are rigid and ensure that the airway will remain open. The open part of the cartilage faces the esophagus to allow for expansion during swallowing. The mucosal lining contains mucus producing goblet cells and ciliated epithelial cells that protect against dust and particulate debris and keep the airways moist. Medial to the lungs the trachea splits into 2 branches of the **primary bronchi.** This junction is reinforced by a cartilage plate called the **carina.**

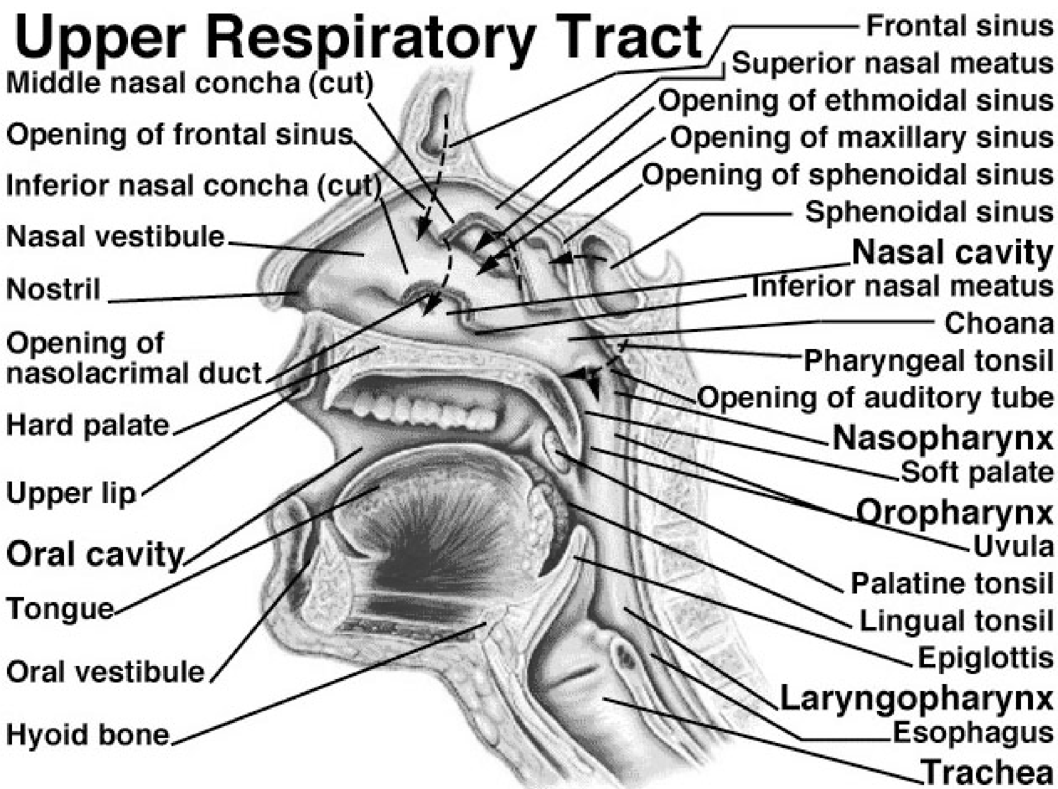
8.5 THE BRONCHIAL TREE

Learning outcomes

After studying this section you should be able to:

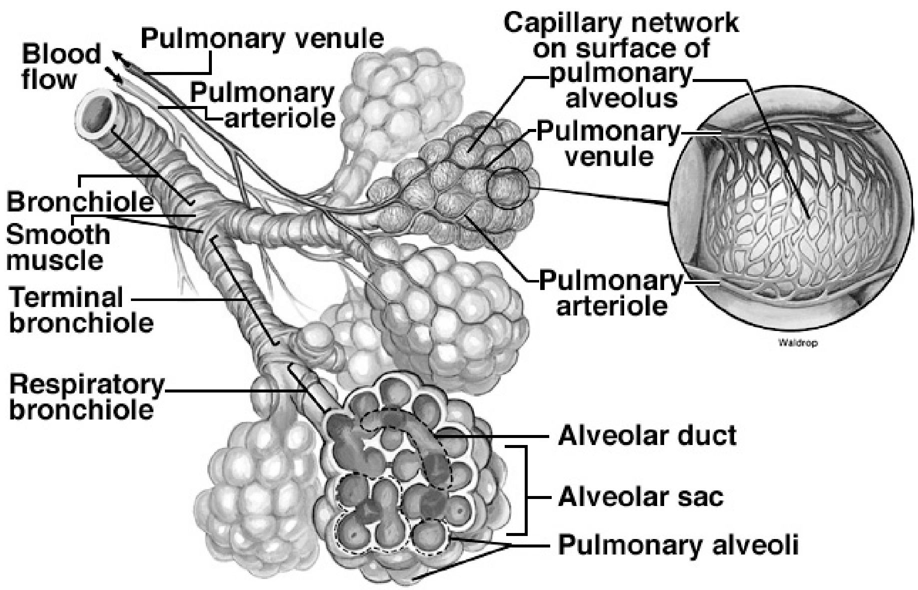
- **Name the air passage of the bronchial tree in descending order of size**
- **Describe the structure and changing functions of the different levels of airway.**

The **bronchial tree** is named because it is composed of a series of respiratory tubes that branch into progressively narrower tubes as they extend into the lungs. The trachea bifurcates into a **right and left primary bronchi** at the level of t he sternal angle behind the manubrium. Each primary bronchi has hyaline cartilage rings supporting it. Because of the more vertical position of the right primary bronchus, foreign particles are more likely to lodge here than in the left primary bronchus. The principle bronchus divides deeper in the lungs to form **lobar (secondary and segmental (tertiary) bronchi.** The bronchial tree continues to branch into even smaller tubules called **bronchioles.** There is little cartilage in the bronchioles. The Thick smooth muscle that encircles their lumina can constrict or dilate these airways. Bronchioles provide the greatest resistance to air flow in the conducting passages (analogous to the arterioles of the circulatory system.) Numerous **terminal bronchioles** connect to **respiratory bronchioles** that lead into **alveolar ducts** and then to **alveolar sacs**. The conduction portion of the respiratory system ends at the terminal bronchioles and the respiratory portion begins at the respiratory bronchioles.



8.5.1 PULMONARY ALVEOLI

The alveolar ducts open into pulmonary alveoli as little out pockets along their length. Alveolar sacs are clusters of pulmonary alveoli. The alveolar ducts, pulmonary alveoli and alveolar sacs make up the respiratory division of the lungs. Gas exchange between oxygen and carbon dioxide occurs in the walls of the tiny pulmonary alveoli. This is why the pulmonary alveoli are considered the functional units of the lung. The vast number of these structures (350 million per lung) provides a very large surface area (760 square feet) for the diffusion of gases. Alveolar cells secrete a substance called surfactant that reduces the tendency of pulmonary alveoli to collapse. The alveoli compose most of the mass of the lung.



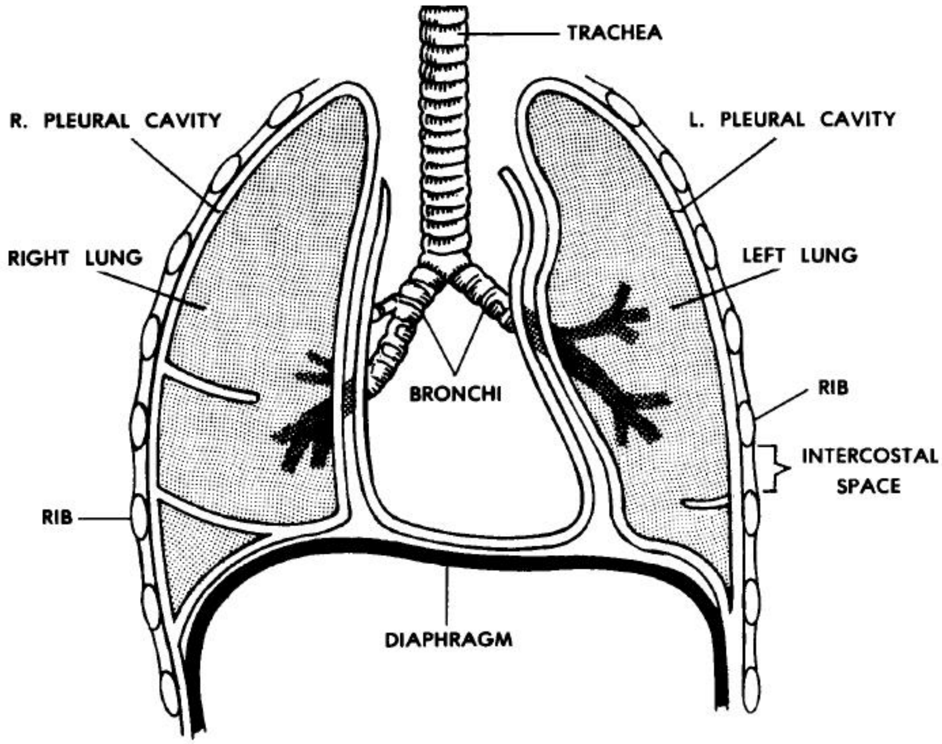
8.6 THE LUNGS

Learning outcomes

After studying this section you should be able to:

- **Describe the location and gross anatomy of the lungs**
- **Identify the functions of pleura**
- **Describe the pulmonary blood supply.**
- **Describe the functions of respiratory system**

The large spongy lungs are paired organs within the thoracic cavity. Each lung extends from the diaphragm to a point just above the clavicle and its surfaces are bordered by the ribs from front to back. The lungs are separated from each other by the heart and other structures of the mediastinum which is the area between the lungs. All the structures of the respiratory system beyond the principal bronchi, including the bronchial tree and the pulmonary alveoli, are contained within the lungs. Each lung has four surfaces that match the contour of the thoracic cavity. The mediastinal (medial) surface of the lung is slightly concave and contains a vertical slit, the hilum, through which pulmonary vessels, nerves and bronchi pass. The inferior surface of the lung, called the base of the lung, is concave as it fits over the convex dome of the diaphragm. The superior surface, the apex of the lung, extends above the clavicle. Finally the broad rounded surface in contact with the membranes covering the ribs is called the costal surface.



Although the right and left lungs are similar they are not identical. The left lung is smaller than the right and has a notch, the cardiac impression, to accommodate the heart. The left lobe is subdivided into a superior and inferior lung by a single fissure. The right lung is subdivided by two fissures into three lobes, the superior, middle and inferior. Each lobe of the lung is divided into many small lobules, which in turn contain the pulmonary alveoli. Lobular divisions of t he lungs make up specific bronchial segments. Each of these segments has its own blood supply and can be surgically isolated if diseased. The right lung contains 10 segments and t he left lung contains 8 segments. Pleurae are serous membranes surrounding the lungs and lining the thoracic cavity. The visceral pleura adhere to the outer surface of the lung and extend into each of the interlobar fissures. The parietal pleura line the thoracic walls and the thoracic surface of the diaphragm. A continuation of the parietal pleura and between the lungs forms the **mediastinum.** Between the visceral and parietal pleurae is a pleural cavity. It contains a lubricating fluid that allows the membranes to slide past one another. An inferiorly extending reflection of the pleural layers around the root of each lung is called the pulmonary ligament. This helps support the lungs. In normal conditions the pleural cavity contains a thin layer of lubricating fluid which allows the visceral and parietal membranes to sit flush against one another like with glass plates. The lungs are stuck to the thoracic wall. Because the lungs remain in contact with the thoracic wall, they get smaller and larger along with the thoracic cavity during inhalation and exhalation. Because the lung is compartmentalized by pleurae and membranes in the thorax, it can confine disease or injury to a compartment or side of the body.

Function of the respiratory system:

The 4 basic functions of the respiratory system are:

1. It provides oxygen to the blood stream and removes carbon dioxide

2. It enables sound production or vocalization as expired air passes over the vocal chords.

3. It assists in abdominal compression needed during micturation (urination), defecation (passing feces) and childbirth. The abdominal muscles become more effective during a deep breath when the air is held in the lungs by closing the glottis and fixing the diaphragm. This is also effective when lifting a heavy object, in which case the diaphragm assists the back muscles.

4. It enables protective and reflexive non breathing air movements such as coughing and sneezing, to keep the air passages clear.

The term respiration refers to 3 separate but related functions:

1) Ventilation (breathing)

2) Gas Exchange, which occurs between the air and blood in the lungs and between blood and other tissues in the body.

3) Oxygen utilization by the tissues in the metabolic reactions of cell respiration. Ventilation and gas exchange in the lungs are known as external respiration. Gas exchange between the blood and other tissues is known as internal respiration. A relaxed adult breathes and average of 15 times per minute, ventilating about 6 liters of air in a minute. In a 24 hour period that comes to 8,000 liters. Strenuous exercise increases oxygen demand and respiratory rate about 15-20 fold to about 100 liters per minute. If breathing stops, a person will lose consciousness in about 4-5 minutes. Brain damage occurs after 7-8 minutes. After 10 minutes a person will die.

8.7 RESPIRATION

Learning outcomes

After studying this section you should be able to:

- **Describe the muscles of respiration**
- **Compare and contrast the mechanical events occurring in inspiration and expiration**
- **Define the term compliance, elasticity and air flow resistance**
- **Describe the principal lung volumes and capacities**
- **Describe oxygen and carbon dioxide transport**

8.7.1 MECHANICS OF BREATHING: (Pulmonary ventilation)

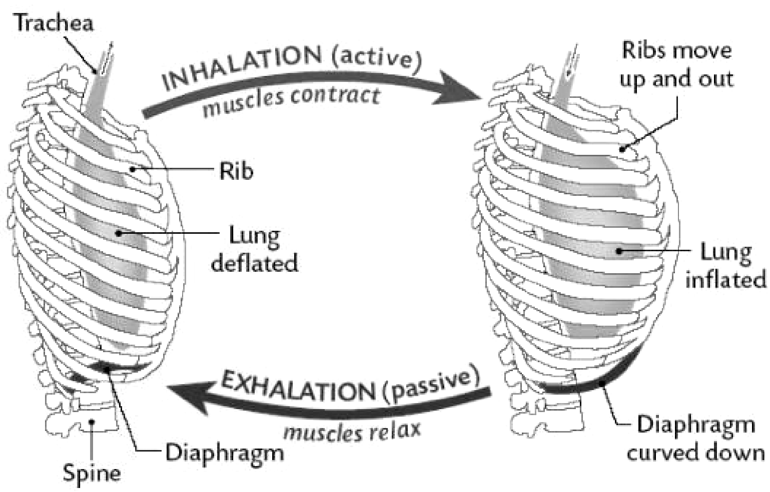
Normal inhalation is achieved by muscle contraction and expiration results from muscle relaxation and elastic recoil. A deeper inhalation and exhalation

can be achieved by forcing contraction of accessory respiratory muscles. Breathing requires the thorax to be flexible in order to function as a bellows during the ventilation cycle. Breathing consists of two phases: **inspiration and expiration.** Inspiration (inhaling) and expiration (exhaling) are accomplished by alternately increasing and decreasing the volume of the thoracic cavity. Breathing in takes place when the air pressure within the lungs is lower than the atmospheric pressure; breathing out takes place when the air pressure within the lungs is greater than the atmospheric pressure.
Pressure gradients change as the size of the thoracic cavity changes. Not only is the thoracic cavity flexible it must be rigid as well to protect the vital organs it contains. The ribs provide attachments for the short powerful respiratory muscles. The rib cage is pliable because the ribs are separated from one another and most of the ribs (the upper 10 of the 12 pairs) are attached to the sternum by flexible costal cartilage. The vertebral attachments are also flexible. The structure of the rib cage and its associated cartilage provides continuous elastic tension, so that expansion of the thorax allows passive return to its original position.

Cycles of respiration
This occurs 12 to 15 times per min which consists of 3 phases:
Inspiration
Expiration
Pause

Inspiration: Inspiration is the active part of the breathing process, which is initiated by the respiratory control centre in medulla oblongata (Brain stem). Activation of medulla causes a contraction of the diaphragm and intercostals muscles leading to an expansion of thoracic cavity and a decrease in the pleural space pressure. The diaphragm is a dome-shaped structure that separates the thoracic and abdominal cavities and is the most important muscle of inspiration. When it contracts, it moves downward and because it is attached to the lower ribs it also rotates the ribs toward the horizontal plane, and thereby further expands the chest cavity. In normal quite breathing the diaphragm moves downward about 1 cm but on forced inspiration/expiration total movement could be up to 10 cm. The external intercostals muscles connect adjacent ribs. When they contract the ribs are pulled upward and forward causing further increase in the volume of the thoracic cavity. As a result fresh air flows along the branching airways into the alveoli until the alveolar pressure equals to the pressure at the airway opening.

Expiration: Expiration is a passive event due to elastic recoil of the lungs. However, when a great deal of air has to be removed quickly, as in exercise, or when the airways narrow excessively during expiration, as in asthma, the internal intercostal muscles and the anterior abdominal muscles contract and accelerate expiration by raising pleural pressure.



Coupling of the Lungs and the Chest Wall: The lungs are not directly attached to the chest wall but they change their volume and shape according to the changes in shape and volume of the thoracic cavity. Pleura covering the surfaces of the lungs (visceral) or the thoracic cavity (parietal) together with a thin (20 μm) layer of liquid between them create a liquid coupling.

Pressure-Volume Relationships: In the pulmonary physiology absolute pressure means atmospheric pressure (760 mm Hg at sea levels). The pressures and the pressure differences of the respiratory system are expressed as relative pressures to the atmospheric pressure. When it is said that alveolar pressure is zero, it means that alveolar pressure = atmospheric pressure.

Compliance: In The slope of the pressure-volume curve, the volume change per unit pressure is known as **compliance**. In normal expanding range (2-10 mm water) the lung is very dispensable, in other words it is very compliant. The compliance of the human lung is 0.15 L/cm H2O. However, it gets stiffer (compliance smaller) as it is expanded above the normal range. Compliance is ***reduced*** when

(1) The pulmonary venous pressure is increased and the lung becomes engorged with blood

(2) There is alveolar edema due to insufficiency of alveolar inflation

(3) The lung remains unventilated for a while e.g. atelectasis and

(4) Because of diseases causing fibrosis of the lung e.g. chronic restrictive lung disease.

8.7.2 Non respiratory air movements

Air Movement	Mechanism	Comments
Coughing	Deep inspiration followed by a closure of of the glottis. The forceful expiration that results abruptly opens the glottis, sending a blast of air through the upper respiratory tract.	Reflexive or voluntary. Stimulus may be foreign material irritating the larynx or trachea.
Sneezing	Similar to a cough, except that the forceful expired air is directed primarily through the nasal cavity. The eyelids close reflexively during a sneeze.	Reflexive response to irritating stimulus of the nasal mucosa. Sneezing clears the upper respiratory passages.
Sighing	Deep, prolonged inspiration followed by a rapid, forceful expiration.	Reflexive or voluntary, usually in response to boredom or sadness.
Yawning	Deep inspiration through a widely opened mouth. The inspired air is usually held for a short period before sudden expiration.	Usually reflexive in response to drowsiness, fatigue, or boredom, but exact stimulus-receptor cause is unknown.
Laughing	Deep inspiration followed by a rapid convulsive expiration. Air movements are accompanied by expressive facial distortions.	Reflexive; may be voluntary to express emotions.
Crying	Similar to laughing, but the glottis remains open during entire expiration and different facial muscles are involved.	Somewhat reflexive but under voluntary control.
Hiccuping	Spasmodic contraction of the diaphragm while the glottis is closed, producing a sharp inspiratory sound.	Reflexive; serves no known function.

8.7.3 REGULATION AND CONTROL OF BREATHING:

In order to maintain normal levels of partial oxygen and carbon dioxide pressure both the depth and rate of breathing are precisely regulated. Basic elements of the respiratory control system are (1) strategically placed sensors (2) central controller (3) respiratory muscles.

CENTRAL CONTROLLER: Breathing is mainly controlled at the level of brainstem. The normal automatic and periodic nature of breathing is triggered and controlled by the respiratory centers located in the pons and medulla. These centers are not located in a special nucleus or a group of nuclei but they are rather poor defined collection of neurons.

1. Medullary respiratory centre:
-**Dorsal medullary respiratory** neurons are associated with inspiration: It has been proposed that spontaneous intrinsic periodic firing of these neurons responsible for the basic rhythm of breathing. As a result, these neurons exhibit a cycle of activity that arises spontaneously every few seconds and establish the basic rhythm of the respiration. When the neurons are active their action potentials travel through reticulospinal tract in the spinal cord and phrenic and intercostal nerves and finally stimulate the respiratory muscles. -

Ventral medullary respiratory neurons are associated with expiration. These neurons are silent during quite breathing because expiration is a passive event following an active inspiration. However, they are activated during forced expiration when the rate and the depth of the respiration is increased e.g. exercise. During heavy breathing increased activity of the **inspiratory centre** neurons activates the expiratory system. In turn, the increased activity of the expiratory system inhibits the inspiratory centre and stimulates muscles of expiration. The dorsal and ventral groups are bilaterally paired and there is cross communication between them. As a consequence they behave in synchrony and the respiratory movements are symmetric.

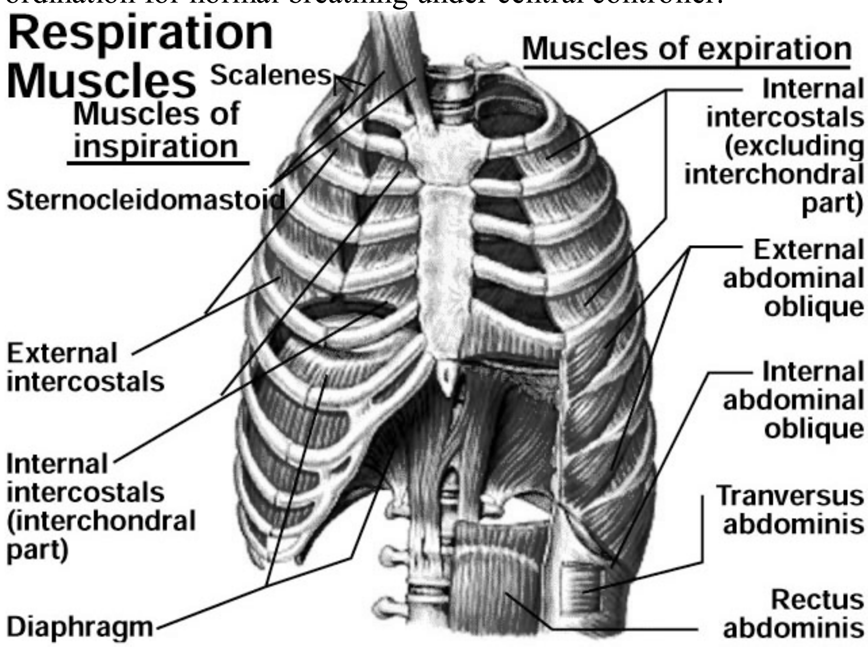
2. Apneustic Centre: It is located in the lower pons. Exact role of this centre in the normal breathing is not known. Lesions covering this area in the pons cause a pathologic respiratory rhythm with increased apnoea frequency. What is known is nerve impulses from the apneustic centre stimulate the inspiratory centre and without constant influence of this centre respiration becomes shallow and irregular.

3. Pneumotaxic centre: It is located in the upper pons. This centre is a group of neurons that have an inhibitory effect on the both inspiratory and apneustic centers. It is probably responsible for the termination of inspiration by inhibiting the activity of the dorsal medullar neurons. It primarily regulates the volume and secondarily the rate of the respiration. Because in the lesions of this area normal respiration is protected it is generally believed that upper pons is responsible for the fine-tuning of the respiratory rhythm. Hypoactivation of this centre causes prolonged deep inspirations and brief, limited expirations by allowing the inspiration centre remain active longer than normal. Hyperactivation of this centre on the other hand results in shallow inspirations. The apneustic and pneumotaxic centers function in co-ordination in order to provide a rhythmic respiratory cycle: Activation of the inspiratory centre stimulates the muscles of inspiration and also the pneumotaxic centre. Then the pneumotaxic centre inhibits both the apneustic and the inspiratory centers resulting in initiation of expiration. Spontaneous activity of the neurons in the inspiratory centre starts another similar cycle again.

Breathing in some extent is also controlled consciously from higher brain centers (e.g. cerebral cortex). This control is required when we talk, cough and vomit. It is also possible voluntarily change the rate of the breathing. Hyperventilation can decrease blood partial carbon dioxide pressure (PCO_2) due to loss of CO_2 resulting in peripheral vasodilatation and decrease in blood pressure. One can also stop breathing voluntarily. That results in an increase in arterial partial oxygen pressure (PO_2), which produces an urge to breathe. When eventually PCO_2 reaches the high enough level it overrides the conscious influences from the cortex and stimulates the inspiratory system. If one holds his breath long enough to decrease PO_2 to a very low level one may loose his consciousness. In an unconscious person automatic control of the respiration takes over and the normal breathing resumes. Other parts of the brain (limbic system, hypothalamus) can also alter the breathing pattern e.g. affective states, strong emotions such as rage and fear. In addition, stimulation of touch, thermal and pain receptors can also stimulate the respiratory system.

8.7.4 MUSCLES OF RESPIRATION:

The expansion of the chest during inspiration occurs as a result of muscular activity and partly involuntary. the main muscles of respiration in normal quite breathing are the intercostal muscles and Diaphragm, the other accessory respiratory muscles of the neck, shoulders and abdomen which work in co-ordination for normal breathing under central controller.



SENSORS:

1. MECHANORECEPTORS: These receptors are placed in the walls of bronchi and bronchioles of the lung and the main function of these receptors is to prevent the overinflation of the lungs.

2. CHEMORECEPTORS: The respiratory system maintains concentrations of O2, CO2 and the pH of the body fluids within the normal range of values. Any deviation from these values has a marked influence on the respiration. Chemoreceptors are specialised neurones activated by changes in O2 or CO2 levels in the blood and the brain tissue, respectively. They are involved in the regulation of respiration according to the changes in PO2 and pH. O2-sensitive chemoreceptors (Peripheral chemoreceptors) are located at the bifurcation of the carotid artery in the neck and the aortic arch. They are small vascular sensory organs encapsulated with the connective tissue. They are connected to the respiratory centre in the medulla by glossopharyngeal nerve (carotid body chemoreceptors) and the vagus nerve (aortic body). Central chemoreceptors are located bilaterally in the chemo sensitive area of the medulla oblongata and exposed to the cerebrospinal fluid (CSF), local blood flow and local metabolism. They actually respond to changes in H+ concentration in these compartments. When the blood partial PCO2 is increased CO2 diffuses into the CSF from cerebral vessels and liberates H+. (When CO2 combines with water forms carbonic acid and liberates H+ and HCO3 -).

CO2 + H2O Ö H2CO3
H2CO3Ö HCO -
3 + H+

An increase in H+ stimulates chemoreceptors resulting in hyperventilation which in turn reduces PCO2 in the blood and therefore in the CSF. Cerebral vasodilatation always accompanies an increased PCO2 and enhances the diffusion of CO2 into the CSF. Because CSF has less protein than blood it has a much lower buffering capacity. As a result changes in pH for a given change in PCO2 are always bigger than the change in blood. CO2 level is a major regulator of respiration. It is much more important than oxygen to maintain normal respiration. Even very small changes in carbon dioxide levels (5 mm Hg increase in PCO2, hypercapnia) in the blood cause large increases in the rate and depth of respiration (100 % increase in ventilation). Hypocapnia, lower than normal PCO2 level in the blood causes in periods in which respiratory movements do not occur. Effects of PO2 (if the changes occur within the normal range) on respiration is very minor. A decrease in PO2 is called hypoxia and only after 50 % decrease in PO2 can produce significant changes in respiration. This is due to the nature of O2-Hb saturation that at any PO2 level above 80 mm Hg Hb is saturated with O2.

8.7.5 VENTILATION *(*How does the inspired air get into the alveoli?)

AIRWAYS AND AIRFLOW: Inhaled air passes through the *conducting airways* and eventually reaches the respiratory epithelium of the lungs. The conducting airways consist of a series of branching tubes which become narrower, shorter and more numerous as they penetrate deeper into the lung. The *trachea* divides into right and left *main bronchi*, which in turn divide into *lobar*, then *segmental bronchi*. This process continues down to the *terminal bronchioles*, which are the smallest airways without alveoli. Since the conducting airways have no alveoli they do not take part in gas exchange but constitute the *anatomical dead space*. Its volume is about 150 ml but it varies because airways are not rigid; during inspiration, respiratory tubes are lengthened and dilated, especially in deep breathing. Since the airways serve as a barrier as well, harmful foreign material including most micro-organisms can not easily enter the lower respiratory passages. The very first barrier starts at the vestibules of the nose, which contain hairs, and healthy, sticky mucus intercepting air-borne particles. Caught particles are then ejected by ciliated epithelium, which covers the entire upper respiratory tract. Various factors can interfere with ciliary activity: for example nicotine and tar in tobacco smoking. Coughing occurs in response to chemical or mechanical irritation of nerve endings in the upper respiratory tract. The larynx and the bifurcation of the trachea are the most sensitive regions and any particles of foreign matter lodged in these regions are removed when a cough sends a rapid blast of air sweeping out the respiratory tree.

The The alveolated region of the lung includes *respiratory bronchioles* (divided from terminal bronchioles and have only occasional alveoli on their walls) and *alveolar ducts* (completely lined with alveoli). This zone is called *respiratory zone* and the gas exchange occurs here. The distance from the terminal bronchiole to the distal alveous is only a few mm, but the respiratory zone makes up most of the lung, its volume being about 2.5 to 3 L. Blood is brought to the other side of the blood-gas barrier from the right heart by pulmonary arteries, which also form a series of branching tubes leading to the pulmonary capillaries and back to the pulmonary veins. The capillaries lie in the walls of the alveoli and form a dense network that the blood continuously runs in the alveolar wall. At resting not all the capillaries are open but when the pressure rises (e.g. exercise) recruitment of the close capillaries occurs. The diameter of a capillary segment is about 10 μm, just large enough for a red blood cell. The pulmonary artery receives the whole output of the right heart, but resistance of pulmonary circuit is very low. This enables the high blood flow to the circuit.

8.7.9 LUNG VOLUMES AND PULMONARY FUNCTION TESTS:

Pulmonary function can be examined by ***the spirometry technique***. Spirometers are the traditional tools of the respiratory physiologists. The subject breathes into a closed system in which air is trapped (bell). As the subject breathes air movement into or out of the mouthpiece causes the bell to rise (inspiration) or fall (expiration). Corresponding movements of an attached pen register the change in volume on a rotating drum recorder. From such a recording we could measure

1. **Tidal volume (TV):** Volume of air inhaled or exhaled with each breath during normal breathing
2. (0.5 L).
3. **Inspiratory reserve volume (IRV):** Maximal volume of air inhaled at the end of a normal inspiration (3 L)
4. **Expiratory reserve volume (ERV)**: Maximal volume of air exhaled at the end of a tidal volume
5. (1.2 L).
6. **Inspiratory capacity (IC):** Maximal volume of air inhaled after a normal expiration (3.6 L) (TV+IRV)
7. **Functional Residual Capacity (FRC):** The volume of gas that remains in the lung at the end of a passive expiration. (2-2.5 L or 40 % of the maximal lung volume) (ERV+RV).

8. **Residual Volume (RV)**: The volume of gas remains in the lung after maximal expiration. (1-1.2 L) FRC and RV can not be measured with an ordinary spirometer (For details see below).
9. **Total Lung Capacity (TLC):** The maximal lung volume that can be achieved voluntarily. (5-6 L) (IRV+ERV+TV+RV)
10. **Vital capacity (VC):** The volume of air moved between TLC and RV. (4-5 L) (IRV+ERV+TV).
11. Multiplying the tidal volume at rest by the number of breaths per minute gives **the total minute volume** (6 L/min). During exercise the tidal volume and the number of breaths per minute increase to produce a total minute volume as high as 100 to 200 L/min.

Measurements of Functional Residual Capacity (FRC) and Residual Volume (RV): There are two techniques to study these volumes:

Helium Spirometry: In this technique a subject is connected to a spirometer filled with helium which is virtually insoluble in the blood. After some breathes the amount of helium in the lung and the spirometer reach equilibrium. Because there is no lost of gas during the experiment the amount of helium before ($C_1 \times V_1$) and after the equilibrium ($C_2 \times [V_1 + V_2]$) is same.

$$V_1 = C_2 \times (V_1 + V_2)$$

$$V_2 = V_1 \times (C_1 - C_2) / C_2$$

$$V_2 = FRC$$

Another way of measuring FRC is with a body **plethysmograph**. It is a big airtight box in which the subject sits. At the end of a normal expiration, the mouthpiece is shut and the subject makes
respiratory efforts. When the subject makes an inspiratory effort against a closed airway s/he slightly increases the volume of his/her lung, airway pressure decreases and the box pressure increases:

$$P_1 \times V_1 = P_2 \times (V_1 - \square V)$$

The pressure in the box before (P1) and after (P2) the respiratory efforts,
V: Volume in the box before the respiratory efforts and □V can be measured.
The Boyle's law can also be applied to the gas in the lung:

$$P_3 \times V_2 = P_4 \times (V_2 + \square V)$$

$$V_2 = FRC$$

P3,4: Mouth pressures before (P3) and after (P4) the respiratory efforts.
If the measurement is done following a forced expiration

$$V_2 = RV$$

In contrast to the helium technique, which measures only the ventilated air, the body plethysmograph measures the total volume in the gas in the volume including the gas trapped in the airways (if there is any). Normally measurements with these techniques are similar. However, the difference is increased in the presence of lung diseases.

TOTAL VENTILATION: The total volume of the gas leaving the lung per unit time. If TV is 500 ml and there are approximately 15 breaths/min the total volume of the gas leaving the lung, total ventilation will be 500 x 15 = 7500 ml/min. It can be measured by having the subject breath through a valve that separates the inspired air from expired air and collecting the expired air.

ALVEOLAR VENTILATION: The volume of the gas reaching the respiratory zone of the airways. However, not all of the total ventilation volume reaches the alveoli. 150 ml of the TV (500 ml) is left behind in the airways, which does not contain alveoli, therefore does not contribute the diffusion (*Anatomic death space*). Thus, the volume of gas entering the respiratory zone, alveolar ventilation, is (500-150) x 15 = 5250 ml/min. The measurement of alveolar ventilation is more difficult. One way is to measure the volume of anatomic dead space and calculate the dead space ventilation. This then subtracted from the total ventilation.

Alveolar ventilation = Total ventilation – Anatomic death space ventilation

Anatomic dead space ventilation = Anatomic dead space volume x respiration frequency

VE: total expiration volume
VT: Tidal volume
VD: Dead Space volume
VA: volume of alveolar gas during tidal breathing
V: volume per unit time

VT = VD + VA

(VT x n) = (VD x n) + (VA x n)

V: volume per unit time
VE: Expired total ventilation
VD: dead space ventilation
VA: alveolar ventilation

VE = VD + VA
VA = VE - VD

The disadvantage of this method is it is not very easy to determine dead space volume without a
considerable error. Another way of measuring the alveolar ventilation is from concentration of CO_2 in expired air. Since the amount of CO_2 in the inspired air is negligible and no gas exchange occurs, we could assume that there is CO_2 in the anatomic dead space. Therefor CO_2 in the expired air comes from alveoli.

$VCO_2 = VA \times \% CO_2 / 100$

VCO_2 = the volume of CO_2 exhaled per unit time.

$VA = (VCO_2 \times 100) / \% CO_2$

% CO_2 = Fractional CO_2 concentration = FCO_2

ANATOMICAL DEAD SPACE: Volume of the conducting airways. It is approximately 150 ml but its volume increases with large inspiration and depends on the size and the posture of the subject. Measurement of dead space: **Fowler's method:** The subject breaths pure oxygen through a valve box and a rapid nitrogen analyser samples and measures the nitrogen concentration in the expired air. After a single inspiration of pure oxygen (100 %) nitrogen concentration in the expired air is increased as the gas in the dead space is washed by pure oxygen. Nitrogen concentration quickly reaches a plateau level (alveolar plateau). The dead space is found by plotting nitrogen concentration against the expired volume. The expired volume up to the vertical line drawn such that area A = area B represents the anatomical dead space volume.

PULMONARY FUNCTION TESTS:

Pulmonary function tests are very useful tests to diagnose several lung diseases. The simplest but one of the most informative tests of lung function is a **forced expiration**.

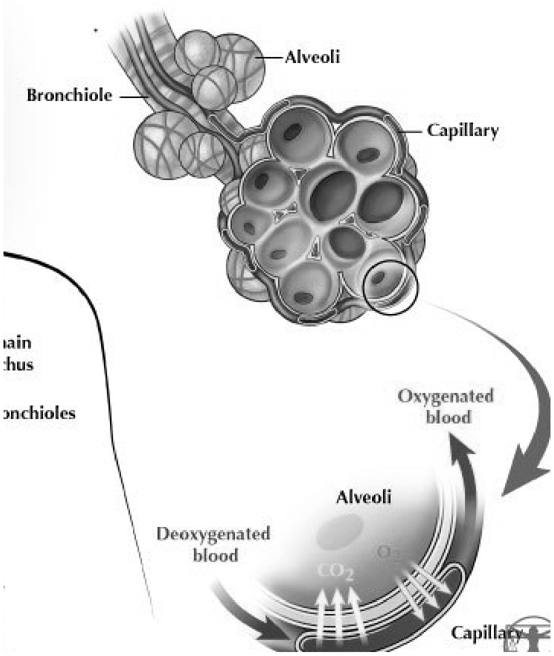
TESTS OF VENTILATORY CAPACITY

Forced Expiratory Volume (FEV): It is the volume of gas exhaled in one second by a forced expiration following a full inspiration (**FEV1).** The total volume of the gas exhaled after a full inspiration represents the vital capacity. However, this value could be slightly smaller than the vital capacity measured with slow (normal speed) expiration. Therefore, this value is called ***forced vital capacity*** **(FVC).** The normal ratio of the FEV1 is 80 % of FVC.

Forced Expiratory Flow (FEF25-75): This measurement represents the expiratory flow rate over the middle half of the FVC (between 25 – 75 %). It is obtained by identifying the 25 % and 75 % volume points of FVC, measuring the time between these points and calculating the flow rate.
Interpretation of tests of forced expiration: On the basis of the knowledge obtained from these functional tests, lung diseases can be classified as ***restrictive*** or ***obstructive*.** In restrictive lung diseases (such as pulmonary fibrosis), the vital capacity is reduced to below normal levels. However, the rate at which the vital capacity is forcefully exhaled is normal. In obstructive lung disease (such as asthma, emphysema, bronchitis) the vital capacity is normal because lung tissue is not damage and its compliance is unchanged. In asthma the small airways (bronchioles) constrict, bronchoconstriction the resistance to airflow. Although the vital capacity is normal, the increased airway resistance makes expiration more difficult and takes longer time. Obstructive disorders are therefore diagnosed by tests that measure the rate of forced expiration, such as the FEV1 and FEF25-75**.** A significant decrease in these values suggests an obstructive lung disease.

DIFFUSION. How do gasses get across the blood-gas barrier?

BLOOD-GAS EXCHANGE: Oxygen and carbon dioxide move between air and blood by simple diffusion: from an area of high to low partial pressure, as simple as water runs downhill. It is a passive process which means requires no energy. ***Fick's law of diffusion*** determines the amount of gas moves across the tissue is proportional to the area of the tissue but inversely proportional to its thickness. Because the blood-gas barrier in the lung is extremely thin and has a very large area (50-100 m2), it is well suited to its function.



Calculations of Oxygen and Carbon Dioxide Partial Pressures:
Dalton's Law: Total pressure of a gas mixture (in our case air) is equal to the sum of the pressures that each gas in the mixture would have independently (**Partial Pressure** of each gas).

Pdry atmosphere = PN2 + PO2 + PCO2 = 760 mmHg
Since oxygen constitutes 21 % of the atmosphere, PO2 = 159 mm Hg. nitrogen 78 PN2 = 593 mmHg Inspired air also contains moisture and its amount may vary with temperature etc. However when the inspired air arrived the alveoli it is normally saturated with water vapour. Because the temperature in the lungs does not change significantly water vapour of the alveolar air could be considered constant (47 mm Hg).

8.9 Summary:

- The respiratory system allows for the exchange of oxygen and carbon dioxide across a moist body surface.
- External respiration is the exchange of oxygen and carbon dioxide between the gas inside the lungs and the blood, gas transport moves oxygen and carbon dioxide between the lungs and tissue and internal respiration exchanges oxygen and carbon dioxide between blood and the lungs.
- The nose warms and moistens the air and clears particles from it.
- The sinuses make the head lighter and help warm and moisten the air.
- The pharynx, or throat, is a passageway for air, food, and drink from the mouth to the larynx.

- The larynx contains the epiglottis that covers the opening in the larynx and prevents food from entering the lungs. The larynx is also the source of the voice, which is generated by the vibration of the vocal cords.
- The trachea is the windpipe that conducts air between the environment and the lungs. The trachea branches into the bronchial tree, a system of air tubules.
- The alveoli are grape-like clusters of sacks that allow for the exchange of oxygen and carbon dioxide between the air and the blood.
- The contraction of the intercostals muscles and diaphragm cause an increase in the volume of the thoracic cavity. The increase in volume results in a decrease in air pressure that results in inhalation.
- The relaxation of the intercostals and diaphragm causes the volume of the lungs to decrease and the pressure to increase. This results in exhalation.
- The tidal volume is the volume of air inhaled or exhaled during normal breathing. The inspiratory and expiratory reserve volume is the additional volume of air that can be forced in or out of the lungs. The residual volume is the air that remains in the lungs after maximum exhaling. The vital capacity is the maximum amount of air that can be moved into and out of the lungs during forceful breathing. The total lung capacity is the total volume of air contained in the lungs after the deepest possible breath.
- Blood transports oxygen to the cells and carbon dioxide away from the cells.
- Most oxygen is carried by hemoglobin in the form of oxyhemoglobin.
- Most carbon dioxide is transported as bicarbonate ion, although some is carried by hemoglobin and some is dissolved in the blood.
- The rhythm of breathing is controlled by the breathing center in the medulla.

Self assessment questions

1. Describe the mechanism of respiration and Draw a neat labeled diagram of lungs.
2. Name the respiratory centers. Explain the neural regulation of respiration.
3. Explain the structure and functions of respiratory membrane.
4. Explain the functions of lungs.
5. Define lung volumes and give their normal values.
6. List the functions of nasal cavities.
7. Name the muscles of respiration.
8. Name the respiratory centers.

9. INTRODUCTION TO NUTRIENTS

Introduction:

A **nutrient** is a chemical that an organism needs to live and grow or a substance used in an organism's metabolism which must be taken in from its environment. Nutrients are the substances that enrich the body. They build and repair tissues, give heat and energy, and regulate body processes. Methods for nutrient intake vary, with animals and protists consuming foods that are digested by an internal digestive system, but most plants ingest nutrients directly from the soil through their roots or from the atmosphere. Some plants, like carnivorous plants, externally digest nutrients from animals, before ingesting them. The effects of nutrients are dose-dependent.

Organic nutrients include carbohydrates, fats, proteins (or their building blocks, amino acids), and vitamins. Inorganic chemical compounds such as dietary minerals, water, and oxygen may also be considered nutrients. A nutrient is essential to an organism if it cannot be synthesized by the organism in sufficient quantities and must be obtained from an external source. Nutrients needed in large quantities are called **macronutrients**; **micronutrients** are required in only small quantities.

An **essential nutrient** is a nutrient required for normal body functioning that either cannot be synthesized by the body at all, or cannot be synthesized in amounts adequate for good health (e.g. niacin, choline), and thus must be obtained from a dietary source.

Some categories of essential nutrients include vitamins, dietary minerals, essential fatty acids, and essential amino acids. Water and oxygen are also essential for human health and life, as oxygen cannot be synthesized by the body, and water, while a biochemical reaction product of metabolism, is not created in sufficient amounts. Both are necessary as biochemical reactants in some processes, and water is used in various ways such as a solvent, carrier, coolant, and integral polar structural member, but both are often not included as nutrients.

A **healthy diet** is one that helps maintain or improve health. It is important for the prevention of many chronic health risks such as: obesity, heart disease, diabetes, and cancer.

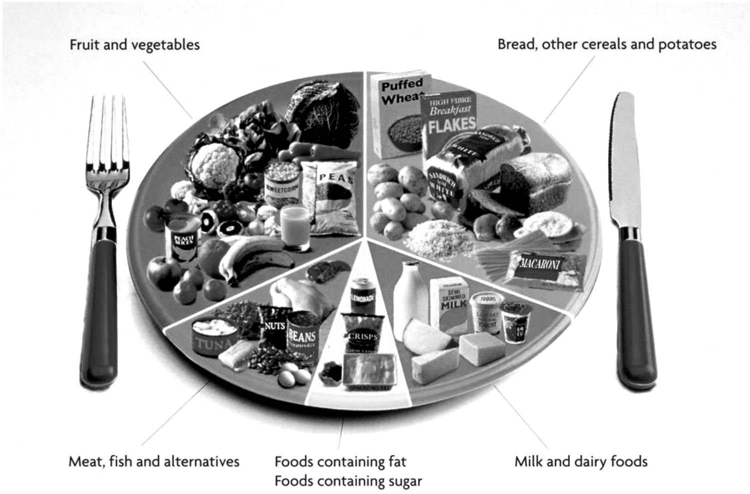
A healthy diet involves consuming appropriate amounts of all nutrients, and an adequate amount of water. Nutrients can be obtained from many different foods, so there are a wide variety of diets that may be considered healthy diets.

Nutrient Balance

Carefully planned nutrition must provide an energy balance and a nutrient balance. The nutrients are:

- **Proteins** - essential to growth and repair of muscle and other body tissues
- **Fats** - one source of energy and important in relation to fat soluble vitamins
- **Carbohydrates** - our main source of energy
- **Minerals** - those inorganic elements occurring in the body and which are critical to its normal functions
- **Vitamins** - water and fat soluble vitamins play important roles in many chemical processes in the body
- **Water** - essential to normal body function - as a vehicle for carrying other nutrients and because 60% of the human body is water
- **Roughage** - the fibrous indigestible portion of our diet essential to health of the digestive system

9.1 THE BALANCED DIET



Learning outcome

After studying this section, you should be able to:

List the constituent food groups of balanced diet :

A balanced diet comprising of diverse and healthy foods is key to promoting good health. After all, we are what we eat - Research continues to prove that eating ***healthy food*** promotes good health and unhealthy food habits lead to a diseased body. Foods contain vital nutrients that aid our body's metabolic function. However, a lack of consumption of these nutrients or feeding upon the wrong kinds of food leads to an accumulation of toxins within the body, resulting in chronic diseases in the long run.

A nutritious diet while ensuring overall well being, helps to maintain a healthy Body Mass Index (BMI), reduces the risk of several debilitating diseases like cancer, cardiovascular ailments, diabetes, osteoporosis and stroke. Thus a nutritious & **healthy diet** is important in the prevention and cure of various diseases.

Healthy Food Groups

Since no single food group can nourish the body with all the vital ingredients it requires, it is important that we consume a variety of *healthy foods* to derive the nutrition our body needs. There are five main food groups, they are:

- Fruits
- Vegetables
- Cereals and Pulses
- Dairy
- Poultry, Fish and Meat products

A healthy balanced diet of these five food groups ensures essential vitamins, minerals and dietary fiber. The food group serving size will depend upon various factors like age, activity level, body size and gender. It is also important that one eat a variety of healthy foods from within and across the food groups. As some foods from within a food group provide more nutrients than others. This will ensure that one gets the maximum recommended nutrition from the food group besides the food variety will make for an interesting meal.

In conclusion, it must be noted that allopathic medicine treats the symptoms rather than the root cause of the disease, which is usually caused by wrong eating habits leading to an accumulation of toxins within the system. Whereas a nutritious healthy diet can rectify underlying causes of diseases and restore one to wholeness of mind and body. Once we realize the connection between a wholesome balanced diet and good health, our food will be our medicine and maintaining good health will be a matter of making the right food choices and leading a healthy lifestyle.

Learning outcome

After studying this section, you should be able to:

Describe the main mono, di and polysaccharides.

List the nutritional function of digestable carbohydrates

5.2 CARBOHYDRATES:

Carbohydrates are organic compounds which may be simple and complex. It include sugars and starches. All carbohydrates are eventually broken down into glucose which is absorbed and utilized by the body in various ways. Glucose is required by red blood cells and is the main source of energy for the brain. It is also essential for the oxidation of fat and for the synthesis of certain non-essential amino acids. Simple carbohydrates like sugar and sugar enriched food is broken down easily and soon absorbed into the blood stream whereas complex carbohydrates like starches take longer time to be broken down by digestive enzymes hence providing a slower and more gradual supply of glucose.

Carbohydrates are the primary source of energy which provide about two-thirds of an individuals total energy needs. Sugars are found in glucose (its basic form) and sweets, biscuits, chocolates, pastries, honey, fruits etc. Starches are found in a wide range of foods including cereals, grains, pulses, bread, beans, potatoes, other vegetables and fruits which are far more useful as they contain accompanying fibre, vitamins and minerals. It is sensible to eat more starch rich foods as excess sugar rich foods may lead to obesity, high blood sugar, tooth decay and a possible increased risk of developing diabetes in later adult life.

The percentage of calories derived from carbohydrates should be at least 40% in well balanced diets. But this consumption differs country wise depending on the difference in diets. While in developing nations it is as high as 60-70%, it is 40-50% in Europe and 30-40% in USA.

Monosaccharides

Monosaccharides (from Greek *monos*: single, *sacchar*: sugar) are the most basic units of biologically important carbohydrates. They are the simplest form of sugar and are usually colorless, water-soluble, crystalline solids. Some monosaccharides have a sweet taste. Examples of monosaccharides include glucose (dextrose), fructose (levulose), galactose, xylose and ribose. Monosaccharides are the building blocks of disaccharides such as sucrose and polysaccharides (such as cellulose and starch). Further, each carbon atom that supports a hydroxyl group (except for the first and last) is chiral, giving rise to a number of isomeric forms all with the same chemical formula. For instance, galactose and glucose are both aldohexoses, but have different chemical and physical properties

Polysaccharides :

Are polymeric carbohydrate structures, formed of repeating units (either mono- or di-saccharides) joined together by glycosidic bonds. These structures are often linear, but may contain various degrees of branching. Polysaccharides are often quite heterogeneous, containing slight modifications of the repeating unit. Depending on the structure, these macromolecules can have distinct properties from their monosaccharide building blocks. They may be amorphous or even insoluble in water. When all the monosaccharides in a polysaccharide are the same type the polysaccharide is called a homopolysaccharide, but when more than one type of monosaccharide is present they are called heteropolysaccharides.examples include storage polysaccharides such as starch and glycogen, and structural polysaccharides such as cellulose and chitin.polysaccharides have a general formula of $c_x(h_2o)_y$ where x is usually a large number between 200 and 2500. Considering that the repeating units in the polymer backbone are often six-carbon monosaccharides, the general formula can also be represented as $(c_6h_{10}o_5)_n$ where $40 \leq n \leq 3000$.

5.3PROTEINS:

Learning outcome

After studying this section, you should be able to:

Describe the structure of amino acids,including essential and non-essential amino acids.
List the nutritional functions of dietry proteins

IMPORTANCE OF PROTEINS IN BIOLOGICAL SYSTEM

Major structural components of the membranes of various cell organelles occur in extracellular fluids chief constituents of protoplasm. All enzymes and certain hormones are proteins. Most of the hormones of pancreas, pituitary and parathyroid glands are peptides in nature. Haemoglobin(a conjugated protein) plays an important role in the exchange of respiratory gases. Immunoglobulin in blood plasma has property of immunity. The loss due to wear and tear in the body is made good by proteins, which are also responsible for growth. Rhodopsin essential for vision is a protein. Melanin pigment Actin and myosin in muscles and globular protein in cilia and flagella are contractile proteins and are responsible for movements. The nutritive protein in the grains of wheat and maize is useful for growth during germination. The egg protein is used for the development of embryo. Casein in mamalian milk has similar function. Fibrinogen and thrombin help in the coagulation of blood. Any two individuals do not resemble completely in their protein structure. Hence there are variations in all living organisms. These are due to their genes, which play a key role in protein synthesis.

Essential and Nonessential Amino Acids:

Dietary protein is the main source of amino acids. Amino acids can be used as fuel, but usually more important roles for them are as building blocks for proteins, and as a source of carbon and nitrogen for biosynthesis of other biochemicals. In the process of digestion, proteins are broken down to free amino acids in the gastrointestinal tract. They are then absorbed and pass into the circulation, and are transported to liver where -NH2 groups are removed by transamination. The resulting alpha-keto acid is then used as fuel, or as a biosynthetic intermediate. Amino acids are not stored in the body like fats or carbohydrate; there are no specialized cells in the body to maintain a reservoir. Of course, amino acids are ubiquitous, being present in structural proteins, enzymes, transport proteins, etc. Some of these proteins (notably serum albumin) can be degraded under conditions of fasting or starvation, to release free amino acids. Adult humans are unable to synthesize all twenty amino acids needed for protein synthesis; those which cannot be synthesized and which must then be acquired via the diet are referred to as essential. The ten which the body can synthesize on its own are nonessential.

The ten essential amino acids for adults are:

Phenylalanine
Valine

Tryptophan
Threonine
Isoleucine
Methionine
Histidine
Arginine
Leucine
Lysine

Dietary intake of amino acids is typically not balanced to exactly match the body's demands for various amino acids. Amino acids taken via the diet must be chemically modified and rearranged to provide adequate levels of all the amino acids needed. There are a large number of pathways in the body for balancing the pool of amino acids, both for synthesis and for degradation. The number of enzymes involved creates a great potential for genetic diseases. Furthermore, disruption (by mutation of just one enzyme) in the metabolism of only one amino acid can have profound consequences for growth and development; some of the genetic diseases are fatal.

5.4 LIPIDS

Learning outcome

After studying this section, you should be able to:

Outline the main source of dietry fat
List the functions of fats in the body

Biological Importance Of Lipids:

Lipids are the foodstuffs of highest calorific value. One gram of lipid, on oxidation, gives 9.3 k. cal. of energy. It is insoluble in water. It is stored in the body as reserve food, which can be utilized through the metabolic process as and when required. It forms an insulating layer. This helps maintain the body temperature. Lipids such as wax form a protective layer on the outer surface of the aerial plant organs. The myelin sheath around the medullated nerve fiber contains lipid that prevents the passage of nerve impulse in the adjacent nerve fibers. Lipids is a solvent for fat soluble vitamins A, D and E. It is also a structural component of several cell organelles. The presence of lipid is inevitable for the activity of certain enzymes., e. g., glucose phosphatase. Steroid hormones and vitamins D and E are synthesized from the derivatives of lipids.

Lipids in the cell :

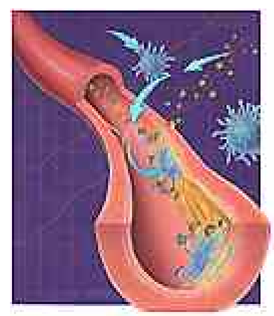
Lipids in their complex forms are found in various cell organelles such as cell membrane, Golgi body and endoplasmic reticulum. There is about 20-30% lipid in mitochondria and chloroplasts.

TRIGLYCERIDES

Triglyceride (**triacylglycerol**, **TAG** or **triacylglyceride**) is an ester composed of a glycerol bound to three fatty acids. It is the main constituent of vegetable oil and animal fats.

Triglycerides
Triglycerides are a form of fat in the bloodstream. People with high triglycerides often have a high total cholesterol, a high LDL (bad) cholesterol and a low HDL (good) cholesterol level. Many people with heart disease also have high triglyceride levels. Several clinical studies

have shown that people with above-normal triglyceride levels (greater than or equal to 200 mg/dL) have an increased risk of heart disease. People with diabetes or who are obese are also likely to have high triglycerides.



Triglyceride Level Classification	
Less than 150 mg/dL	Normal
150-199 mg/dL	Borderline-high
200-499 mg/dL	High
500 mg/dL	or higher Very high

5.5 VITAMINS

Learning outcome

After studying this section, you should be able to:

Outline the sources and functions of the fat soluble vitamins

Describe the source and functions of water soluble vitamins

The vitamins are a disparate group of compounds; they have little in common either chemically or in their metabolic functions. Nutritionally, they form a cohesive group of organic compounds that are required in the diet in small amounts (micrograms or milligrams per day) for the maintenance of normal health and metabolic integrity. They are thus differentiated from the essential minerals and trace elements (which are inorganic) and from essential amino and fatty acids, which are required in larger amounts.

The discovery of the vitamins began with experiments performed by Hopkins at the beginning of the twentieth century; The first of the accessory food factors to be isolated and identified was found to be chemically an amine; therefore, in 1912, Funk coined the term *vitamine*, from the Latin vita for "life" and amine, for the prominent chemical reactive group.

Vitamins are essential nutrients. They are required in small amounts, but have important and specific functions such as promoting growth, reproduction and the maintenance of health. Although needed to stay healthy they are not a cure all. Vitamins do NOT give energy. They are organic – that is easily destroyed by Heat, UV radiation and O_2. Are available in foods .Vitamin deficiencies should be corrected by eating certain foods, NOT from taking pills. Vitamins only occur naturally in foods. "Natural vitamins" do NOT come in a bottle.

The 14 vitamins defined today are classified into 2 groups, fat soluble and water soluble. Vitamins A, D, E, and K are water soluble, while vitamin C and B vitamins, including biotin, pantothenic acid, and choline are water soluble vitamins.

Fat Soluble Vitamins

Fat soluble – Hydrophobic .Vitamins A, D, E & K .these vitamins have specific roles in growth and maintenance of the body. Found in oils and fats they Enter the lymphatic system when absorbed Many require protein carriers in order to be transported. May get trapped in fat storing cells and remain there .Since the body can store them; toxic levels can be reached faster than the water-soluble vitamins.

Vitamin A

In 1913 the first vitamin, vitamin A, was isolated from the retina. Vitamin A is a family of compounds that includes retinal, retinol, retinoic acid, and carotenoids. Retinal and retinol are found in foods of animal origin and can be used directly by the body. Carotenoids, provitamin form of vitamin A, of which beta carotene is the most active, is found in plants. Pro-vitamin is converted into vitamin A through enzymatic process.

Source:

Liver, fish, dairy products, egg yolks, carrots, sweet potatoes, tomatoes, fortified breakfast cereals.

Functions

Vitamin A plays an essential role in helping eyes work properly, especially with night vision. It also promotes the growth and health of cells and tissues throughout the body including bones and soft tissues. Vitamin A is involved in immune system. Carotenoids act as antioxidants and protect against certain cancers and diseases associated with aging, such as heart disease.

Deficiency of vitamin cause:

hypovitaminosis A

1. Symptoms include night blindness,
2. xerophthalmia,
3. keratinization of cells,
4. anemia,
5. kidney stones,
6. poor bone growth and
7. tooth enamel formation

Toxicity is called hypervitaminosis A

1. Affects all body systems
2. May cause birth defects.
3. Symptoms include decalcification of bone, RBC's lose hemoglobin and potassium, slowed clotting time, cessation of menstruation, skin rashes, nausea, vomiting blurred vision and appetite loss. The liver enlarges due to fat and Vitamin A accumulating in large amounts and jaundice develops.

Vitamin D

Vitamin D is also known as "sunshine" vitamin since our body uses ultraviolet sun light to produce vitamin D. Ten minutes of sun exposure per day is thought to be adequate. However, dietary sources of vitamin D continue to be important for people that don't get enough sun and for the elderly, who have a diminished ability to make vitamin D. Rickets, a disease of malformed bones, is nearly eliminated in children due to fortified milk, but osteomalacia, another bone disease that occurs in the elderly with low vitamin D intake, continues to be a problem.

Source:

Saltwater fish, eggs from hens that have been fed vitamin D, fortified milk products and fortified cereals.

NOTE: Vitamin D is also made in your body after you've been in the sunlight.

Functions:

The primary function of vitamin D is for homeostasis of calcium and phosphorus in the body. Vitamin D ensures bones and teeth are strong as well as making sure that nerves and muscles work properly by regulating calcium levels in the blood. It is also thought that vitamin D is involved in insulin production, the immune system, and in treating skin disorders.

Deficiencies:

a. may occur as a result of diseases in the liver and kidney
b. occur more often in elderly people
c. the symptoms are those of a calcium deficiency
d. rickets – occurs in children
e. osteomalacia – adult form of rickets
Toxicities – Hypervitaminosis D
a. Causes an increase in calcium absorption
b. Kidney stones
c. Calcification of blood vessels

Vitamin E :

Vitamin E is a powerful antioxidant that protects our body by neutralizing cell damage. It was first named tocopherol, which in Greek means childbirth and to bear, after it was shown to prevent fetal death. Of the various tocopherals and tocotrienols classified as vitamin E, α-tocopheral is the most abundant and biologically active.

Source:

Fish, milk, egg yolks, vegetable oils, nuts, fruits, peas, beans, broccoli, spinach, fortified cereals.

Functions :

Due to its ability to neutralize free radicals that are produced in the body or from the environment, vitamin E can protect against heart disease, cancer, Alzheimer's disease and other chronic diseases.

Deficiencies:

Are usually caused by diseases that cause malabsorption of fat, such as cystic fibrosis.

a. Symptoms include Erythrocytic hemolysis (RBC's break apart)
b. Neuromuscular dysfunction of the spinal cord and retina.

Toxicities: are rare but extremely high doses may interfere with Vitamin K. Vitamin E may benefit fibrocystic breast disease and intermittent claudication (cramping of legs caused by abnormal blood flow).

Vitamin K

Vitamin K is actually a group of compounds derived from naphthoquinone. In the gut, intestinal bacteria can synthesized vitamin K. Limited amounts of vitamin K are stored in the body.

source:

Cheese, spinach, broccoli, Brussels sprouts, kale, cabbage, tomatoes, plant oils, margarine.

Functions:

Vitamin K is essential in the production of prothrombin, a protein essential for blood coagulation; therefore, vitamin K is critical in regulating normal blood clotting. It also is involved in bone and kidney metabolism.

Deficiencies :

May occur if absorption of fat is impaired. Which Can be fatal since blood clots will not form.

Toxicities:

Are uncommon unless supplements are being taken. Which Will interferes with anticoagulant therapy .Symptoms include RBC hemolysis, jaundice, and brain damage.

Water Soluble Vitamins:

Water soluble B vitamins have many similar functions in the body. They are critical in releasing energy from macronutrients. Thanks to fortification of grains and bread products in the US, deficiency of B vitamins are no longer the serious public health issue it once was. Beriberi, a disease of thiamin deficiency, and pellagra, a disease of niacin deficiency, are very rare. However, alcoholics are one group vulnerable to suboptimum levels of water soluble vitamins due to their poor dietary habits. It is important to meet daily needs for these vitamins since any excess of these vitamins are excreted rather than stored in the body. And typically, multiple deficiencies will be evident since food sources for these vitamins are often the same. Clinical symptoms of mild deficiencies can be quickly reversed by eating a nutrient-rich diet.

Thiamin:

Thiamin is also known as vitamin B1, since it was the first B vitamin to be discovered. Beriberi is a disease of thiamin deficiency.

Functions :

Thiamin is required for normal function of all body cells, especially nerves. It plays a critical part in releasing acetylcholine, the nerve chemical that regulates memory. Like other B vitamins, thiamin is involved in numerous body processes that break down macronutrients for energy.

source:

Lean beef, pork, liver, legumes, nuts, enriched whole-grain products
Deficiency leads to Beriberi

Toxicity: not reported till now.

Riboflavin

Riboflavin is important for normal growth and development, the production and regulations of certain hormones, and the formation of red blood cells. Riboflavin helps activate vitamin B6 and converts tryptophan to niacin.

Source:
Lean beef, pork, liver, legumes, eggs, cheese, milk, nuts, enriched whole-grain products.

Deficiency: may cause cracks in the corners of the mouth and a painful purplish tongue.

Toxicity: None reported

Niacin:

Like vitamins D and K, the body can make niacin from the amino acid tryptophan.

Functions:

Niacin is known to be involved in more than 50 body processes and also in detoxifications of several drugs and chemicals. Niacin can also decrease blood cholesterol levels. body process protein and fats; helps maintain a healthy nervous system, skin and digestion.

Source:

Liver, turkey, tuna, salmon, swordfish, peanuts, beans, yeast, enriched whole-grain breads and cereals.

Deficiency:

causes pellagra with 4 classic symptoms; dermatitis, diarrhea, dementia, and death.

Toxicity: Toxic if taken in extremely large doses. Symptoms may include a niacin flush and drug like affect on blood lipids and blood glucose.

Vitamin B6 :

Pyridoxine, pyridoxamine, and pyridoxal are 3 compounds that make up vitamin B6.

Functions:

Primary role of B6 is synthesis of amino acids and protein. This vitamin is involved in the manufacture of protein- related compounds such as hormone, hemoglobin, nerve chemicals, and many enzymes. It also plays a critical role in regulating mental processes and mood.

Source:

Organ meats, pork, beef, poultry, fish, eggs, peanuts,bananas, carrots, yeast, fortified cereals.

Deficiency:

Initial stages, symptoms of a deficiency include weakness, irritability and insomnia. In advanced stages, symptoms include failure to grow, motor function impairment, convulsions and immune system compromise.

Toxicity:

symptoms include neuromuscular disorders and nerve damage leading to numbness and muscle weakness. Nerve damage to the arms and legs, trouble walking and pain.

Vitamin B12

Vitamin B12 is a group of cobalamin containing compounds. Vitamin B12 is an interesting water soluble vitamin in that it is stored in the liver, kidney and other tissues and deficiency is only manfested upon years of inadequate intake. The elderly are at risk of B12 deficiency due to decreased absorption resulting from low levels of intrinsic factor, found in gastric juice. Synthetic form of vitamin B12 is cyanocobalamin.

Functions:

Along with its role in breaking down macronutrients, this vitamin plays a critical role in myelin sheath and neurotransmitter formation. It is also thought that low levels of vitamin B12 may contribute to Alzheimer's disease, pernicious anemia, and diabetes.

Source:

Liver, poultry, clams, sardines, flounder, herring, eggs, milk, blue cheese, fortified cereals.

Deficiencies:

occur mainly because of inadequate absorption caused by atrophic gastritis (lack of HCl) or a lack of the intrinsic factor (Prenacious Anemia) Inadequate absorption may be caused by drug interactions such as those taken during chemotherapy, salicylates (aspirin and antacids) and oral contraceptives. Deficiencies impair cell division and protein synthesis.

- ❖ Most obvious symptom of a deficiency is the anemia of folate deficiency with its large immature RBC's.
- ❖ Production of DNA slows down and body cells can't divide.
- ❖ Anemia develops because RBC's aren't replaced and GI problems develop because cells in the GI tract aren't replaced.

Toxicity: None reported

Folic Acid- Folate

Coenzyme form is THF. it is Important in metabolism and DNA synthesis.

Functions:

Folic acid plays a critical role in regulating cell division and the transfer of inherited traits from one cell to another. Beginning in 1999, all grain products are fortified with folic acid to protect unborn babies against neural tube defects. Also, it is involved in production of neurotransmitters, such as serotonin, that regulate appetite, sleep, and mood.

Source:

Dark leafy vegetables, dry beans and peas, oranges, fortified cereals and grain products.

Toxicity: Risks are low

NOTE: High levels of folic acid may hide signs of B12 deficiency (a deficiency that can cause nerve damage), especially in older adults.

Pantothenic Acid:

This vitamin is named after the Greek word panto, meaning "everywhere." It's found in both plants and animal products.

Source:

Organ meats, beef, chicken, lobster, milk, eggs, peanuts, peas, beans, lentils, broccoli, yeast, cereals, whole grains.

Functions

Pantothenic acid is essential for production of coenzyme A, an important catalyst in the breakdown of fats, carbohydrates, and protein for energy. Coenzyme A also functions in the synthesis of fats, cholesterol, bile, vitamin D, red blood cells, and some hormones, and neurotransmitters.

Deficiencies:

rarely occur, but when it occurs there is a general failure of all systems of the body.

Toxicity: None reported

Choline:

Choline is the latest nutrient to be added as an essential nutrient by the Institute of Medicine. Choline plays an important role in brain development in the young and memory retention in the old. Choline deficiency has been shown to increase the risk of liver damage.

Vitamin C

Humans are one of few species that cannot produce vitamin C (ascorbic acid). Prior to its discovery, scurvy, a disease of vitamin C deficiency, claimed the lives of many crew members on long ocean voyages.

Source:

Broccoli, green peppers, spinach, brussels sprouts, citrus fruits, tomatoes, potatoes, strawberries, cabbage.

Functions:

Vitamin C plays an important role in the formation and maintenance of collagen, "cement" that holds all cells together. Vitamin C promotes the healing of wounds. Vitamin C is also a powerful antioxidant that works with vitamin E to fight oxidative stressors that damage cells and can cause cancer and other chronic diseases.

Toxicity: Upset stomach; kidney stones; increased iron absorption

Biotin (Vitamin B7)

Like vitamin K, some biotin is produced by bacteria in the intestine. Biotin has many similar functions as other B vitamins.
Source: Liver, kidney, egg

Functions:

in energy metabolism as a coenzyme that carries CO_2 and keeps the TCA Cycle going by giving a C to pyruvate. Plays a role in gluconeogensis, metabolism of fatty acids and the breakdown of amino acids. Can be synthesized by bacteria in the GI tract.

Deficiencies rarely occur. A deficiency may occur if more than 24 raw eggs are eaten. They contain a protein that binds biotin and prevents its absorption.

5.6 MINERALS

<u>Learning outcome</u>

After studying this section, you should be able to:

List the common mineral salts required by the body and describe their functions

Calcium

Among minerals, Calcium is present in the highest amount in the body mostly in the skeleton. Calcium is essential for the formation of bone and teeth, for clotting of blood, contraction of heart and muscle etc. A deficiency can cause 'Osteoporosis' in which decalcification of bone occurs. Even minor accidents can cause fractures. In children, a deficiency can cause a decreased rate in growth. Small fish eaten along with bones, skim milk powder etc are excellent sources and milk, milk products like curd, sesame seeds, ragi, green leafy vegetables like carrot leaves, drumstick leaves etc are other good sources. The daily recommended allowances for calcium is Adults 400-500mg, children between 400- 700 mg.

Iron

A greater part of the Iron in the body is present as Haemoglobin. Iron deficiency causes anaemia and is widely prevalent among children, adolescent girls and expectant and nursing mothers. Cereals are the most important sources of iron for Vegetarians and the other important sources are legumes, green leafy vegetables and jaggery. Meat, fish and eggs are also important sources of iron. The daily recommended allowances for iron is Adults 20-30mg, children between15-20 mg, pregnant and nursing women need more iron.

Iodine

Iodine is a constituent of thyroxine, the active principle of the thyroid gland. The thyroid gland plays an important role in energy metabolism and in the growth of the body. A deficiency can cause enlargement of thyroid, resulting in the disease called goitre. In children, severe iodine deficiency may result in serious retardation of growth known as cretinism. Iodine requirements for adults are about 0.15 to 0.2 mg daily and for infants and children 0.05 to 0.10 mg daily. This requirement is normally supplied by a well balanced diet and by drinking water except in mountainous regions where the food and water is deficient in iodine. Crude common salt prepared from sea water and sea fish are good sources.

Sodium Chloride (Nacl)

All minerals except Sodium Chloride (Nacl) are usually present in sufficient amounts in a well - balanced diet. Sodium chloride is the only mineral which is taken in more or less pure form in addition to the amount present in natural foods. Salt taken in food is the source of Nacl. The requirements depend on the climate and occupation. People doing heavy work in hot humid climates need more Nacl. A deficiency can cause heat cramps- intense and painful contractions of skeletal muscle. But consumption of excessive amounts of Nacl causes Oedema in protein deficiency and increases blood pressure in hypertension. Foods of animal origin contain more Nacl than those of Vegetable origin. The daily requirements for tropical climates are Adults 10-15 (light work), 20-25 (hard work) and children 5-10g/day.

Potassium

The adult human body contains about 250g of potassium which is present almost entirely in the cells of different tissues, muscles, etc. Only small quantities are present in the extra cellular fluid. Potassium is the major basic of ion of the body cells. The functions of potassium are : Regulation of pH of cell contents, Regulation of the osmotic pressure of cell contents and Potassium ion increases the relaxation of heart muscle which is antagonized by calcium ion. Potassium deficiency causes weakness and muscular paralysis. But Consumption of excessive amounts of potassium also causes the similar symptoms. Deficiency seldom occurs as potassium is present in abundance of foods.

Daily energy requirements and daily energy intakes

Energy requirements and recommended levels of intake are often referred to as *daily requirements* or *recommended daily intakes*. These terms are used as a matter of convention and convenience, indicating that the requirement represents an average of energy needs over a certain number of days, and that the recommended energy intake is the amount of energy that should be ingested as a daily average over a certain period of time. There is no implication that exactly this amount of energy must be consumed every day, nor that the requirement and recommended intake are constant, day after day. Neither is there any biological basis for defining the number of days over which the requirement or intake must be averaged. As a matter of convenience, taking into account that physical activity and eating habits may vary on some days of the week, periods of seven days are often used when estimating the average daily energy expenditure and recommended daily intake.

Human beings need energy for the following:

- Basal metabolism.
- Metabolic response to food.
- Physical activity.
- Discretionary activities,
- Growth.
- Pregnancy and Lactation

5.7 ENZYMES

Learning outcome

After studying this section, you should be able to:

List the functions of enzymes and their biological importance in diet

By definition, enzymes are catalysts, substances that cause a chemical reaction to move faster. Enzymes are the catalysts of biochemical reactions in living organisms. That includes the formation, breakdown and rearranging of molecules to provide organisms with the energy and materials needed to live and function. Without enzymes, these reactions would occur far too slowly for proper metabolism. Like all catalysts, enzymes take part in the reaction - that is how they provide an alternative reaction pathway. But they do not undergo permanent changes and so remain unchanged at the end of the reaction. They can only alter the rate of reaction, not the position of the equilibrium.

Most chemical catalysts catalyze a wide range of reactions. They are not usually very selective. In contrast enzymes are usually highly selective, catalyzing specific reactions only. This specificity is due to the shapes of the enzyme molecules.

Many enzymes consist of a protein and a non-protein (called the **cofactor**). The proteins in enzymes are usually globular. The intra- and intermolecular bonds that hold proteins in their secondary and tertiary structures are disrupted by changes in temperature and pH. This affects shapes and so the catalytic activity of an enzyme is pH and temperature sensitive.

Cofactors may be:

- organic groups that are permanently bound to the enzyme (**prosthetic groups**)
- cations - positively charged metal ions (**activators**), which temporarily bind to the active site of the enzyme, giving an intense positive charge to the enzyme's protein
- organic molecules, usually vitamins or made from vitamins (**coenzymes**), which are not permanently bound to the enzyme molecule, but combine with the enzyme-substrate complex temporarily.

MECHANISM OF ACTION OF ENZYMES

For two molecules to react they must collide with one another. They must collide in the right direction (orientation) and with sufficient energy. Sufficient energy means that between them they have enough energy to overcome the energy barrier to reaction. This is called the **activation energy**. Enzymes have an **active site**. This is part of the molecule that has just the right shape and functional groups to bind to one of the reacting molecules. The reacting molecule that binds to the enzyme is called the **substrate**. An enzyme-catalysed reaction takes a different 'route'. The enzyme and substrate form a reaction intermediate. Its formation has a lower activation energy than the reaction between reactants without a catalyst.

A simplified picture
Route A
reactant 1 + reactant 2 → product

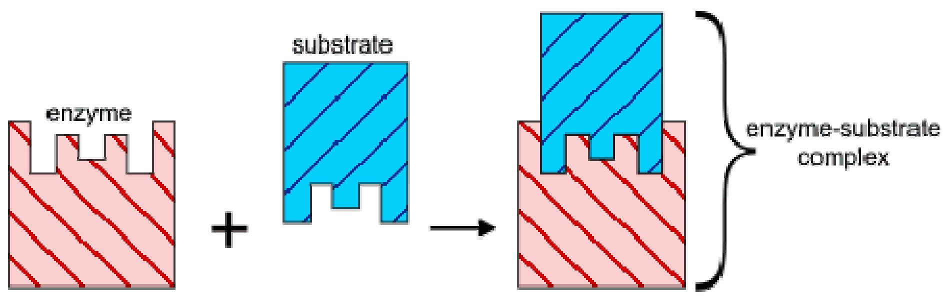
Route B
reactant 1 + enzyme → intermediate

intermediate + reactant 2 → product + enzyme

So the enzyme is used to form a reaction intermediate, but when this reacts with another reactant the enzyme reforms.

Lock and key hypothesis

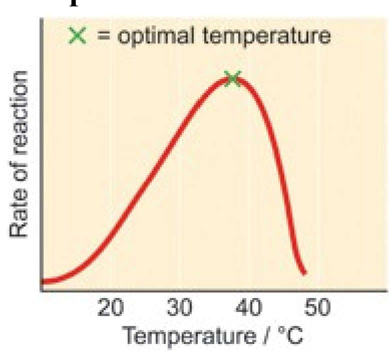
This is the simplest model to represent how an enzyme works. The substrate simply fits into the active site to form a reaction intermediate.



Induced fit hypothesis

In this model the enzyme molecule changes shape as the substrate molecules gets close. The change in shape is 'induced' by the approaching substrate molecule. This more sophisticated model relies on the fact that molecules are flexible because single covalent bonds are free to rotate.
Factors affecting catalytic activity of enzymes

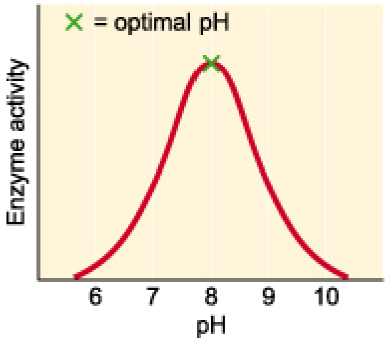
Temperature



As the temperature rises, reacting molecules have more and more kinetic energy. This increases the chances of a successful collision and so the rate increases. There is a certain temperature at which an enzyme's catalytic activity is at its greatest (see graph). This optimal temperature is usually around human body temperature (37.5 ^{o}C) for the enzymes in human cells.

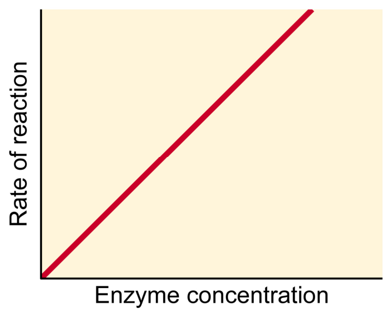
Above this temperature the enzyme structure begins to break down (**denature**) since at higher temperatures intra- and intermolecular bonds are broken as the enzyme molecules gain even more kinetic energy.

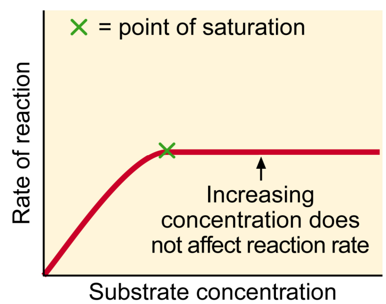
pH



Each enzyme works within quite a small pH range. There is a pH at which its activity is greatest (the optimal pH). This is because changes in pH can make and break intra- and intermolecular bonds, changing the shape of the enzyme and, therefore, its effectiveness.

Concentration of enzyme and substrate





The rate of an enzyme-catalysed reaction depends on the concentrations of enzyme and substrate. As the concentration of either is increased the rate of reaction increases (see graphs). For a given enzyme concentration, the rate of reaction increases with increasing substrate concentration up to a point, above which any further increase in substrate concentration produces no significant change in reaction rate. This is because the active sites of the enzyme molecules at any given moment are virtually saturated with substrate. The enzyme/substrate complex has to dissociate before the active sites are free to accommodate more substrate. (See graph) Provided substrate concentration is high and that temperature and pH are kept constant, the rate of reaction is proportional to the enzyme concentration. (See graph)

Inhibition of enzyme activity

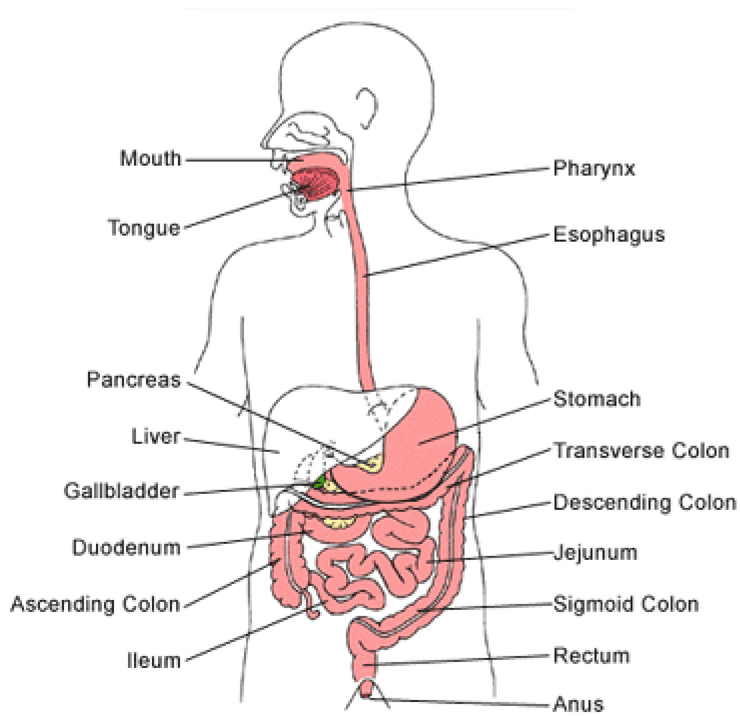
Some substances reduce or even stop the catalytic activity of enzymes in biochemical reactions. They block or distort the active site. These chemicals are called **inhibitors**, because they inhibit reaction. Inhibitors that occupy the active site and prevent a substrate molecule from binding to the enzyme are said to be **active site-directed** (or **competitive**, as they 'compete' with the substrate for the active site).

Inhibitors that attach to other parts of the enzyme molecule, perhaps distorting its shape, are said to be **non-active site-directed** (or **non competitive**).

9.8 summary:

The diet is selection of foods eaten by an individual.a balanced diet is essential for health.it provides the appropriate amounts of all nutrients in the correct proportions to meet the requirements of the body cells. An essential nutrient is a substance that cannot be made by the body and must therefore be included in the diet.

10. HUMAN DIGESTIVE SYSTEM



Organs of the digestive system

- **10.1mouth**
- **10.2pharynx**
- **10.3oesophagus**
- **10.4stomach**
- **10.5small intestine**
- **10.6largeintestine**
- **10.7iver**
- **10.8pancreas**
- **10.9summary digestion of food**
- **10.11 summary**

Learning outcomes

After studying this section you should be able to:

- **Describe the passage of food through the gastrointestinal tract from the mouth to the anus.**
- **Explain the function of each organ and accessory organ of the digestive system.**
- **Describe the role of the teeth, tongue. and salivary glands in the preparation of food for swallowing.**
- **Explain the structure of a tooth and the factors affecting decay and gum disease.**

- **Describe swallowing and the role of the palate and epiglottis.**
- **Describe peristalsis as a mechanism for moving food through the digestive system.**
- **Explain how the structure of the stomach lining protects it from high acid concentrations.**
- **Describe the chemical breakdown of different types of foods (carbohydrates, proteins, and fats) as they pass through the digestive tract.**
- **Contrast the chemical and mechanical breakdown of food in the stomach.**
- **Describe the digestive activities of the small intestine, including the secretion of intestinal and pancreatic enzymes and bile.**
- **Describe the structure of the villi and how they function in the absorption of food molecules.**
- **Explain the function of the liver as it regulates blood sugar levels.**
- **Describe the role of bacteria in the large intestine.**
- **Compare neural and hormonal control of digestion.**

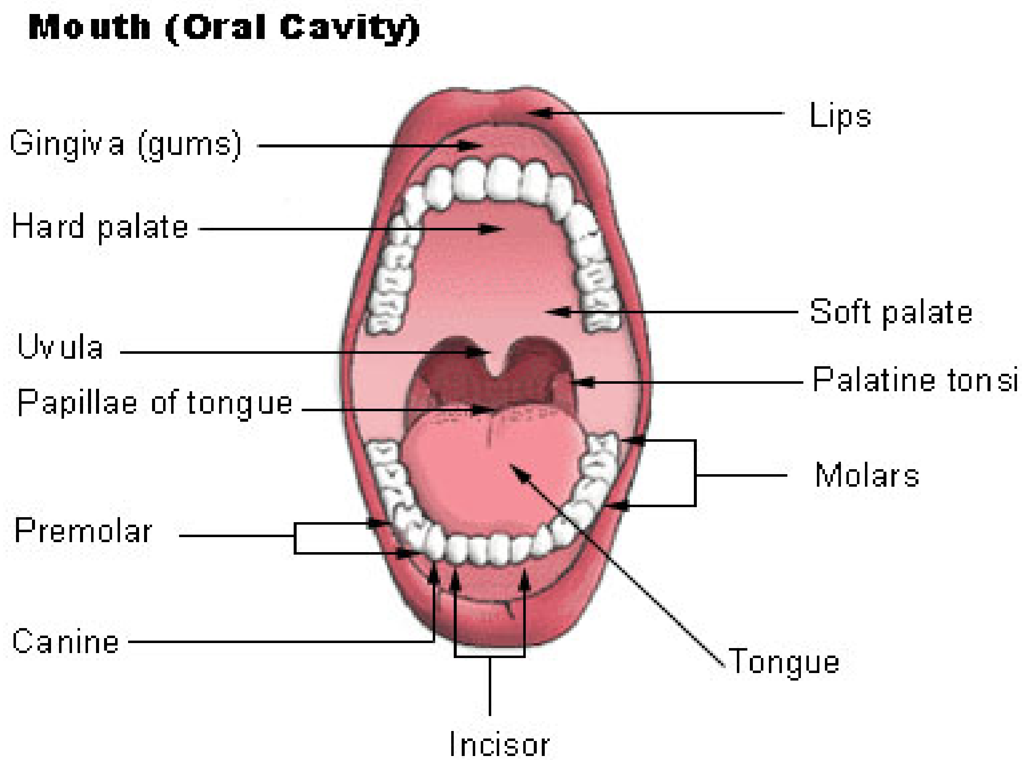
Introduction

The digestive system is made up of a series of hollow organs joined in a long, twisting tube from the mouth to the anus together with the other organs that help the body break down and absorb food (see figure). Inside these hollow organs is a lining called the mucosa. The mucosa contains tiny glands that produce juices to help digest food. The digestive tract also contains a layer of smooth muscle that helps break down food and move it along the tract. Two "solid" digestive organs, the liver and the pancreas, produce digestive juices that reach the intestine through small tubes called ducts. The gallbladder stores the liver's digestive juices until they are needed in the intestine. Parts of the nervous and circulatory systems also play major roles in the digestive system.

ANATOMY AND FUNCTIONS IN THE DIGESTIVE SYSTEM

10.1 Mouth and Tongue:

The mouth is the first portion of the alimentary canal that receives food and begins digestion by mechanically breaking up the solid food particles into smaller pieces and mixing them with saliva. During chewing, the tongue moves food about and manipulates it into a mass called a bolus. The bolus is pushed back into the throat and is forced through the opening to the esophagus



10.2 Pharynx

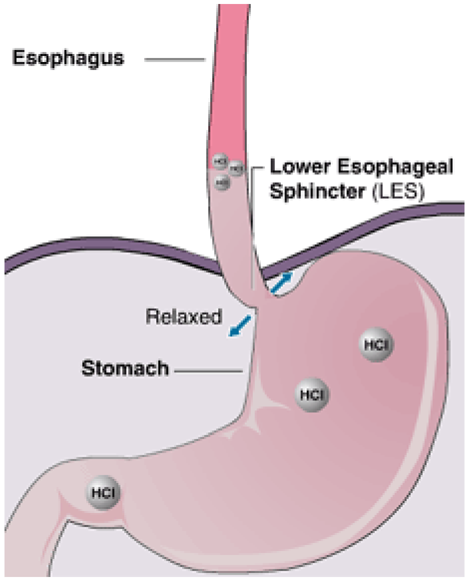
Pharynx describes the part of the throat that begins from behind the nose to the beginning of the voice box and the oesophagus. The nasal airway and the food passage share the same pharyngeal passage to conduct air and food. After passing the pharynx, the airway goes into the lungs while food goes into the esophagus. It blocks food from entering the windpipe preventing us to choke.

10.3Oesophagus

The oesophagus is a muscular tube in the chest that connects the mouth and throat to the stomach. Muscular contractions and relaxations will enable food to propel forward. When the food reaches the sphincter, the sphincter will open up and allow food to pass it and into the ctomach where further digestion take place.

10.4 Stomach

In most mammals, the stomach is a hollow, muscular organ of the digestive system, between the throat and the small intestine. It is involved in the second phase of digestion, following chewing. The stomach churns food before it moves on to the rest of the body.



The stomach is composed of five layers. Starting from the inside and working our way out, the innermost layer is called the mucosa. Stomach acid and digestive juices are made in the mucosa layer. The next layer is called the submucosa. The submucosa is surrounded by the muscularis, a layer of muscle that moves and mixes the stomach contents. The next two layers, the subserosa and the serosa are the wrapping for the stomach. The serosa is the outermost layer of the stomach.

10.5 **Small intestine** - After being in the stomach, food enters the duodenum, the first part of the small intestine. It then enters the jejunum and then the ileum (the final part of the small intestine). In the small intestine, bile (produced in the liver and stored in the gall bladder), pancreatic enzymes, and other digestive enzymes produced by the inner wall of the small intestine help in the breakdown of food.

10.6 Large intestine - After passing through the small intestine, food passes into the large intestine. In the large intestine, some of the water and electrolytes (chemicals like sodium) are removed from the food. Many microbes (bacteria like *Bacteroides*, *Lactobacillus acidophilus*, *Escherichia coli*, and *Klebsiella*) in the large intestine help in the digestion process. The first part of the large intestine is called the cecum (the appendix is connected to the cecum). Food then travels upward in the ascending colon. The food travels across the abdomen in the transverse colon, goes back down the other side of the body in the descending colon, and then through the sigmoid colon. The large intestine is about 1.5 m long and consists of the caecum, appendix, colon and rectum - which are distributed in the abdominal cavity.The large intestine does the following:

1. reabsorbs water and maintains the fluid balance of the body
2. absorbs certain vitamins
3. processes undigested material (fibre)
4. stores waste before it is eliminated

Caecum

The caecum is the first part of the large intestine. Shaped like a small pouch and located in the right lower abdomen, it is the connection between the small intestine and the colon. The caecum accepts and stores processed material from the small intestine and moves it towards the colon.

Appendix

The appendix is a small projection emerging from the caecum. In human beings, the appendix has no known function and is thought to be a remnant from a previous time in human evolution.

Colon

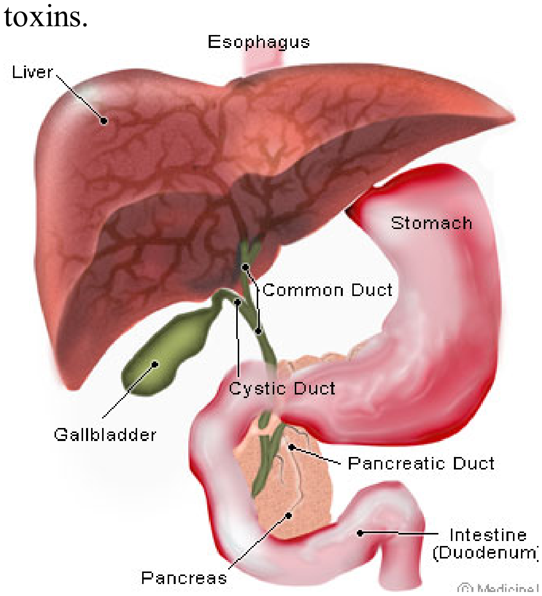
Shaped like an inverted 'U', the colon is the longest part of the large intestine. Within the colon, the mixture of fibre, small amounts of water, and vitamins, etc, mixes with mucus and with bacteria that live in the large intestine - and starts to form faeces. As faeces travels through the colon, the lining of the colon absorbs most of the water and some vitamins and minerals.

Rectum:

The rectum is the final part of the large intestine. It is where stool (faeces) is stored before being passed as a bowel motion.

10.7 Liver :

The liver is an organ in the upper abdomen that aids in digestion and removes waste products and worn-out cells from the blood. The liver is the largest solid organ in the body. The liver has a multitude of important and complex functions. Some of these functions are to: 1. Metabolize and store carbohydrates, which are used as the source for the sugar (glucose) in blood that red blood cells and the brain use. 2. Synthesize, store, and process (metabolize) fats, including fatty acids (used for energy) and cholesterol. 3. Detoxify, by metabolizing and/or secreting, drugs, alcohol, and environmental toxins.



10.8 Pancreas

A fish-shaped spongy grayish-pink organ about 15 cm long that stretches across the back of the abdomen, behind the stomach. The head of the pancreas is on the right side of the abdomen and is connected to the duodenum (the first section of the small intestine). The narrow end of the pancreas, called the tail, extends to the left side of the body. The pancreas makes pancreatic juices and hormones, including insulin. The pancreatic juices are enzymes that help digest food in the small intestine As pancreatic juices are made, they flow into the main pancreatic duct. This duct joins the common bile duct, which connects the pancreas to the liver and the gallbladder.

Gallbladder

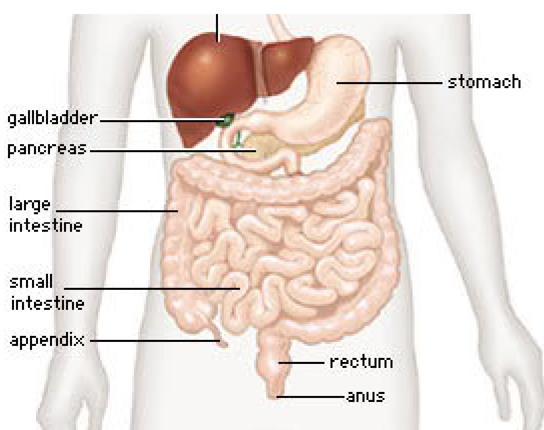
The function of the gallbladder is to store bile and concentrate. Bile is a digestive liquid continually secreted by the liver. The bile emulsifies fats and neutralizes acids in partly digested food. A muscular valve in the common bile duct opens, and the bile flows from the gallbladder into the cystic duct, along the common bile duct, and into the duodenum (part of the small intestine).

Duodenum

The duodenum is a short portion of the small intestine connecting the rest of the intestine to the stomach. Though the duodenum is such a tiny fraction of the small intestine, it is the site of most of the breakdown of the food passing through it. The duodenum is lined with Brunner's glands, which secrete alkaline mucus that supports the intestinal enzymes and aids in the absorption of nutrients.

IIeum

The ileum is a very long part of the small intestine. After protein digestion in the stomach and starch digestion in the mouth, the ileum releases many enzymes to digest the remaining products of starch hydrolyis (which are sugars).



IMPORTANCE OF DIGESTION

When you eat foods—such as bread, meat, and vegetables—they are not in a form that the body can use as nourishment. Food and drink must be changed into smaller molecules of nutrients before they can be absorbed into the blood and carried to cells throughout the body. Digestion is the process by which food and drink are broken down into their smallest parts so the body can use them to build and nourish cells and to provide energy**.**

10.9 SUMMARY OF DIGESTION OF FOOD

Digestion involves mixing food with digestive juices, moving it through the digestive tract, and breaking down large molecules of food into smaller molecules. Digestion begins in the mouth, when you chew and swallow, and is completed in the small intestine.

Movement of Food through the System

The large, hollow organs of the digestive tract contain a layer of muscle that enables their walls to move. The movement of organ walls can propel food and liquid through the system and also can mix the contents within each organ. Food moves from one organ to the next through muscle action called peristalsis. Peristalsis looks like an ocean wave traveling through the muscle. The muscle of the organ contracts to create a narrowing and then propels the narrowed portion slowly down the length of the organ. These waves of narrowing push the food and fluid in front of them through each hollow organ. The first major muscle movement occurs when food or liquid is swallowed. Although you are able to start swallowing by choice, once the swallow begins, it becomes involuntary and proceeds under the control of the nerves.

Swallowed food is pushed into the esophagus, which connects the throat above with the stomach below. At the junction of the esophagus and stomach, there is a ring like muscle, called the lower esophageal sphincter, closing the passage between the two organs. As food approaches the closed sphincter, the sphincter relaxes and allows the food to pass through to the stomach.

The stomach has three mechanical tasks. First, it stores the swallowed food and liquid. To do this, the muscle of the upper part of the stomach relaxes to accept large volumes of swallowed material. The second job is to mix up the food, liquid, and digestive juice produced by the stomach. The lower part of the stomach mixes these materials by its muscle action. The third task of the stomach is to empty its contents slowly into the small intestine. Several factors affect emptying of the stomach, including the kind of food and the degree of muscle action of the emptying stomach and the small intestine. Carbohydrates, for example, spend the least amount of time in the stomach, while protein stays in the stomach longer, and fats the longest. As the food dissolves into the juices from the pancreas, liver, and intestine, the contents of the intestine are mixed and pushed forward to allow further digestion.

Finally, the digested nutrients are absorbed through the intestinal walls and transported throughout the body. The waste products of this process include undigested parts of the food, known as fiber, and older cells that have been shed from the mucosa. These materials are pushed into the colon, where they remain until the feces are expelled by a bowel movement.

Production of Digestive Juices

The digestive glands that act first are in the mouth—the salivary glands. Saliva produced by these glands contains an enzyme that begins to digest the starch from food into smaller molecules. An enzyme is a substance that speeds up chemical reactions in the body. The next set of digestive glands is in the stomach lining. They produce stomach acid and an enzyme that digests protein. A thick mucus layer coats the mucosa and helps keep the acidic digestive juice from dissolving the tissue of the stomach itself. In most people, the stomach mucosa is able to resist the juice, although food and other tissues of the body cannot.

After the stomach empties the food and juice mixture into the small intestine, the juices of two other digestive organs mix with the food. One of these organs, the pancreas, produces a juice that contains a wide array of enzymes to break down the carbohydrate, fat, and protein in food. Other enzymes that are active in the process come from glands in the wall of the intestine. The second organ, the liver, produces yet another digestive juice—bile. Bile is stored between meals in the gallbladder. At mealtime, it is squeezed out of the gallbladder, through the bile ducts, and into the intestine to mix with the fat in food. The bile acids dissolve fat into the watery contents of the intestine, much like detergents that dissolve grease from a frying pan. After fat is dissolved, it is digested by enzymes from the pancreas and the lining of the intestine.

Absorption and Transport of Nutrients

Most digested molecules of food, as well as water and minerals, are absorbed through the small intestine. The mucosa of the small intestine contains many folds that are covered with tiny fingerlike projections called villi. In turn, the villi are covered with microscopic projections called microvilli. These structures create a vast surface area through which nutrients can be absorbed. Specialized cells allow absorbed materials to cross the mucosa into the blood, where they are carried off in the bloodstream to other parts of the body for storage or further chemical change. This part of the process varies with different types of nutrients.

The digestible carbohydrates—starch and sugar—are broken into simpler molecules by enzymes in the saliva, in juice produced by the pancreas, and in the lining of the small intestine. Starch is digested in two steps. First, an enzyme in the saliva and pancreatic juice breaks the starch into molecules called maltose. Then an enzyme in the lining of the small intestine splits the maltose into glucose molecules that can be absorbed into the blood. Glucose is carried through the bloodstream to the liver, where it is stored or used to provide energy for the work of the body.

Sugars are digested in one step. An enzyme in the lining of the small intestine digests sucrose, also known as table sugar, into glucose and fructose, which are absorbed through the intestine into the blood. Milk contains another type of sugar, lactose, which is changed into absorbable molecules by another enzyme in the intestinal lining.

Fiber is un-digestible and moves through the digestive tract without being broken down by enzymes. Many foods contain both soluble and insoluble fiber. Soluble fiber dissolves easily in water and takes on a soft, gel-like texture in the intestines. Insoluble fiber, on the other hand, passes essentially unchanged through the intestines.

An enzyme in the juice of the stomach starts the digestion of swallowed protein. Then in the small intestine, several enzymes from the pancreatic juice and the lining of the intestine complete the breakdown of huge protein molecules into small molecules called amino acids. These small molecules can be absorbed through the small intestine into the blood and then be carried to all parts of the body to build the walls and other parts of cells.

The first step in digestion of a **fat** such as butter is to dissolve it into the watery content of the intestine. The bile acids produced by the liver dissolve fat into tiny droplets and allow pancreatic and intestinal enzymes to break the large fat molecules into smaller ones. Some of these small molecules are fatty acids and cholesterol. The bile acids combine with the fatty acids and cholesterol and help these molecules move into the cells of the mucosa. In these cells the small molecules are formed back into large ones, most of which pass into vessels called lymphatics near the intestine. These small vessels carry the reformed fat to the veins of the chest, and the blood carries the fat to storage depots in different parts of the body.

Vitamins: Another vital part of food that is absorbed through the small intestine is vitamins.

Water and salt: Most of the material absorbed through the small intestine is water in which salt is dissolved. The salt and water come from the food and liquid you swallow and the juices secreted by the many digestive glands.

Mechanism of digestion control

Hormone Regulators

The major hormones that control the functions of the digestive system are produced and released by cells in the mucosa of the stomach and small intestine, where they stimulate digestive juices and cause organ movement.

The main hormones that control digestion are gastrin, secretin, and cholecystokinin (CCK):

- **Gastrin** causes the stomach to produce an acid for dissolving and digesting some foods. Gastrin is also necessary for normal cell growth in the lining of the stomach, small intestine, and colon.
- **Secretin** causes the pancreas to send out a digestive juice that is rich in bicarbonate. The bicarbonate helps neutralize the acidic stomach contents as they enter the small intestine. Secretin also stimulates the stomach to produce pepsin, an enzyme that digests protein, and stimulates the liver to produce bile.
- **CCK** causes the pancreas to produce the enzymes of pancreatic juice, and causes the gallbladder to empty. It also promotes normal cell growth of the pancreas.

Additional hormones in the digestive system regulate appetite:

- **Ghrelin** is produced in the stomach and upper intestine in the absence of food in the digestive system and stimulates appetite.
- **Peptide YY** is produced in the digestive tract in response to a meal in the system and inhibits appetite.

Nervous Regulation Two types of nerves help control the action of the digestive system.Extrinsic, or outside, nerves come to the digestive organs from the brain or the spinal cord. They release two chemicals, acetylcholine and adrenaline. Acetylcholine causes the muscle layer of the digestive organs to squeeze with more force and increase the “push” of food and juice through the digestive tract. It also causes the stomach and pancreas to produce more digestive juice. Adrenaline has the opposite effect. It relaxes the muscle of the stomach and intestine and decreases the flow of blood to these organs, slowing or stopping digestion.The intrinsic, or inside, nerves make up a very dense network embedded in the walls of the esophagus, stomach, small intestine, and colon. The intrinsic nerves are triggered to act when the walls of the hollow organs are stretched by food. They release many different substances that speed up or delay the movement of food and the production of juices by the digestive organs.

Mechanism of Salivary secretion

The parasympathetic nervous system is the primary instigator of salivary secretion. Stimulation by the parasympathetic nervous system results in an abundant, watery saliva with a decrease in [amylase] in saliva and an increase in [amylase] in the serum. Acetylcholine is the active neurotransmitter, binding at muscarinic receptors in the salivary glands. In the case of the parotid, parasympathetic fibers originate from CN IX, travel via the Lesser Superficial Petrosal nerve to synapse in the Otic ganglion, then to the Auriculotemporal nerve and finally the salivary gland. In the case of the Submandibular and Sublingual glands, the parasympathetic fibers originate in CN VII, travel via the Chorda Tympani to the Submandibular ganglion, then release acetylcholine in close proximity to the glands with no true postganglionic synapses.

Stimulation by the sympathetic nervous system results in a scant, viscous saliva rich in organic and inorganic solutes with an increase in [amylase] in the saliva and no change in [amylase] in the serum. For all of the salivary glands, these fibers originate in the Superior Cervical ganglion then travel with arteries to reach the glands:

1) External Carotid artery in the case of the Parotid
2) Lingual artery in the case of the Submandibular, and
3) Facial artery in the case of the Sublingual.

Salivary Flow

The average volume of saliva secreted in a 24 hour period is 1-1.5 liters (approximately 1 cc/minute), most of which is secreted during meals.

The basal salivary flow rate=0.001-0.2 ml/minute/gland.

With stimulation, salivary flow rate=0.18-1.7 ml/min/gland.

Salivary flow rate from the minor salivary glands is independent of stimulation, constituting 7-8% of total salivary output.

GASTRIC JUICES

Gastric juices are liquids found in the stomach. In their normal state, these liquids are usually primarily clear in color. The juices in the stomach begin the process of breaking down food so that nutrients can be extracted by the intestines, and they are produced by glands in the stomach as needed. The precise composition and pH balance of gastric juices varies, depending on the animal involved, but they are famously very acidic.

The major components of gastric juices are mucus, pepsin, and hydrochloric acid. In humans, the pH balance hovers between one and three, making this stomach secretion very acidic. The acidity is important, because it breaks down foods to make them accessible to the digestive tract. The high acidity of the stomach also kills many bacteria and microorganisms which cannot survive in that environment, protecting the body from infection with many common pathogens.

Production of gastric juices is triggered when the hormone gastrin is released in the blood. Gastrin is released by the body in response to the presence of food in the stomach, indicating that the stomach needs to kick into gear and start the digestion process. Various glands in the stomach are responsible for producing different components of gastric juices, and for achieving the right balance of components. Because of the intense acidity of the gastric juices, the stomach lining is specially designed to withstand harsh conditions. This fluid would eat through ordinary tissue, just like it breaks down meat when people and animals consume it. The stomach is made from very tough material, and lined with mucus to prevent the gastric juices from irritating the stomach wall. People with ulcers can experience extreme stomach pain because the gastric juices irritate the ulcerated area of the stomach.

Gastric juices can cause problems when they enter the esophagus. In most people, a flap keeps the juices of the stomach contained while the stomach is working, so that the juices cannot creep their way up out of the stomach. However, people can experience heart burn and acid reflux syndrome, conditions in which the esophagus becomes irritated and inflamed by chronic exposure to gastric juices. People who are prone to vomiting can also develop esophageal damage, along with damage to the enamel of the teeth caused by the high acidity of the stomach contents.

10.11 summary

- The gastrointestinal tract consists of the mouth, pharynx, esophagus, stomach, small intestine, and large intestine. Auxiliary organs include the salivary glands, liver, gallbladder, and pancreas.
- The mouth prepares food for swallowing and monitors food quality.
- Teeth mechanically break food into smaller fragments for swallowing.
- In the mouth, salivary amylase begins to digest complex carbohydrates into shorter chains of sugars.
- Food moves into the pharynx, then into the larynx past the epiglottis and down the esophagus to the stomach.
- Food moves throughout the gastrointestinal tract by peristalsis.
- The stomach functions to store food, digest proteins, and kill ingested microorganisms.
- The small intestine is the major site of digestion and absorption of nutrients.
- Intestinal enzymes, pancreatic enzymes, and bile break proteins, polysaccharides, polypeptides, and triglycerides (fats) into their component parts.
- The pleated lining of the small intestine and the villi increase surface area of the small intestine to aid absorption of nutrients.
- The liver produces bile and keeps blood glucose levels steady.
- The gallbladder stores, concentrates, and releases bile into the small intestine where it emulsifies fats.

- The large intestine absorbs water and vitamins that remain in the indigestible food, stores feces, and eliminates waste from the body.
- Both neural and hormonal mechanisms regulate the release of digestive secretions.

Self assessment questions

1. Describe the phases of gastric secretion.
2. Name the phases of deglutition.
3. Explain the movements of stomach.mention the factors influencing gastric emptying.
4. Describe the functions of saliva.
5. Explain the composition and functions of gastric juice.
6. List four functions of stomach.
7. Name the four functions of liver.
8. List four functions of bile.

11. The Human Excretory System

11.1kidneys
11.2 ureters
11.3 urinary bladder
11.4 urethra
11.5 micturation
11.6 summary

Excretion: Is the process of ridding the body of waste in order to maintain homeostasis.

Structures (organs) involved in Excretion are:

• Skin - Sweat is removed by the skin as a waste product (trying to remove heat)
• Lungs -Removes waste gases such as CO2
• Liver - Removes Nitrogenous waste (Urea)
Kidneys (Urinary System)- removes waste in the form of urine

Learning outcome

After studying this section you should be able to:

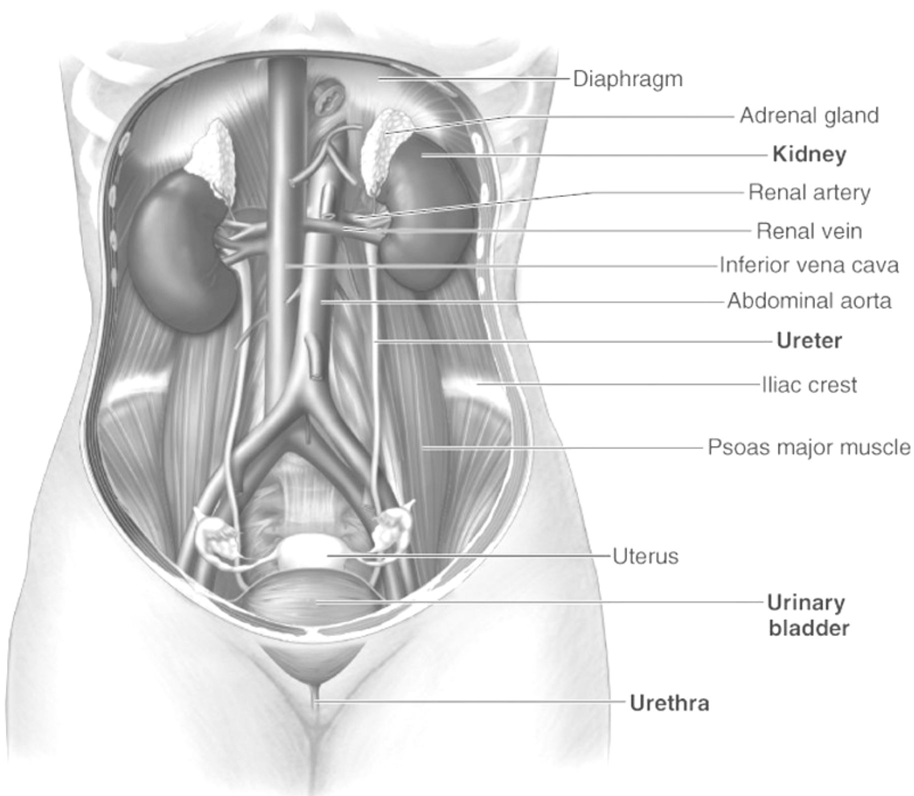
- **list the organs and systems that eliminate waste.**
- **identify and give the function of each of the organs of the urinary system.**
- **describe the structure of the kidney.**

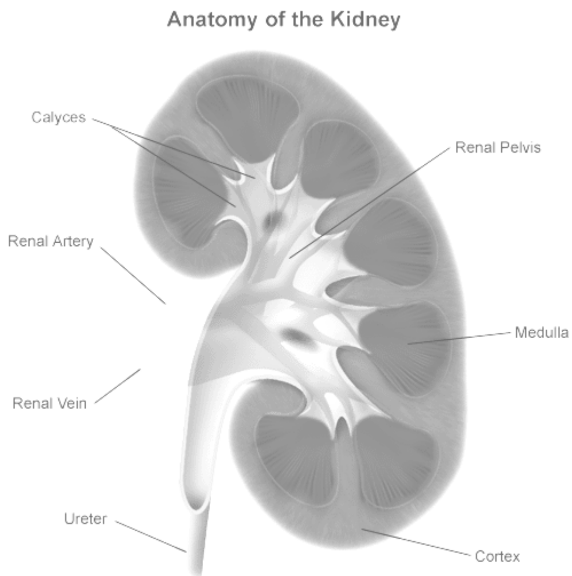
- **trace in detail the flow of filtrate through the nephron.**
- **describe the processes of glomerular filtration, tubular reabsorption, and tubular secretion.**
- **explain the role of the kidney in the maintenance of pH balance, water retention, red blood cell production, and activation of vitamin D.**
- **describe hormonal regulation of kidney function and name the hormones that are involved**

THE URINARY SYSTEM

RENAL ANATOMY AND CIRCULATION

RENAL ANATOMY- Each human kidney is composed of approximately 1 million nephrons. The structure of the two kinds of nephrons as well as their relationship to the vasculature is shown below:





The Nephron. This basic functional unit of the kidney is composed of a glomerulus with its associated afferent and efferent arterioles, and a renal tubule.

Glomerulus. The glomerulus consists of a tuft of 20-40 capillary loops and Bowman's capsule.

Renal Tubule. The renal tubule begins at Bowman's capsule, which is an expanded, invaginated bulb surrounding the glomerulus. The renal tubule consists of Bowman's capsule, the proximal convoluted tubule, the loop of Henle, the distal convoluted tubule, and the collecting duct that carries the final urine to the renal pelvis and the ureter.

Types of Nephrons.

a) Cortical nephrons comprise about 85% of the nephrons in the kidney and have glomeruli located in the renal cortex. These nephrons have short loops of Henle, which descend only as far as the outer layer of the renal medulla.
b) Juxtamedullary nephrons are located at the junction of the cortex and the medulla of the kidney. Juxtamedullary nephrons have long loops of Henle, which penetrate deep into the medulla and sometimes reach the tip of the renal papillae.
These nephrons are important in the countercurrent system, by which the kidneys concentrate urine.

Renal Blood Vessels.

Renal arteries. Each kidney receives a renal artery, a major branch from the aorta, which divides to form interlobular arteries.

Afferent and Efferent Arterioles. Each renal artery subdivides into progressively smaller branches, and the smallest branches give off a series of afferent arterioles. Each afferent arteriole forms a tuft of capillaries, which protrudes into a Bowman's capsule. These capillaries come together and form a second arteriole, the efferent arteriole, which divides shortly after to form the peritubular capillaries that surround the various portions of the renal tubule.

Peritubular capillaries. These capillaries differ in organization depending on their association with different nephrons.
a) Efferent arterioles of cortical nephrons divide into peritubular capillaries that connect with capillaries surrounding other nephrons, forming a rich meshwork of microvessels. This meshwork functions to remove water and solutes that have diffused from the cortical renal tubules.
b) Efferent arterioles of juxtamedullary nephrons also form peritubular capillaries, a special portion of which are the vasa recta. The small vessels of the vasa recta descend with the long loops of Henle into the renal medulla and return to the area of the glomerulus.

Renal veins are formed from the confluence of the peritubular capillaries and exit the kidney at the hilus to return blood to the vena cava.
Note: 90% of the blood flow goes to the cortex and only 10% to the remainder of the kidney.

Structure of nephron
Epithelial cells of the nephron.
The nephron from Bowmans capsule to the collecting duct is formed of epithelial cells. However, the ultrastructure of these cells varies along the nephron depending upon the function of that region.
1. Proximal convoluted tubule- Large concentrations of mitochondria; marked basal membrane in-foldings, well developed brush border, junctions between cells are more open than those of the distal tubule.
2. Descending loop of Henle- Flat cells, few mitochondria, sparse brush border.
3. Thick ascending limb, loop of Henle- Fewer mitochondria and sparser brush border than proximal tubule but more than thin segment, very tight junctions between cells.
4. Distal convoluted tubule- Similar to thick ascending limb.
5. Connecting tubule and collecting duct- Composed of principal cells (Na^+ reabsorption) and intercalated cells (acid secreting). Very tight junctions between cells.
DESCENDING < PROXIMAL < THICK ASCENDING =
DISTAL CONVOLUTED* = COLLECTING DUCT*

Glomerulus

The glomerulus consists of the glomerular capillaries and Bowman's capsule. The capillaries are composed of endothelial cells and Bowman's capsule is composed of epithelial cells. At the surfaces where ultrafiltration occurs these two cells are in close apposition to one another being separated by a thin (200 nm) basement membrane.

The basement membrane consists of three layers, the lamina rara externa which is closest to the epithelium, the lamina densa in the middle and the lamina rara interna which is closest to the endothelium.

Proposed mechanisms of the filtration barrier. The endothelium acts as a valve that screens out cells and controls access to the main filter which is the basement membrane. The epithelium monitors this main filtration barrier. There are also mesangial cells which abut the capillary loops. These cells are thought to recondition and unclog the filter and to influence the size and number of fenestrations through contractile properties. The higher transmural filtration rate of glomerular as opposed to extrarenal capillaries is due to a combination of: 1) a much greater permeability for water and crystalloids per unit of surface area, 2) a larger capillary surface area per volume of tissue and 3) a slightly higher mean net ultrafiltration pressure.

Juxtaglomerular Apparatus (JGA)

The JGA includes cells located in both the glomerulus and the initial portion of the distal tubule. Specialized cells in the distal tubule are called, macula densa cells. Interspersed between other cell types in the juxtaglomerular apparatus is a second cell type called mesangial cells. Finally, the JGA contains specialized secretory or granular cells located in the afferent and efferent arterioles which are called juxtaglomerular cells (JG cells). The JGA is also innervated by sympathetic nerves. Renin is released from JG cells located predominantly in the afferent arteriole and this leads to formation of angiotensin II. The release of renin is controlled by a number of different events. One of these is flow past the macula densa cells in the distal tubule. The factor sensed is probably NaCl concentration, i.e., when flow in the ascending limb of the loop of Henle decreases a greater fraction of the NaCl is reabsorbed leading to a decrease in NaCl concentration in the fluid entering the distal tubule. This in turn is sensed by the macula densa cells and initiates a poorly understood series of events (perhaps involving the interposed mesangial cells and prostaglandin synthesis) which feeds back onto the glomerulus leading to an increase in GFR and release of renin. This relationship is shown here for the events following a decrease in mean arterial pressure.

Two pathways are actually occurring here simultaneously, i.e., renin release and autoregulation of GFR. The autoregulation of GFR is also referred to as Tubuloglomerular Feedback (TGF; not to be confused with glomerulotubular balance to be discussed later). Not shown in this diagram but also a contributor to TGF are changes in capillarypermeability produced by the mesangial cells, i.e., when GFR goes down, additional feedback mechanisms appear to cause relaxation of mesangial cells which increases capillary permeability. This in turn will increase GFR.

RENAL VASCULAR FUNCTION

A. Deliver waste products, endogenous substances and xenobiotics to the kidney for excretion.

B. Return reabsorbed and synthesized materials to the systemic circulation.

C. Deliver 0_2 and metabolic substrates to the nephron.

D. Synthesize renin within the granular cells of the afferent arteriole.

RENAL BLOOD FLOW

A. Renal blood flow is high. The two kidneys together receive approximately 25% of the cardiac output.

B. Blood flow is not evenly distributed in the kidney. The renal cortex is highly vascularized, comprises on a weight basis 75% of the kidney, and receives > 90% of total renal blood flow.

11.5 MICTURITION

•It is a process by which urine is voided from the urinary bladder. It is a reflex process. However, in grown up children and adults, it can be controlled voluntarily to some extent.

FUNCTIONAL ANATOMY OF URINARY BLADDER

•Urinary bladder consists of the body, neck and internal urethral sphincter. The smooth muscle forming the body of bladder is called detrusor muscle. At the posterior surface of the bladder wall there is a triangular area called trigone. At the upper angles of this trigone, two ureters enter the bladder.

NERVE SUPPLY TO URINARY BLADDER AND SPHINCTERS

•Urinary bladder and internal sphincter are supplied by sympathetic and parasympathetic divisions of autonomic nervous system, whereas, the external sphincter is supplied by the somatic nerve fibres

Innervation

1. The parasympathetic division stimulates urinary bladder contraction. The parasympathetic division is responsible for controlling **micturition** (urination).
2. The sympathetic division inhibits bladder contraction and stimulates internal urinary sphincter contraction. It does not play a role in normal micturition. The sympathetic division is active during ejaculation, preventing

retrograde ejaculation of semen into the urinary bladder. Females do not have an internal urinary sphincter.

3. The external urinary sphincter is tonically contracted as a result of stimulation from the brain. It can relax as a result of reflex activity or from voluntary motor control.

4. Higher centers in the pons and cerebral cortex can facilitate (EPSPs) or inhibit (IPSPs) the reflex center in the spinal cord.

FILLING OF URINARY BLADDER

•PROCESS OF FILLING

Urine is continuously formed in the nephrons and it is transported drop by drop through the ureters into the urinary bladder. When urine collects in the pelvis of ureter, the contraction sets up in pelvis. The contraction is transmitted through rest of the ureter in the form of peristaltic wave up to trigone of the urinary bladder. The peristaltic wave moves the urine into the bladder. After leaving the kidney, the direction of the ureter is initially downward and outward. Then, it turns horizontally before entering the bladder.

At the entrance of ureters into urinary bladder, a valvular arrangement is present. When peristaltic wave pushes the urine towards the bladder, this valve opens towards the bladder. The position of ureter and the valvular arrangement at the end of ureter prevent the backflow of urine from bladder into the ureter when the detrusor muscle contracts. Thus urine is collected in bladder drop by drop. A reasonable volume of urine can be stored in urinary bladder without any discomfort and without much increase in pressure in bladder. It is due to the adaptation of detrusor muscle.

MICTURITION REFLEX

•Micturition occurs by a reflex called micturition reflex. This reflex starts because of the stimulation of stretch receptors, situated on the wall of urinary bladder and urethra. The rise in pressure stretches the bladder resulting in stimulation of stretch receptors and generation of sensory impulses. The sensory impulses from the receptors reach the sacral segments of spinal cord via the sensory fibres of pelvic nerve. The motor impulses produced in spinal cord, travel through motor fibres of pelvic nerve towards bladder and internal sphincter. The motor impulses cause contraction of detrusor muscle and relaxation of internal sphincter so that, urine enters the urethra from the bladder.

Once urine enters the urethra, the stretch receptors in the urethra are stimulated and send afferent impulses to spinal cord via pelvic fibres. These impulses inhibit pudendal nerve. So the external sphincter relaxes and micturition occurs.during micturition, the flow of urine is facilitated by the increase in the abdominal pressure due to the voluntary contraction of abdominal muscles.

Higher Centres for Micturition

•Spinal centres for mictrition are present in sacral and lumbar segments. But these spinal centres are regulated by higher centres. The higher centres, which control micturition are of two types, inhibitory centres and facilitatory centres.

11.6 summary

- The main function of the urinary system is to regulate the volume, pressure, and composition of the blood.
- The kidneys filter wastes and excess materials from the blood, assist in the regulation of blood pH, and maintain fluid balance by regulating the volume and composition of blood and urine.
- Nephrons are the functional units of the kidneys. They carry out glomerular filtration, tubular reabsorption, and tubular secretion.
- Glomerular filtration occurs as blood pressure forces water and dissolved substances from the blood in the glomerulus to the inside of Bowman's capsule.
- Tubular reabsorption is the process that removes useful materials from the filtrate and returns them to the blood.
- Tubular secretion removes wastes, ions, and large molecules from the blood wastes that escaped glomerular filtration.
- The kidneys help maintain pH balance through the reabsorption of bicarbonate ions, and by removing excess hydrogen ions from the blood.
- The kidneys help conserve water through the production of concentrated urine. Urine concentration is largely determined by the concentration of solutes in the interstitial fluid from the cortex to the medulla of the kidneys.
- Three hormones adjust kidney function.
    - Antidiuretic hormone (ADH) regulates the amount of water reabsorbed by the distal convoluted tubules and collecting ducts of the nephrons.
    - Aldosterone increases reabsorption of sodium by the distal convoluted tubules and collecting ducts.
    - Atrial natriuretic peptide (ANP) decreases water and solute reabsorption by the kidneys by either increasing the permeability of the glomerular filter or by dilating afferent arterioles.
- The kidneys release erythropoietin that stimulates the production of red blood cells and transform vitamin D into its active form, calcitriol.
- Hemodialysis, the use of artificial devices to cleanse the blood, and transplant surgery help during renal failure.
- Urination involves both voluntary and involuntary actions. The lack of voluntary control over urination is called urinary incontinence.

- Microorganisms can enter the urinary system and cause urinary tract infections (UTIs).

Self assessment questions

1. Describe the mechanism of urine formation.
2. Describe the structure of nephron.
3. Explain the structure of juxta-glomerular apparatus?what are its functions?
4. Draw a neat labled diagram of nephron.
5. List the functions of kidneys.
6. Micturation.

Section IV

Protection and Survival

- **The skin**
- **Immunity and resistance**
- **The muskelo-skeletal system**
- **The reproductive system**

12. THE SKIN

12.1 structure of skin
12.2 functions of skin
12.3 regulation of body temperature
12.4 summary

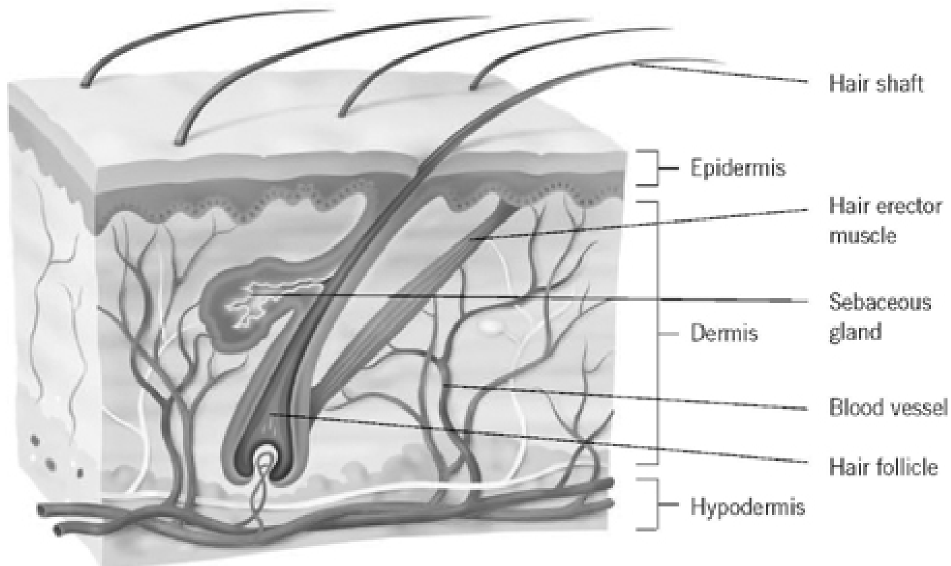
Learning outcomes
After studying this section you should be able to:
Describe the structure and functions of skin

Introduction:

The integument or skin is the largest organ of the body, making up 16% of body weight, with a surface area of 1.8m2. It has several functions, the most important being to form a physical barrier to the environment, allowing and limiting the inward and outward passage of water, electrolytes and various substances while providing protection against micro-organisms, ultraviolet radiation, toxic agents and mechanical insults. There are three structural layers to the skin: the epidermis, the dermis and subcutis. Hair, nails, sebaceous, sweat and apocrine glands are regarded as derivatives of skin. Skin is a dynamic organ in a constant state of change, as cells of the outer layers are continuously shed and replaced by inner cells moving up to the surface. Although structurally consistent throughout the body, skin varies in thickness according to anatomical site and age of the individual.

10.1 Skin anatomy

The epidermis is the outer layer, serving as the physical and chemical barrier between the interior body and exterior environment; the dermis is the deeper layer providing the structural support of the skin, below which is a loose connective tissue layer, the subcutis or hypodermis which is an important depot of fat.



Your skin protects you against chemicals, bacteria and radiation, helps you maintain a stable body temperature, and stops you from losing fluid and vital body chemicals.

Epidermis

The epidermis is stratified squamous epithelium. The main cells of the epidermis are the keratinocytes, which synthesise the protein keratin. Protein bridges called desmosomes connect the keratinocytes, which are in a constant state of transition from the deeper layers to the superficial The four separate layers of the epidermis are formed by the differing stages of keratin maturation. The epidermis varies in thickness from 0.05 mm on the eyelids to 0.8±1.5 mm on the soles of the feet and palms of the hand. Moving from the lower layers upwards to the surface, the four layers of the epidermis are:

_ stratum basale (basal or germinativum cell layer)
_ stratum spinosum (spinous or prickle cell layer)
_ stratum granulosum (granular cell layer)
_ stratum corneum (horny layer).

Dermoepidermal junction/basement membrane

This is a complex structure composed of two layers. The structure is highly irregular, with dermal papillae from the papillary dermis projecting perpendicular to the skin surface. It is via diffusion at this junction that the epidermis obtains nutrients and disposes of waste. The dermoepidermal junction ¯attens during ageing which accounts in part for some of the visual signs of ageing.

Dermis

The dermis varies in thickness, ranging from 0.6 mm on the eyelids to 3 mm on the back, palms and soles. It is found below the epidermis and is composed of a tough, supportive cell matrix. Two layers comprise the dermis:

_ a thin papillary layer
_ a thicker reticular layer.

Subcutis
This is made up of loose connective tissue and fat, which can be up to 3 cm thick on the abdomen.

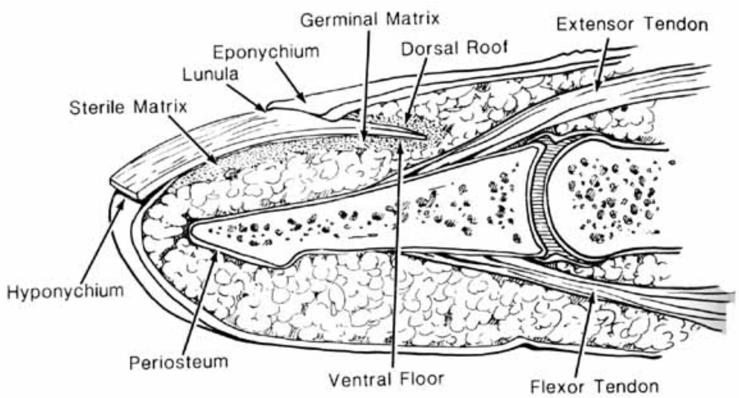
Blood and lymphatic vessels
The dermis receives a rich blood supply. A superficial artery plexus is formed at the papillary and reticular dermal boundary by branches of the subcutis artery. Branches from this plexus form capillary loops in the papillae of the dermis, each with a single loop of capillary vessels, one arterial and one venous. The veins drain into mid-dermal and subcutaneous venous networks. Dilatation or constriction of these capillary loops plays a direct role in thermoregulation of the skin. Lymphatic drainage of the skin occurs through abundant lymphatic meshes that originate in the papillae and feed into larger lymphatic vessels that drain into regional lymph nodes.
Nerve supply
The skin has a rich innervation with the hands, face and genitalia having the highest density of nerves. All cutaneous nerves have their cell bodies in the dorsal root ganglia and both myelinated and non-myelinated fibres are found. Free sensory nerve endings lie in the dermis where they detect pain, itch and temperature. Specialised corpuscular receptors also lie in the dermis allowing sensations of touch to be received by Meissner's corpuscles and pressure and vibration by Pacinian corpuscles. The autonomic nervous system supplies the motor innervation of the skin: adrenergic fibres innervate blood vessels, hair erector muscles and apocrine glands while cholinergic ®bres innervate eccrine sweat glands. The endocrine system regulates the sebaceous glands, which are not innervated by autonomic fibres.

Derivative structures of the skin

Hair
Hair can be found in varying densities of growth over the entire surface of the body, exceptions being on the palms, soles and glans penis. Follicles are most dense on the scalp and face and are derived from the epidermis and the dermis. Each hair follicle is lined by germinative cells, which produce keratin and melanocytes, which synthesise pigment. The hair shaft consists of an outer cuticle, a cortex of keratinocytes and an inner medulla. The root sheath, which surrounds the hair bulb, is composed of an outer and inner layer. An erector pili muscle is associated with the hair shaft and contracts with cold, fear and emotion to pull the hair erect, giving the skin `goose bumps'.

Nails
Nails consist of a dense plate of hardened keratin between 0.3 and 0.5mm thick. Fingernails function to protect the tip of the fingers and to aid grasping.

The nail is made up of a nail bed, nail matrix and a nail plate. The nail matrix is composed of dividing keratinocytes, which mature and keratinise into the nail plate. Underneath the nail plate lies the nail bed. The nail plate appears pink due to adjacent dermal capillaries and the white lunula at the base of the plate is the distal, visible part of the matrix. The thickened epidermis which underlies the free margin of the nail at the proximal end is called the hyponychium. Fingernails grow at 0.1 mm per day; the toenails more slowly.



Sebaceous glands
These glands are derived from epidermal cells and are closely associated with hair follicles especially those of the scalp, face, chest and back; they are not found in hairless areas. They are small in children, enlarging and becoming active at puberty, being sensitive to androgens. They produce an oily sebum by holocrine secretion in which the cells break down and release their lipid cytoplasm. The full function of sebum is unknown at present but it does play a role in the following:
_ maintaining the epidermal permeability barrier, structure and differentiation
_ skin-specific hormonal signalling
_ transporting antioxidants to the skin surface
_ protection from UV radiation.

Sweat glands
There are thought to be over 2.5 million on the skin surface and they are present over the majority of the body. They are located within the dermis and are composed of coiled tubes, which secrete a watery substance. They are classified into two different types: eccrine and apocrine.
_ Eccrine glands are found all over the skin especially on the palms, soles, axillae and forehead. They are under psychological and thermal control. Sympathetic (cholinergic) nerve fibres innervate eccrine glands. The watery fluid they secrete contains chloride, lactic acid, fatty acids, urea, glycoproteins and mucopolysaccharides.
_ Apocrine glands are larger, the ducts ofwhich empty out into the hair follicles. They are present in the axillae, anogenital region and areolae and are

under thermal control. They become active at puberty, producing an odourless protein-rich secretion which when acted upon by skin bacteria gives out a characteristic odour. These glands are under the control of sympathetic (adrenergic) nerve fibres.

12.2 Functions of the skin.

_ Provides a protective barrier against mechanical, thermal and physical injury and
noxious agents.
_ Prevents loss of moisture.
_ Reduces the harmful e€ects of UV radiation.
_ Acts as a sensory organ.
_ Helps regulate temperature control.
_ Plays a role in immunological surveillance.
_ Synthesises vitamin D3 (cholecalciferol).
_ Has cosmetic, social and sexual associations.

12.3 REGULATION OF BODY TEMPERATURE

The human body's chemical reactions can proceed at life sustaining rates, **Body Temperature** must be maintained around 36.1 – 37.5 ^{o}C. Body temperature reflects the balance between heat production and heat loss. The body uses four mechanisms of heat transfer – radiation, conduction, convection and evaporation.

RADIATION

Radiation is the loss of heat in the form of infrared waves. An object that is warmer than its environment will transfer heat. The direction of radiant flow is always from warmer to cooler. The body can also gain heat by radiation as demonstrated by the warming of the skin during sunbathing.

CONDUCTION/CONVECTION

Conduction is the transfer of heat between objects that are in direct contact with each other. Unlike radiation conduction requires molecule-to-molecule contact of objects – Thermal energy must move through a material medium. Convection is the transfer of heat into the surrounding air. The warm air expands and rises to be replaced by cooler more dense air molecules. Convection enhances heat exchange from the body surface to the air because the cooler air absorbs heat by conduction. Conduction and convection account for 15-20% of heat loss into the environment. The process is enhanced by anything that moves air more rapidly across the body surface, forced convection.

EVAPORATION

Because water absorbs a lot of heat before vaporising, its evaporation from the body surface removes a substantial amount of body heat.

HEAT REGULATING CENTRE

The temperature regulating centre is situated in the hypothalamus. The anterior hypothalamus controls the heat loss by means of vasodilatation of the skin and sweating when the body temperature is rising. The posterior hypothalamus is the centre for conserving heat and for heat production when the body temperature is falling. The temperature regulating centre acts as a body thermostat. In bacterial and viral infections this thermostat is set at a higher level. White blood cells, injured tissue cells and macrophages release pyrogens, chemical substances that act directly on the hypothalamus initiating the release of prostaglandins which cause the "resetting" of hypothalamic thermostat. By increasing the body temperature, the metabolic rate increases helping to speed up the various healing processes also to attempt to inhibit bacterial/viral growth. Any damage or injury to the hypothalamus can cause thermoregulatory disturbances. Spinal cord injury can also cause temperature regulation problems because of lack of body function beyond the point of injury. As long as heat production and heat loss are properly balanced, body temperature remains constant

.

HYPERTHERMIA :the Body temperature is more than $37.8^{o}C$ As body temperature rises, catalysis is accelerated. With each rise of $1^{o}C$, the rate of chemical reaction becomes approximately 10% faster. As the temperature spikes upward neurones are depressed and proteins begin to degrade. Patients may begin to convulse at a temperature of $41^{o}C$ and a temperature more than $43^{o}C$ is endangering to life. Hyperthermic patients > $38.5^{o}C$ need active cooling – Removal of clothing, forced convection – cool air fanning, conduction – immersion in cool water, paracetamol – to lower the hypothalamus thermostat setting, antibiotics if bacterial infection has been isolated.

HYPOTHERMIA: the body temperature less than $35.5^{o}c$

The body tissues can withstand marked reductions in temperature as long as other conditions are carefully controlled. However, in the extreme, low temperature can cause death, cardiac arrhythmia, a reduced metabolic rate leading to delayed recovery from illness/surgery, discomfort, and an increased oxygen demand caused by shivering, pneumonia.The very young and the old are susceptible to hypothermia. In infants core temperature will cool more rapidly than in adults because infants have a larger body surface area relative to total body mass. Older individuals have a much lower metabolic rate than the young; therefore it is difficult to maintain normal body temperature in older environments. Alcohol ingestion increases the risk of hypothermia by causing vasodilatation, impairment of shivering mechanism, hypothalamic dysfunction and a decrease in awareness of environmental conditions.

12.3 Summary:

- The skin and organs from the circulatory, respiratory, digestive, and urinary systems eliminate waste.
- The skin completely covers the body and is continuous with the membranes lining the body orifices.
- Skin is involved in regulation of body temperature
- Protects the underlying structures from injury and invasion of bacteri

Self assesment questions:

1. What is normal body temperature? Describe the role of hypothalamus in its regulation.
2. Explain the mechanism of heat loss and gain by the body.
3. What are the functions of skin.
4. Draw a neat labled diagram of skin structure.

13. THE IMMUNE SYSTEM

13.1 Non-specific defence mechanism

13.2 Immunity

13.3 summary

Learning outcomes

After studying this section you should be able to:

- **List the body's three lines of defense again foreign organisms, cells, or molecules.**
- **Describe the body's nonspecific physical and chemical surface barriers.**
- **Describe each of the defensive cells and their function.**
- **Explain how interferons and the complement system function in the body's defense mechanism.**
- **Give the order of events in an inflammatory response.**
- **Define a fever and explain its role in our immune response.**

- **Define antigen and mhc markers and explain their role in cell identity.**
- **Describe the role of various cells involved in the immune response.**
- **List the steps in our immune response.**
- **Compare an antibody-mediated immune response with a cell-mediated immune response.**
- **Explain immunological memory and its role in immunity.**
- **Describe what happens in an autoimmune disorder and give an example.**
- **Explain what happens when there is an allergic response.**

13.1 Non-specific defence mechanism

THE NATURAL IMMUNE SYSTEM (INNATE / NATIVE)

These mechanisms exist prior to exposure. They do not (necessarily)distinguish foreign substances.

(Not functioning completely seperate from specific system - the two systems act in concert)

1.PHYSICAL BARRIERS: skin, mucous membranes

2.GENERAL BARRIERS: fever, pH

3.BIOLOGICAL BARRIERS: inflammation, phagocytosis

4.CHEMICAL BARRIERS: enzymatic action, beta-lysin, interferon, complement

13.2 IMMUNITY

The body's ability to resist or protect itself from the harmful effects of disease producing substance or organisms is called Immunity. Any substance that causes this type of response in the body is known as **antigen**. Antigen may be bacteria, viruses, or allergens (such as pollen grains) Antigens enable the body to protect itself with the help of antibodies produced by lymphocytes (WBC) Immunity could be **natural or acquired**. Natural immunity is by birth. Acquired immunity develops during lifetime. It develops due to exposure to a disease or by vaccination.

Acquired immunity is of two types

(a) Active Immunity: Develops during exposure to disease causing germ. The body produces antibodies that remain in the blood to prevent further infection by that particular pathogen or disease causing organism. Vaccine containing weakened germs are administered to provide active immunity e.g. DPT vaccine given for developing immunity against diphtheria, pertusis (whooping cough) and tetanus and BCG vaccine given for immunity against tuberculosis People also develop immunity against chicken pox, small pox and measles after suffering from these disease. This form of immunity is usually a life long immunity

(b) Passive Immunity: This form of immunity is short lived. It is developed by injecting readymade antibodies (collected from other animals). **Anti tetanus serum (ATS vaccine)** provides temporary immunity against tetanus.

A vaccine is a sample of an antigen, too small to cause a disease, but enough to produce antibodies. Vaccines have been developed for a number of diseases like polio, mumps, measles, tetanus, diphtheria, cholera, etc.

First-Line Defenses - The body's first line of defense against pathogens uses mostly physical and chemical barriers such as sweat, skin, tears, mucus, stomach acid, and so on. Our skin and other membranes which line the body passages are fairly effective in keeping most pathogens out of the body. Mucus can trap pathogens, which are then washed away or destroyed by chemicals. Tears, sweat, and saliva have certain chemicals which can kill different pathogens.

Second-Line Defenses - If a pathogen is able to get past the body's first line of defense, and an infection starts, the body can rely on its second line of defense. This will result in what is called an inflammatory response. This is a reaction that causes redness, heat, swelling, and pain in the area of infection. Redness and heat are due to capillary dilation resulting in increased blood flow. Swelling is caused by the passage of plasma from the blood stream and into the damaged tissue. The pain is mainly due to the tissue destruction, and to a lesser extent, the swelling.

Third-Line Defenses - Sometimes the second line of defense is still not enough and the pathogen is then heading for the body's last line of defense, the immune system. The immune system will recognize, attack, destroy, and remembers each foreign substance and pathogen that enters the body. It does this by making specialized cells and antibodies that makes the pathogens useless. Unlike the first line and second line defense the immune system determines between kinds of pathogens. For each type of pathogen, the immune system produces cells that are specific for that particular pathogen.

The Immune Response - The immune system includes all parts of the body that help in the recognition and destruction of foreign materials. White blood cells, phagocytes and lymphocytes, bone marrow, lymph nodes, tonsils, thymus, and your spleen are all part of the immune system. Immunity is the body's ability to fight off foreign substances, viruses, or bacteria by producing antibodies or cells that can deactivate these foreign substances or cells. The whole idea of immunity is that the body is able to distinguish between its own substances or foreign substances. When the body recognizes foreign cells or molecules, it makes special antibodies or cells that attach to the pathogens and inactivate them. When these antibodies and special cells are produced it is called the immune response.

Cells of Immune System

Lymphocytes are cells of the immune system. There are two major types of lymphocytes, T-cells and B-cells, both develop in the **Bone Marrow**

Immunity is the result of the action of two types lymphocytes, the B lymphocytes and the T lymphocytes. The B and T cells are produced in the bone marrow. The T cells mature in the thymus gland while the B cells mature in the bone marrow. Millions of these matured B and T cells move through the circulatory and lymphatic systems.

B and T cells have different functions. B cells produce antibodies that are secreted into the blood and lymph. Unlike B cells, the T cells do not produce antibodies. Instead the T cells just attack the cells that have antigens that they recognize. It has been estimated that during our lifetime, we will encounter a million different antigens, and our bodies need the same amount of lymphocytes to defend against them. There will always be a different type of lymphocyte for each possible antigen. None of these lymphocytes are supposed to attack the bodies own cells. It very rarely may be possible that a lymphocyte will respond to the body's own proteins.

Difference between T- lymphocytes and B-lymphocytes

T-Cells	**B-Cells**
1. Mature in thymus glands.	Mature in lymphoid tissues like tonsils and appendix.
2. T-cells identify antigens and destroy them.	Recognise antigen with the help of surface receptors
3. Attack directly.	Produce a large number of antibodies for attack
4. Life span is upto 3-4 years.	Anitbodies are short lived.

A person may lack T-cells or B-cells, or both. Such persons are highly prone to infections.

10.3 summary

- The body's defense system targets pathogens and cancerous cells.
- The body has three lines of defense:

  1) Physical (skin and mucous membranes) and chemical barriers that prevent entry by pathogens,

  2) Nonspecific defensive cells (phagocytes, eosinophils, and natural killer cells) and proteins (interferons and complement system), inflammation and fever, and

  3) The immune system that has specific targets and memory.

- The immune system mounts antibody-mediated and cell-mediated responses.
- Substances that trigger an immune response are called antigens.
- Our own nucleated cells have MHC markers that identify them as "self."
- During maturation, B lymphocytes (B cells) and T lymphocytes (T cells) develop receptors on their surfaces that allow them to recognize one specific antigen and to recognize cells that belong in the body.
- When that antigen is detected they divide rapidly forming effector cells and memory cells.
- Macrophages present antigens to helper T cells to trigger an immune response.
- Helper T cells activate B cells and T cells to destroy the specific antigen.
- B cells mount an antibody-mediated immune response against antigens free in the blood or bound to a cell surface.
- Cytotoxic T cells mount a cell-mediated immune response to destroy antigen-bearing cells.
- Suppressor T cells turn off the immune response
- Immunological memory allows for a more rapid secondary response on subsequent exposure to the antigen.
- Immunity can be active, when the body participates in forming memory cells against a particular antigen, or passive, when the body receives antibodies that were produced by another person or animal. Passive immunity is short lived.
- Monoclonal antibodies are used in research, clinical diagnosis, and disease treatment to identify the presence of a specific antigen.
- Autoimmune disorders occur when the immune system attacks the body's own cells.
- Allergies are immune responses to harmless substances.

Self assessment questions

1. How dose the immune system works
2. What are the types of immunity
3. What are the cells of immune system
4. Distinguish between cell mediated and antibody mediated immunity
5. Distinguish between active and passive immunity

14. MUSKELO-SKELETAL SYSTEM

Musculoskeletal System: Major substructures include:
Tendons.
Ligaments.
Fascia.
Cartilage.
Bone.
Muscle.
Joints - allow motion between body segments.

14.1 The Muscular System

Learning outcome

After studying this section you should be able to:

- **State the function of the muscular system.**
- **Name the three kinds of muscles.**
- **List the four traits that all muscles have in common.**
- **Describe the attachment of muscle to bone and how that leads to movement.**
- **Demonstrate and explain the use of antagonistic muscles.**
- **Describe the banded appearance of striated muscles using the terms myofibril, myofilaments, actin, and myosin.**
- **Explain muscle contraction at the molecular level of the actin and myosin filaments.**
- **Explain why atp is essential to muscle contraction and relaxation.**
- **Describe the role of the tropomyosin-troponin complex in muscle contraction.**
- **Draw a neuromuscular junction and explain the role of acetylcholine in muscle contraction and the release of calcium ions.**

Introduction

Muscular System: consists of skeletal muscles and their connective tissue attachments.the muscle prefixes “myo” – muscle,“mys” – muscle, “sarco” – flesh

14.1.1Types of muscles

The body contains **3 types of muscle tissue.** The differences in these types of muscle are due to their microscopic structure, their location in the body and their function and how their functions are controlled: either voluntary or involuntary (autonomic).

A) Skeletal muscles-attach to the skeleton are responsible for voluntary body movements.

B) Smooth muscles- occur mainly in blood vessels and tubular organs of the GI tract, reproductive, urinary and respiratory systems. These muscles are under autonomic control- they are involuntary.

C) Cardiac muscle- is found only in the wall of the heart and has the unique property of auto-rythmicity. Its contractions are involuntary and have an intrinsic rhythm. No external stimuli is needed to make it contract.

1. SKELETAL MUSCLE
location: Attached to thebones for movement
Characteristics : Long, cynlindrical cells; multinucleated, and striated
Nervous Control:Voluntary

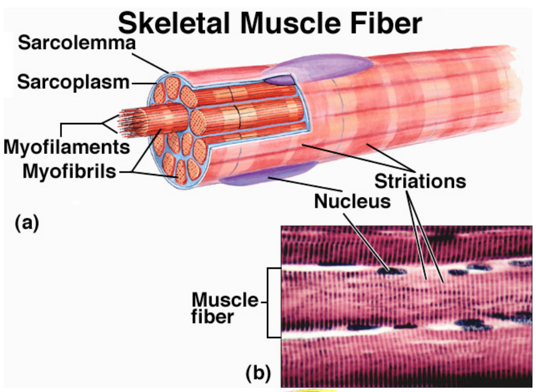
2. CARDIAC MUSCLE
Location : Muscle of theHeart
Characteristic: Short, branching cells, mononucleated, faintly striated. Forms functional syncytia.
Nervous Control: Involuntary, and myogenic

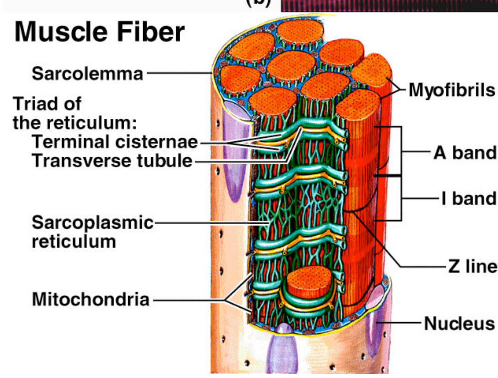
3. SMOOTH MUSCLE
Location: Single Unit: GI, Respiratory, & Genitourinary tract mucous membranes.
Multi-unit: smooth muscle in blood vessel walls.
Characteristic:Small oblong cells, mononucleated, also may form a functional syncytium.
Nervous control: involuntary and myogenic

Skeletal Muscle System: we are referring to skeletal muscle only. The body has more than 600 skeletal muscles. Technically speaking, each one of these muscles is an organ- it is composed of muscle tissue, nerve and connective tissue

14.1.2 Structure of a Skeletal Muscle fiber

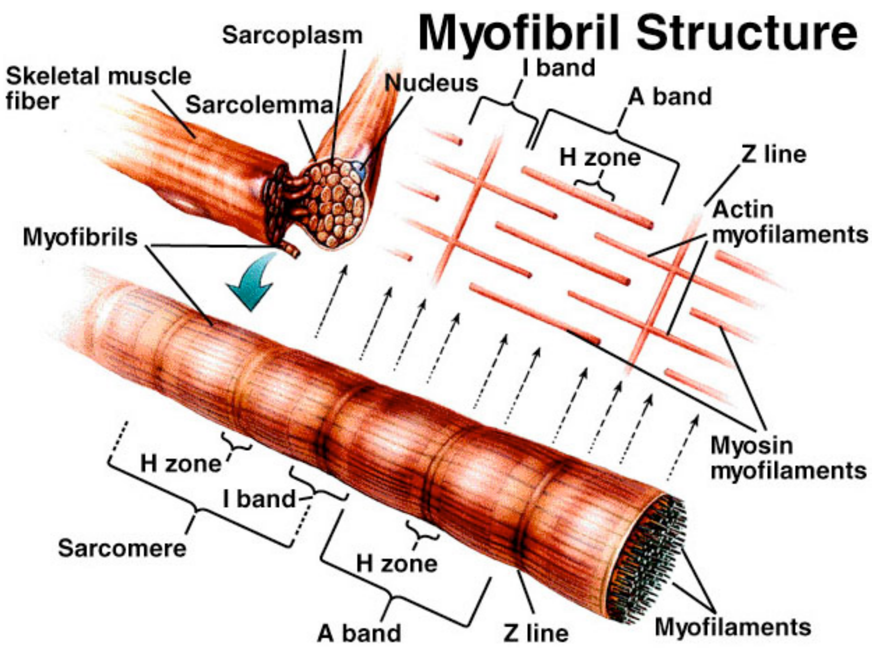
Sarcolemma- is a Cell membrane of the muscle fiber
Sacoplasmic reticulum- is a network of membranous channels that extends through the cytoplasm of the cell
Sarcoplasm- is the cytoplasm of the fiber
T tubules (transverse tubules)- is a system of tubules that run perpendicular to the sarcoplasmic reticulum.
Myofibrils- is thread like structures embedded in the muscle fiber
Myofilaments- is **smaller** protein filaments that make up the myofibril.
Actin- is Thin filaments which are made up of this protein
Myosin- is Thick filaments which are made up of this protein





14.1.3 Muscle contraction:

it is best understood by **Sliding Filament Model:** in this As the myofilaments slide the Z lines are brought closer together. The A bands remain the same during contraction, but the H and I bands narrow progressively and eventually may be obliterated. Other wise it can be explained as the shortening of sarcomeres, and the resulting muscle contraction, is due to the sliding of the actin and myosin myofilaments against one another.



Types of muscle contractions

Isotonic- Contraction leads to shortening of the muscle. This type of contraction involves movement against resistance and is a dynamic contraction. Lifting free weights is primarily isotonic. Movements such as bench press, squats, dead lift and biceps curls are isotonic.

Isometric- is a static contraction in which the muscle remains the same length. There is no shortening of the muscle and in this type of contraction it is usually performed against a resistance that can't be moved. Example: In yoga, the crow pose, downward dog or plank pose

14.1.4 Muscle attachments:

Tendons: Is dense connective tissue that attaches the muscle to bone. When a muscle contracts, it shortens and puts tension on the tendon and the bone. The muscle tension causes movement of the bone at a synovial joint.

Origin: The less moveable attachment of the muscle is called the **origin.** At the girdles and appendages the most proximal muscle attachment is the **origin.**

Insertion: Movement of the bone at the synovial joint causes one of the attached bones to move more than the other. The more moveable bony attachment of the muscle is called the **insertion**. In muscles associated with girdles and appendages the more distal attachment is the **insertion.**

Belly: the fleshy thick part of the muscle. Also called the **gaster.**

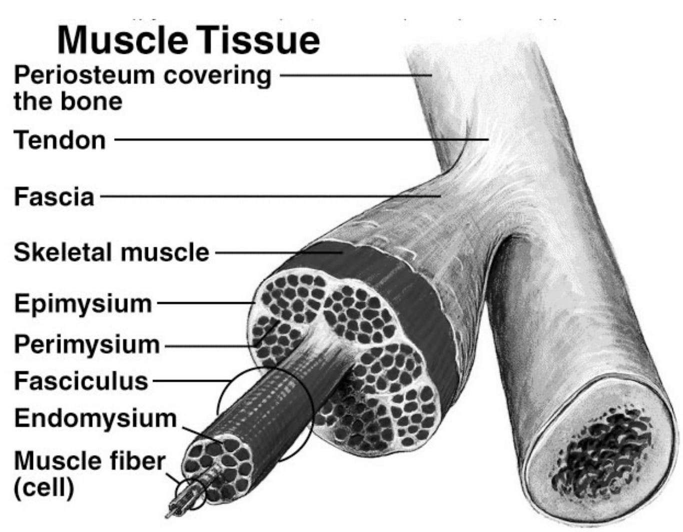
Aponeuroses: is a flattened sheet like tendon

Retinaculum: is a strong band of connective tissue that covers entire groups of tendons and keeps the tendons from bowing during muscle contraction.

They are attached to articulating bones and are found at the wrist and the ankle.

The Associated connective tissues of muscle

Endomysium the outer covering of individual muscle fibers. It binds individual fibers together and supports capillaries and nerve endings serving the muscle.
Perimysium-another sheath covering that binds groups of muscle fibers together into bundles called **fasciculi.** The perimysium supports the nerves and blood vessels that serve the surrounding fasciculi.
Epimysium- The entire muscle is covered by a sheath called the
Epimysium, which in turn is part of a tendon
Fascia- a fibrous connective tissue that covers the muscle and attaches to the skin. **Superficial fascia** secures skin to the underlying structures. In areas such as the abdomen, buttocks the fascia is thick and is laced with adipose tissue. In areas such as the back of the hand, around the face and the elbows, ankles and wrists, the superficial fascia is very thin.
Deep fascia is an extension of the superficial fascia to deeper surfaces. It lacks adipose tissue and blends with the epimysium. It is composed of dense connective tissue. Deep fascia surrounds adjacent muscle, compartmentalizing and binding them into functional groups. **Subserous fascia** extends between deep fascia and serous membranes. It is composed of loose connective tissue.



14.1.5 Blood and Nerve supply to the Muscle
Muscles have a high rate of metabolical activity and require an extensive blood supply to receive nutrients and eliminate wastes. Skeletal muscle cannot contract without stimulation by a nerve impulse. The muscle requires

extensive innervation to ensure the connection of each muscle fiber with a nerve cell.

There are 2 neural pathways for each muscle fiber:
Motor (efferent) neurons: a nerve cell that conducts impulses to the muscle fiber, stimulating it to contract.
Sensory (afferent) neurons: Nerve cells that conducts impulses away from the muscle to the CNS**,** which responds to the activity of the muscle fiber. Muscle fibers will atrophy if not periodically stimulated to contract.

Types of joint movements:

Flexion: is the bending at the joint. It decreases the joint angle on a anteroposteriorly plane. Muscles that pass in front of a joint flex the bone to which they are attached
Extension: the opposite of flexion. It is straightening of the joint to a 180º angle. The joint angle is increased to 180º. Extension returns a body part to the anatomical position. Muscles that pass behind a joint extend the bone to which they are attached.
Hyperextension: occurs when a part of the body is extended beyond the anatomical position so that the joint angle is greater than 180º.
Abduction: movement of a body part away from the axis of the body, away from the midsagittal plane in a lateral direction.
Adduction: The opposite of abduction. it moves a body part towards the main axis of the body.
Rotation: is a circular motion that occurs in joints that have a rounded or oval articular surface that corresponds to a depression in another bone. It is a movementof a bosy part around its own axis. Example: turning of the head or twisting at the waist.

14.1.6 Functions of the muscular system

1)Movement: The primary function of skeletal muscle in the body is movement. Even the smallest areas such as the eyeball and the ear have associated muscles responsible for their movements. The contraction of skeletal muscle is also important in functions such as breathing and movement of bodily fluids. The stimulation of individual muscle fibers maintains a state of muscle contraction known as **tonus.** This is important in maintaining the movement of blood and lymph through out the body**.** When muscle is cut off from nerve supply, a condition that occurs when spinal nerves are severed, the muscles lose tonus and become flaccid and eventually atrophy (shrink). The involuntary contraction of smooth muscle is also essential for movement of fluids and material through the body. Likewise the involuntary pumping of the cardiac muscle keeps blood flowing through the body.
2) Body heat production: The body maintains a fairly constant temperature. Physiologically this is one of the principles of **homeostasis - the body's ability to regulate its functions.** Muscle metabolism produces heat as an end product. Because muscles constitute about 40-45% of the body's weight and

are in a constant state of fiber activity, they are the primary source of body heat. The rate of heat production rises with increased muscle activity. That is why emaciated and elderly people, who have reduced muscle mass have difficulty staying warm.

3) Posture and Support of body: the skeletal system provides a framework for body support but the muscles do all the heavy lifting. Skeletal muscles maintain posture, stabilize the joints and support the viscera. Postural muscles of the head, neck and trunk are working even when you think you are relaxed. The head, in particular is constantly being held at the atlanto-occipital joint up by the muscles of the neck. When you start to get drowsy, these muscles will relax and your head nods forward.

14.1.7 Properties of Muscle

A) Irritability (Electrical Excitability): muscle responds to electrical stimulation
from nerve impulses.

B) Contractility: muscle responds to stimuli by contracting lengthwise, or shortening.

C) Extensibility: once stimulus has subsided and the muscle fiber is relaxed it is capable of being stretched beyond its resting length by the contraction of an opposing muscle. Muscle can be stretched up to 30% of it's resting length.
The fibers are then prepared for another contraction.

D) Elasticity: Muscle fibers, after being stretched, have a tendency to recoil to their original resting length.

AMAZING FACTS ABOUT THE MUSCULAR SYSTEM

- There are about 60 muscles in the face. Smiling is easier than frowning. It takes 20 muscles to smile and over 40 to frown.
- The longest muscle in the body is the *sartorius*, from the outside of the hip, down and across to the inside of the knee. It rotates the thigh outwards and bends the knee.
- The smallest muscle in the body is the *stapedius*, deep in the ear. It is only 5mm long and thinner than cotton thread. It is involved in hearing.
- The biggest muscle in the body is the *gluteus maximus*, in the buttock. It pulls the leg backwards powerfully for walking, running and climbing steps.

13.2 The Skeletal system

Learning outcome

After studying this section you should be able to:

- List the functions of bone.
- Compare the structure of compact and spongy bone.
- Label a diagram of bone structure.

- Describe the development of bone beginning with the formation of cartilage in the embryo.
- Explain the process of bone growth and what controls it.
- Describe how bones heal after a fracture or break.
- Compare the function of osteocytes, osteoblasts, and osteoclasts.
- Explain what is meant by the continual remodeling of bone.
- List the components of the axial skeleton and the appendicular skeleton.
- Describe the structure of the vertebral column as a series of vertebrae separated by cartilaginous disks.
- List the components of the pectoral and pelvic girdles.
- Compare the three types of joints in terms of structure and motion.
- Explain the difference between a ligament and a tendon.
- Describe the structure of a synovial joint.

Introduction:

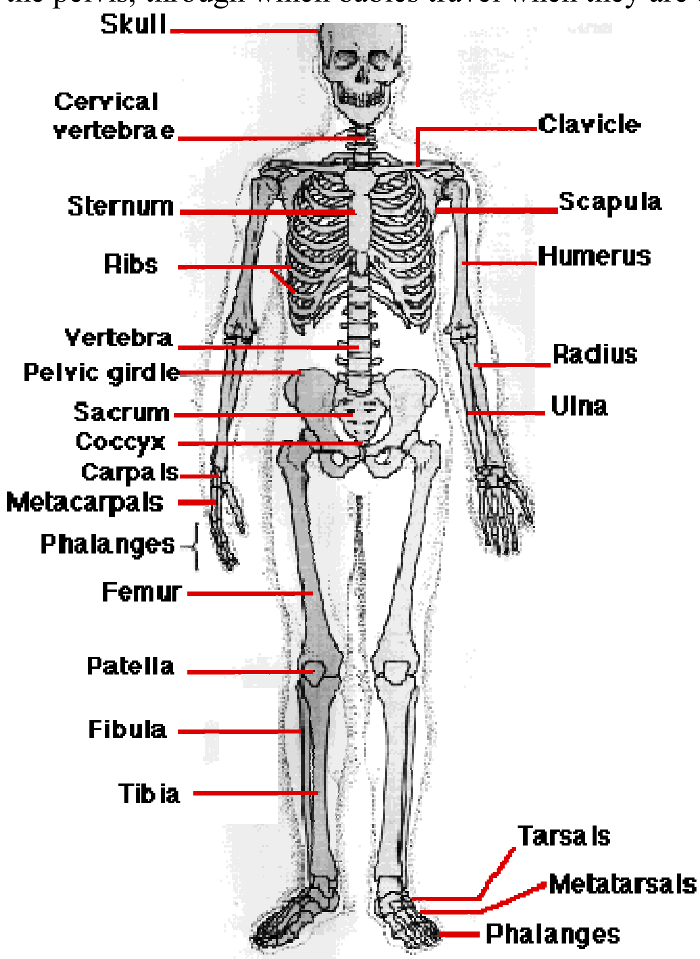
The **skeletal system** is composed of **bones** and strong elastic tissues which make up the **ligaments, tendons** and **cartilages**.

The word *skeleton* comes from the Greek word meaning “dried-up body,” our internal framework is so beautifully designed and engineered that it puts any modern skyscraper to shame. Strong, yet light, it is perfectly adapted for its functions of body protection and motion. Shaped by an event that happened more than one million years ago—when a being first stood erect on hind legs—our skeleton is a tower of bones arranged so that we can stand upright and balance ourselves. No other animal has such relatively long legs (compared to the arms or forelimbs) or such a strange foot, and few have such remarkable grasping hands. Even though the infant’s backbone is like an arch, it soon changes to the swayback, or S-shaped, structure that is required for the upright posture.

The skeleton is subdivided into two divisions: the **axial skeleton,** the bones that form the longitudinal axis of the body, consist of the skull, ribs, spine and sternum. And the **appendicular skeleton,** the bones of the limbs and girdles, are the bones of arms and legs, scapula, clavicle, and pelvis.. In addition to bones, the **skeletal system** includes *joints, cartilages,* and *ligaments* (fibrous cords that bind the bones together at joints). The joints give the body flexibility and allow movement to occur.

The human skeleton consists of 206 bones. We are actually born with more bones (about 300), but many fuse together as a child grows up. This set of forty-one pieces connects to form a human skeleton that displays the structure’s major parts. These bones support our body and allow us to move. Bones contain a lot of **calcium** (an element found in milk, broccoli, and other foods). Bones manufacture blood cells and store important minerals. The longest bone in our bodies is the **femur** (thigh bone). The smallest bone is the stirrup bone inside the ear. Each hand has 26 bones in it. our nose and ears are not made of bone; they are made of cartilage, a flexible substance that is not as hard as bone. **Joints**: Bones are connected to other bones at joints. There are many different types of joints, including: fixed joints (such as in the skull, which consists of many bones), hinged joints (such as in the fingers and toes), and ball-and-socket joints (such as the shoulders and hips).

Differences in males and females: Males and females have slightly different skeletons, including a different elbow angle. Males have slightly thicker and longer legs and arms; females have a wider pelvis and a larger space within the pelvis, through which babies travel when they are born.



Functions of the Bones

Besides contributing to body shape and form, our bones perform several important body functions:

1. Support. Bones, the "reinforced concrete" of the body, form the internal framework that supports and anchors all soft organs. The bones of the legs act as pillars to support the body trunk when we stand, and the rib cage supports the thoracic wall.

2. Protection. Bones protect soft body organs. For example, the fused bones of the skull provide a snug enclosure for the brain. The vertebrae surround the spinal cord, and the rib cage helps protect the vital organs of the thorax.

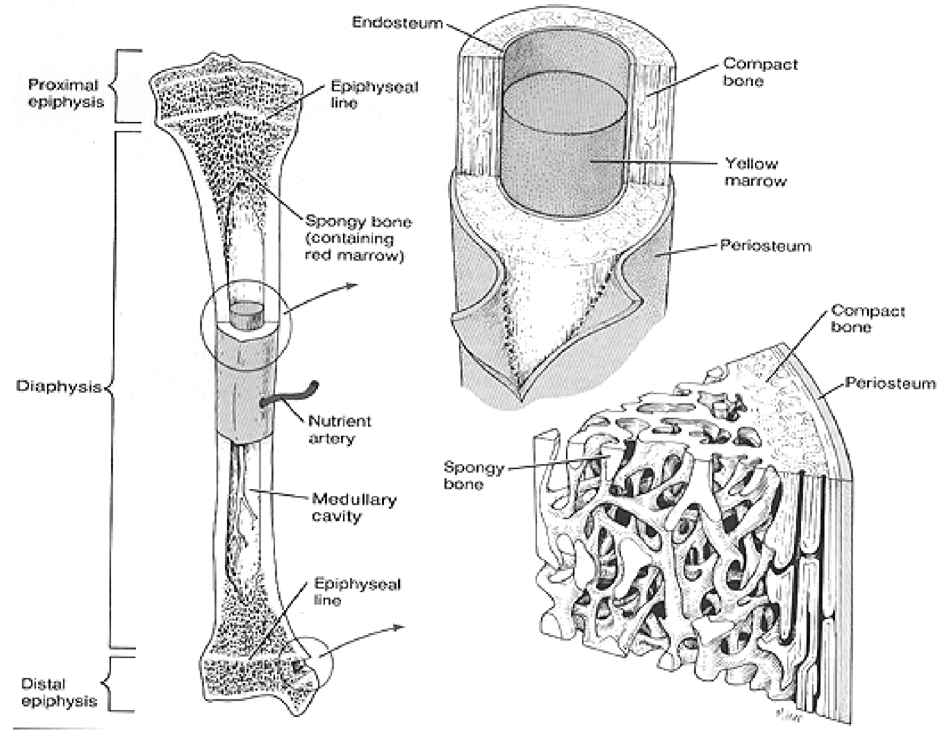
3. Movement. Skeletal muscles, attached to bones by tendons, use the bones as levers to move the body and its parts. As a result, we can walk, swim, throw a ball, and breathe.

4. Storage. Fat is stored in the internal cavities of bones. Bone itself serves as a storehouse for minerals, the most important being calcium and phosphorus, although others are also stored. A small amount of calcium in its ion form (Ca2+) must be present in the blood at all times for the nervous system to transmit messages, for muscles to contract, and for blood to clot. Because most of the body's calcium is deposited in the bones as calcium salts, the bones are a convenient place to get more calcium ions for the blood as they are used up. Problems occur not only when there is too little calcium in the blood, but also when there is too much. Hormones control the movement of calcium to and from the bones and blood according to the needs of the body. Indeed, "deposits" and "withdrawals" of calcium (and other minerals) to and from bones go on almost all the time.

5. Blood cell formation. Blood cell formation, or hematopoiesis (hem_ah-to-poi-e_sis), occurs within the marrow cavities of certain bones.

Classification of Bones

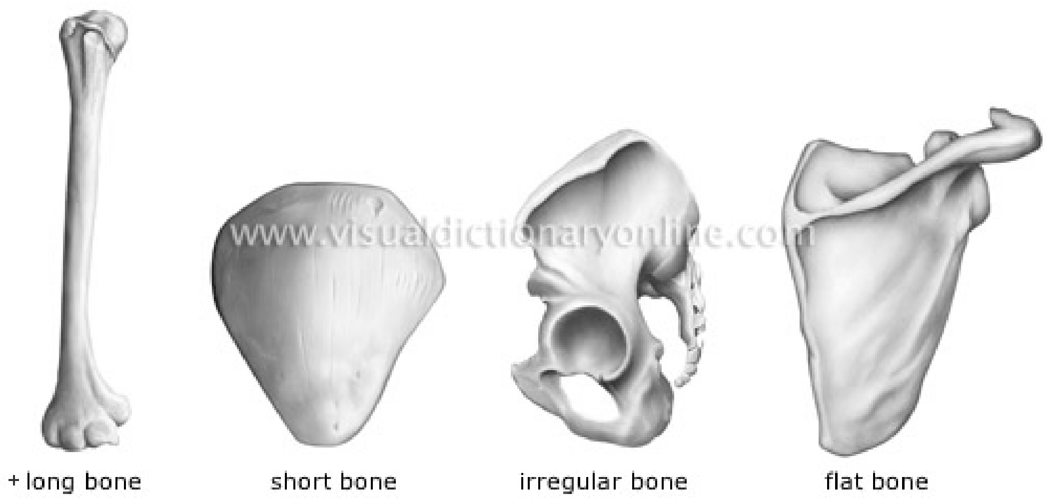
There are two basic types of osseous, or bone, tissue: **Compact bone** is dense and looks smooth and homogeneous. **Spongy bone** is composed of small needlelike pieces of bone and lots of open space.



Bones come in many sizes and shapes. For example, the tiny pisiform bone of the wrist is the size and shape of a pea, whereas the femur, or thigh bone, is nearly 2 feet long and has a large, ball-shaped head. The unique shape of each bone fulfills a particular need. Bones are classified according to shape into four groups: long, short, flat, and irregular As their name suggests, **long bones** are typically longer than they are wide. As a rule they have a shaft with heads at both ends. Long bones are mostly compact bone. All the bones of the limbs, except the wrist and ankle bones, are long bones.

Short bones are generally cube-shaped and contain mostly spongy bone. The bones of the wrist and ankle are short bones. *Sesamoid* (ses_ahmoyd) *bones,* which form within tendons, are a special type of short bone. The best-known example is the patella or kneecap.

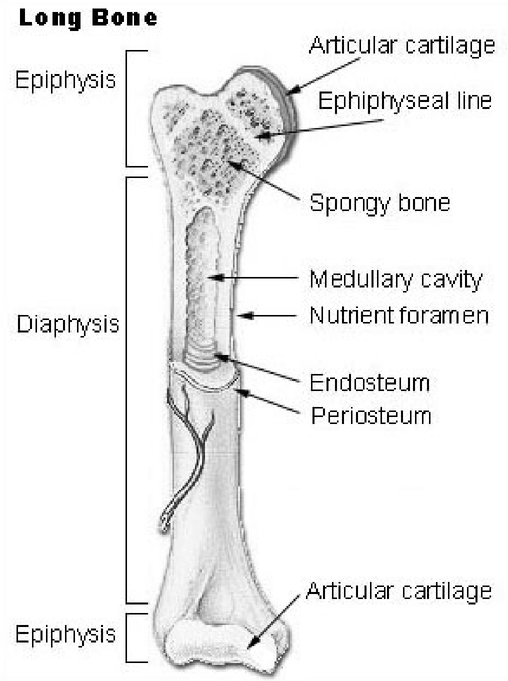
Flat bones are thin, flattened, and usually curved. They have two thin layers of compact
bone sandwiching a layer of spongy bone between them. Most bones of the skull, the ribs, and the sternum (breastbone) are flat bones. Bones that do not fit one of the preceding categories are called **irregular bones.** The vertebrae, which make up the spinal column, and the hip bones fall into this group.



Structure of a Long Bone:

Anatomy
The gross structure of a long bone is shown below The **diaphysis**, or shaft, makes up most of the bone's length and is composed of compact bone. The diaphysis is covered and protected by a fibrous connective tissue membrane, the **periosteum**. Hundreds of connective tissue fibers, called *Sharpey's fibers,* secure the periosteum to the underlying bone. The **epiphyses** are the ends of the long bone. Each epiphysis consists of a thin layer of compact bone enclosing an area filled with spongy bone. **Articular cartilage,** instead of a periosteum, covers its external surface. Because the articular cartilage is

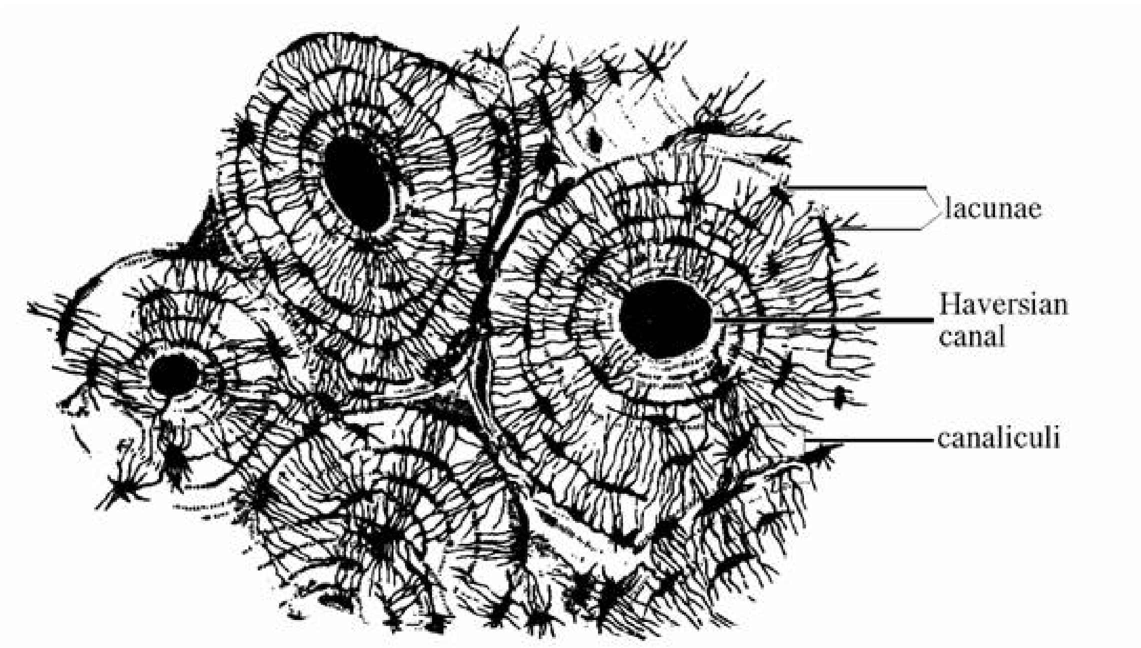
glassy hyaline cartilage, it provides a smooth, slippery surface that decreases friction at joint surfaces.



In adult bones, there is a thin line of bony tissue spanning the epiphysis that looks a bit different from the rest of the bone in that area. This is the **epiphyseal line.** The epiphyseal line is a remnant of the **epiphyseal plate** (a flat plate of hyaline cartilage) seen in a young, growing bone. Epiphyseal been completely replaced by bone, leaving only the epiphyseal lines to mark their previous location. In adults the cavity of the shaft is primarily a storage area for adipose (fat) tissue. It is called the **yellow marrow,** or **medullary, cavity.** However, in infants this area forms blood cells, and **red marrow** is found there. In adult bones, red marrow is confined to the cavities of spongy bone of flat bones and the epiphyses of some long bones. Even when looking casually at bones, one can see that their surfaces are not smooth but scarred with bumps, holes, and ridges. These muscles, tendons, and ligaments were plates cause the lengthwise growth of a long bone. By the end of puberty, when hormones stop long bone growth, epiphyseal plates have attached, and where blood vessels and nerves passed.

Microscopic Anatomy

To the naked eye, spongy bone has a spiky, open appearance, whereas compact bone appears to be very dense. Looking at compact bone tissue through a microscope, however, one can see that it has a complex structure. It is riddled with passageways carrying nerves, blood vessels, and the like, which provide the living bone cells with nutrients and a route for waste disposal. The mature bone cells, **osteocytes**, are found in tiny cavities within the matrix called **lacunae**. The lacunae are arranged in concentric circles called **lamellae** around **central (Haversian) canals.** Each complex consisting of central canal and matrix rings is called an **osteon** or **Haversian system.** Central canals run lengthwise through the bony matrix, carrying blood vessels and nerves to all areas of the bone. Tiny canals, **canaliculi**, radiate outward from the central canals to all lacunae. The canaliculi form a transportation system that connects all the bone cells to the nutrient supply through the hard bone matrix.



Because of this elaborate network of canals, bone cells are well nourished in spite of the hardness of the matrix, and bone injuries heal quickly and well. The communication pathway from the outside of the bone to its interior (and the central canals) is completed by **perforating (Volkmann's) canals,** which run into the compact bone at right angles to the shaft. Bone is one of the hardest materials in the body, and although relatively light in weight, it has a remarkable ability to resist tension and other forces acting on it. Nature has given us an extremely strong and exceptionally simple (almost crude) supporting system without giving up mobility.

The calcium salts deposited in the matrix give bone its hardness, whereas the organic parts (especially the collagen fibers) provide for bone's flexibility and great tensile strength.

13.3 JOINTS OF HUMAN SKELETON

Introduction:

Except the hyoid bone of the neck, every bone in the body forms a joint with at least one other bone. **Joints,** also called **articulations,** have two functions: They hold the bones together securely but also give the rigid skeleton mobility. The immovable joints of the skull, for instance, form a snug enclosure for our vital brain are also present. Joints are classified in two ways—functionally and structurally.

The functional classification focuses on the amount of movement allowed by the joint. they are:

1. **synarthroses** or immovable joints,
2. **amphiarthroses** or slightly movable joints, and
3. **diarthroses** or freely movable joints.

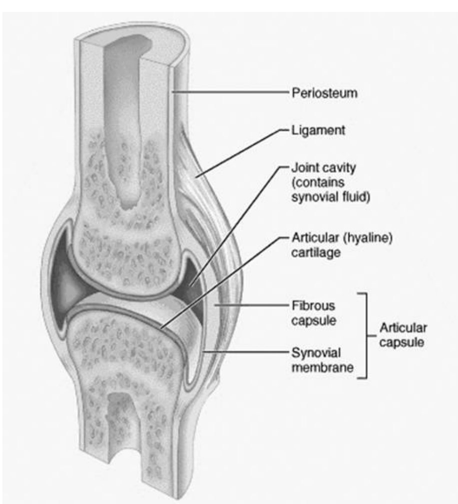
Freely movable joints predominate in the limbs, where mobility is important. Immovable and slightly movable joints are restricted mainly to the axial skeleton, where firm attachments and protection of internal organs are priorities.

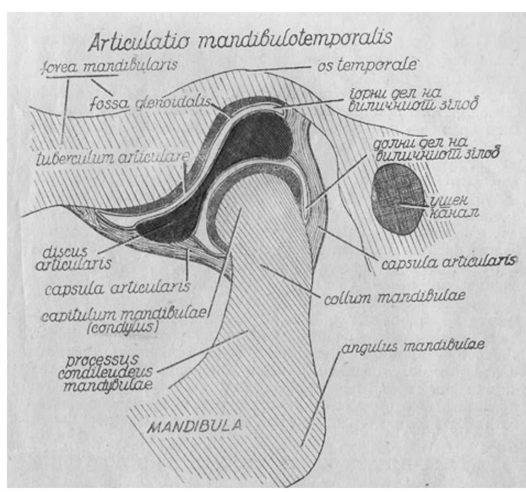
Structurally, there are *fibrous, cartilaginous,* and *synovial joints* based on whether fibrous tissue, cartilage, or a joint cavity separates the bony regions at the joint. As a general rule, fibrous joints are immovable and synovial joints are freely movable. Although cartilaginous joints have both immovable and slightly movable examples, most are amphiarthrotic. The joint types are shown below and described next.

In **fibrous joints,** the bones are united by fibrous tissue. The best examples of this type of joint are the *sutures* of the skull. In sutures, the irregular edges of the bones interlock and are bound tightly together by connective tissue fibers, allowing essentially no movement to occur.

In **syndesmoses**, the connecting fibers are longer than those of sutures; thus the joint has more "give." The joint connecting the distal ends of the tibia and fibula is a syndesmosis. Cartilaginous Joints

In **cartilaginous joints,** the bone ends are connected by cartilage. Examples of this joint type that are slightly movable (amphiarthrotic) are the *pubic symphysis* of the pelvis and *intervertebral joints* of the spinal column, where the articulating bone surfaces are connected by pads (discs) of fibrocartilage. The hyaline-cartilage epiphyseal plates of growing long bones and the cartilaginous joints between the first ribs and the sternum are immovable (synarthrotic) cartilaginous joints.





Synovial joints are those in which the articulating bone ends are separated by a joint cavity containing synovial fluid. All synovial joints have four distinguishing features as described below:

1. Articular cartilage. Articular (hyaline) cartilage covers the ends of the bones forming the joint.

2. Fibrous articular capsule. The joint surfaces are enclosed by a sleeve or capsule of fibrous connective tissue, and the capsule is lined with a smooth *synovial membrane* (the reason these joints are called synovial joints).

3. Joint cavity. The articular capsule encloses a cavity, called the joint cavity, which contains lubricating synovial fluid.

4. Reinforcing ligaments. The fibrous capsule is usually reinforced with ligaments. Bursae and tendon sheaths are not strictly part of synovial joints, but they are often found closely associated with them. Essentially bags of lubricant, they act like ball bearings to reduce friction between adjacent structures during joint activity. **Bursae** are flattened fibrous sacs lined with synovial membrane and containing a thin film of synovial fluid. They are common where ligaments, muscles, skin, tendons, or bones rub together. A **tendon sheath**, is essentially an elongated bursa that wraps completely around a tendon subjected to friction.

The shapes of the articulating bone surfaces determine what movements are allowed at a joint. Based on such shapes, our synovial joints can be classified as *plane, hinge, pivot, condyloid, saddle,* and *ball-and-socket joints*

• In a **plane joint**, the articular surfaces are essentially flat, and only short slipping or gliding movements are allowed. The movements of plane joints are **nonaxial;** that is, gliding does not involve rotation around any axis. Example,The intercarpal joints of the wrist.

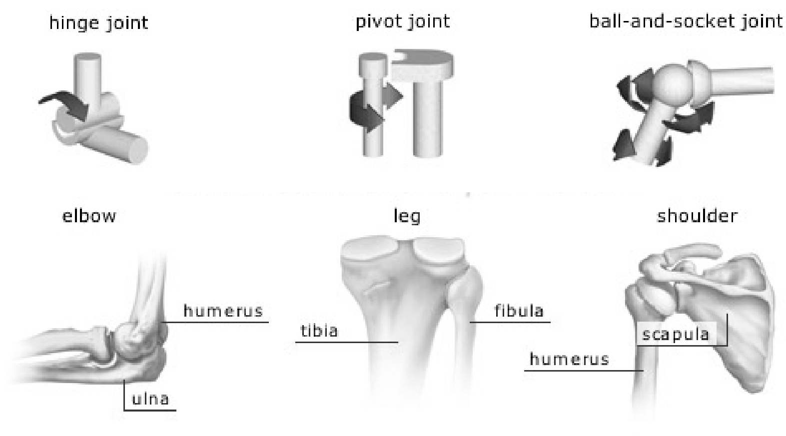
• In a **hinge joint**, the cylindrical end of one bone fits into a trough-shaped surface on another bone. Angular movement is allowed in just one plane, like a mechanical hinge. Examples are the elbow joint, ankle joint, and the joints between the phalanges of the fingers. Hinge joints are classified as **uniaxial**; they allow movement around one axis only.

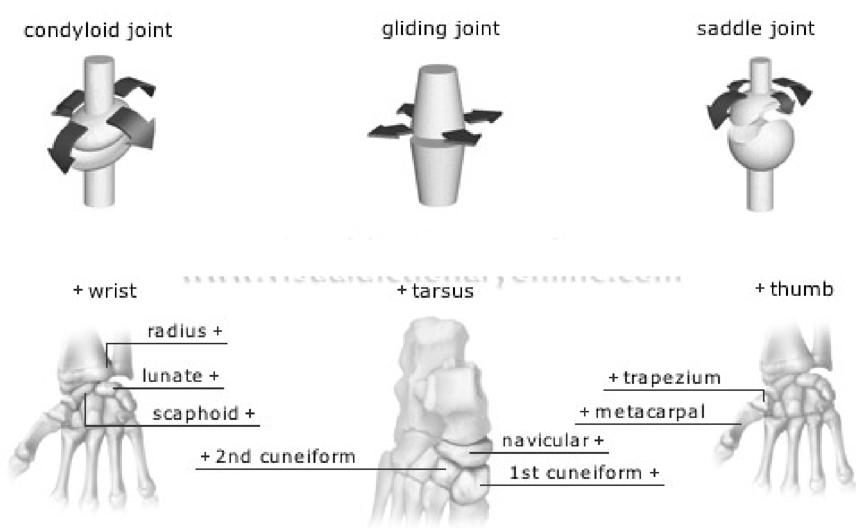
• In a **pivot joint**, the rounded end of one bone fits into a sleeve or ring of bone (and possibly ligaments). Because the rotating bone can turn only around its long axis, pivot joints are also uniaxial joints.example,The proximal radioulnar joint and the joint between the atlas and the dens of the axis.

• In a **condyloid joint** (“knucklelike”), the egg-shaped articular surface of one bone fits into an oval concavity in another. Both of these articular surfaces are oval. Condyloid joints allow the moving bone to travel (1) from side to side and (2) back and forth, but the bone cannot rotate around its long axis. Movement occurs around two axes, hence these joints are **biaxial**, as in knuckle (metacarpophalangeal) joints.

• In **saddle joints,** each articular surface has both convex and concave areas, like a saddle. These biaxial joints allow essentially the same movements as condyloid joints. Examples,of saddle joints are the carpometacarpal joints in the thumb.

• In a **ball-and-socket joint**, the spherical head of one bone fits into a round socket in another. These **multiaxial** joints allow movement in all axes, including rotation and are the most freely moving synovial joints. The shoulder and hip are examples.

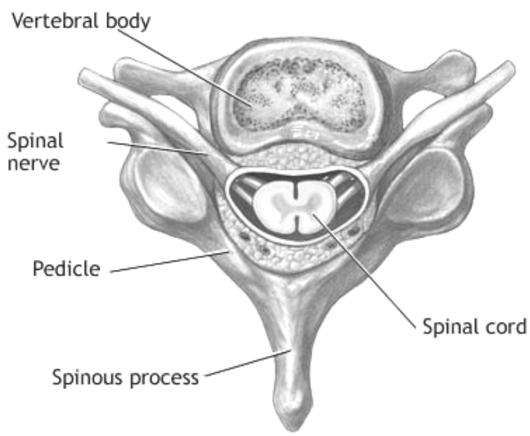




14.4 Vertebral Column (Spine)

Serving as the axial support of the body, the **vertebral column,** or **spine,** extends from the skull, which it supports, to the pelvis, where it transmits the weight of the body to the lower limbs. The spine is formed from 26 irregular bones connected and reinforced by ligaments in such a way that a flexible, curved structure results. Running through the central cavity of the vertebral column is the delicate spinal cord, which it surrounds and protects. Before birth, the spine consists of 33 separate bones called **vertebrae,** but 9 of these eventually fuse, forming the two composite bones, the *sacrum* and the *coccyx,* that construct the inferior portion of the vertebral column. Of the 24 single bones, the 7 vertebrae of the neck are cervical vertebrae, the next 12 are the thoracic vertebrae, and the remaining 5 supporting the lower back are lumbar vertebrae.

The single vertebrae are separated by pads of flexible fibrocartilage— **intervertebral discs**— which cushion the vertebrae and absorb shocks. In a young person, the discs have a high water content (about 90 percent) and are spongy and compressible. But as a person ages, the water content of the discs decreases (as it does in other tissues throughout the body), and the discs become harder and less compressible. All vertebrae have a similar structural pattern. The common features are listed below:



• **Body** or **centrum:** disclike, weight-bearing part of the vertebra facing anteriorly in the vertebral column.

Vertebral arch: arch formed from the joining of all posterior extensions, the *laminae* and *pedicles,* from the vertebral body.

• **Vertebral foramen:** canal through which the spinal cord passes.

• **Transverse processes:** two lateral projections from the vertebral arch.

• **Spinous process:** single projection arising from the posterior aspect of the vertebral arch (actually the fused laminae).

• **Superior and inferior articular processes:** paired projections lateral to the vertebral foramen, allowing a vertebra to form joints with adjacent vertebrae.

In addition to the common features just described, vertebrae in the different regions of the spine have very specific structural characteristics. These unique regional characteristics of the vertebrae are described below.

Cervical Vertebrae

The seven **cervical vertebrae** (identified as C1 to C7) form the neck region of the spine. The first two vertebrae (*atlas* and *axis*) are different because they perform functions not shared by the other cervical vertebrae. the **atlas** (C1) has no body. The superior surfaces of its transverse processes contain large depressions that receive the occipital condyles of the skull. This joint allows you to nod "yes." The **axis** (C2) acts as a pivot for the rotation of the atlas (and skull) above. It has a large upright process, the **Odontoid process,** or **dens,** which acts as the pivot point. The joint between C1 and C2 allows us to rotate our head from side to side to indicate "no." The "typical" cervical vertebrae (C3 through C7) are shown in Figure. They are the smallest, lightest vertebrae, and most often their spinous processes are short and divided into two branches. The transverse processes of the cervical vertebrae contain foramina (openings) through which the vertebral arteries pass on their way to the brain above.

Thoracic Vertebrae

The 12 **thoracic vertebrae** (T1–T12) are all typical. they are larger than the cervical vertebrae. The body is somewhat heart shaped and has two costal demifacets (articulating surfaces) on each side, which receive the heads of the ribs. The spinous process is long and hooks sharply downward, causing the vertebra to look like a giraffe's head viewed from the side.

Lumbar Vertebrae

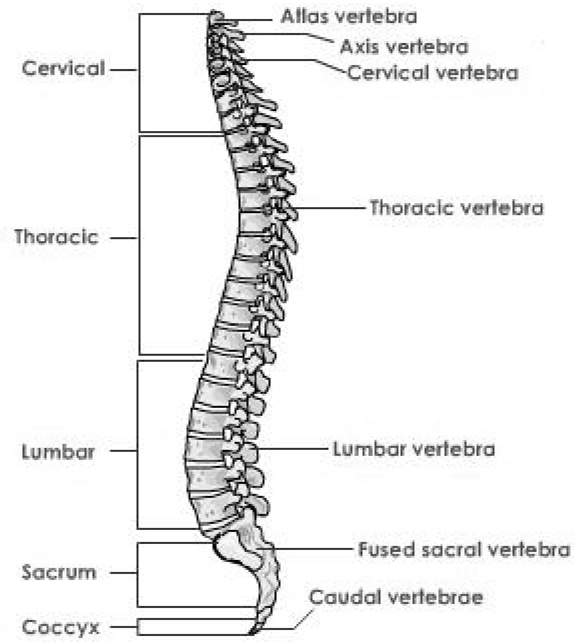
The five **lumbar vertebrae** (L1–L5) have massive, blocklike bodies. Their short, hatchet-shaped spinous processes make them look like a moose head from the lateral aspect. Since most of the stress on the vertebral column occurs in the lumbar region, these are the sturdiest of the vertebrae.

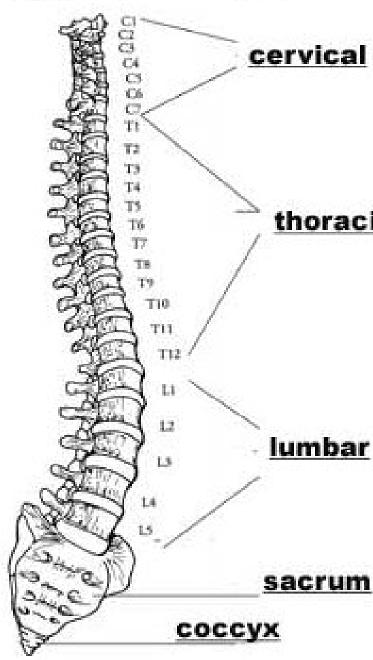
Sacrum:

The **sacrum** is formed by the fusion of five vertebrae. Superiorly it articulates with L5, and inferiorly it connects with the coccyx. The winglike **alae** articulate laterally with the hip bones, forming the sacroiliac joints. The sacrum forms the posterior wall of the pelvis. Its dorsal midline surface is roughened by the **median sacral crest,** the fused spinous processes of the sacral vertebrae. This is flanked laterally by the dorsal sacral foramina. The vertebral canal continues inside the sacrum as the **sacral canal.**

Coccyx

The **coccyx** is formed from the fusion of three to five tiny, irregularly shaped vertebrae. It is the human "tailbone," a remnant of the tail that other vertebrate animals have.





14.4 Summary:

- The skeleton is a framework of bone and cartilage that supports and protects the internal organs, allows for movement, stores minerals and fat, and produces red blood cells.
- Compact bone is dense bone found on the outside of all bones and covered by the periosteum.

- Spongy bone is an open latticework of bone found in flat bones and near the ends of long bones.
- The shaft of long bones is filled with a fatty yellow marrow. The spongy bone of some long bones in adults is filled with red marrow.
- The structural unit of the bone is called an osteon. It consists of a central canal with bone cells, called osteocytes, arranged in concentric circles. Bone matrix is hardened by calcium salts and strengthened by fibers of collagen.
- The embryonic skeleton forms as cartilage that is gradually replaced by bone during a process called endochondrial ossification. Osteoplasts form a bony collar around the shaft of the bone. Then cartilage within the shaft breaks down and is replaced by bone. Epiphyseal plates of cartilage remain and allow for bone growth of the long bones.
- Bone growth is stimulated by growth hormone from the anterior pituitary gland.
- Repair of bones begins with a blood clot at the site of the fracture. A cartilaginous callus links the broken ends of the bone. This cartilage is gradually replaced by bone.
- Bone is constantly being remodeled. Osteoblasts deposit new bone and osteoclasts break down existing bone. Weight-bearing stress fosters strong bones and forestalls osteoporosis.
- Joints are places where bones meet. They are classified according to the movement they permit.
- Bones are connected to other bones by ligaments and to muscles by tendons.
- Fibrous joints usually allow no movement and cartilaginous joints allow very limited movement.
- Synovial joints are the most common and allow for the most movement. They have cartilage on the adjoining surfaces and a lubricant. The bones are held together by ligaments.
- The muscular system produces movement and maintains posture.
- There are three kinds of muscles: skeletal, cardiac, and smooth.
- All muscles are excitable, contractile, extensible, and elastic.
- Muscles are attached to bone by tendons and are arranged in opposing, or antagonistic, pairs.
- Sarcomeres are the contractile units of muscle.
- The striated appearance of muscles is caused by the arrangement of myofibrils within the muscle cell. Each myofibril contains groups of myofilaments composed of actin and myosin proteins.

- A muscle contracts when myosin binds to action causing the filaments to slide past one another. Contraction is powered by ATP and controlled by two regulatory proteins and calcium ions.
- Nerves stimulate muscle contraction at the neuromuscular junction. Acetylcholine, released from the motor neuron, causes a change in muscle cell permeability resulting in the release of calcium ions and contraction.
- A motor neuron and all the muscle cells it stimulates are called a motor unit. The strength of a muscle contraction depends on the number of motor units involved.
- A muscle twitch is the contraction caused by a stimulus to the muscle. Successive contractions, prior to complete relaxation, build upon the first by wave summation. A sustained contraction is called tetanus.
- ATP is required for muscle contraction. A small amount of ATP is stored in the muscle cells and more can be generated from the energy stored in creatine phosphate. The rest comes from aerobic respiration and lactic acid fermentation.

Self assessment questions:

1. State the function of the muscular system.
2. Name the three kinds of muscles.
3. Describe the attachment of muscle to bone and how that leads to movement.
4. List the functions of bone.
5. Compare the structure of compact and spongy bone.
6. Label a diagram of bone structure.

15. HUMAN REPRODUCTIVE SYSTEM

15.1 male reproductive system
15.2 female reproductive system
15.3 summary

Introduction:

Humans are sexually reproducing and viviparous. The reproductive events in humans include formation of gametes (gametogenesis), i.e., sperms in males and ovum in females, transfer of sperms into the female genital tract (insemination) and fusion of male and female gametes (fertilisation) leading to formation of zygote. This is followed by formation and development of blastocyst and its attachment to the uterine wall (implantation), embryonic development (gestation) and delivery of the baby (parturition). You have learnt that these reproductive events occur after puberty. There are remarkable differences between the reproductive events in the male and in the female, for example, sperm formation continues even in old men, but formation of ovum ceases in women around the age of fifty years.

15.1 THE MALE REPRODUCTIVE SYSTEM

Learning out come

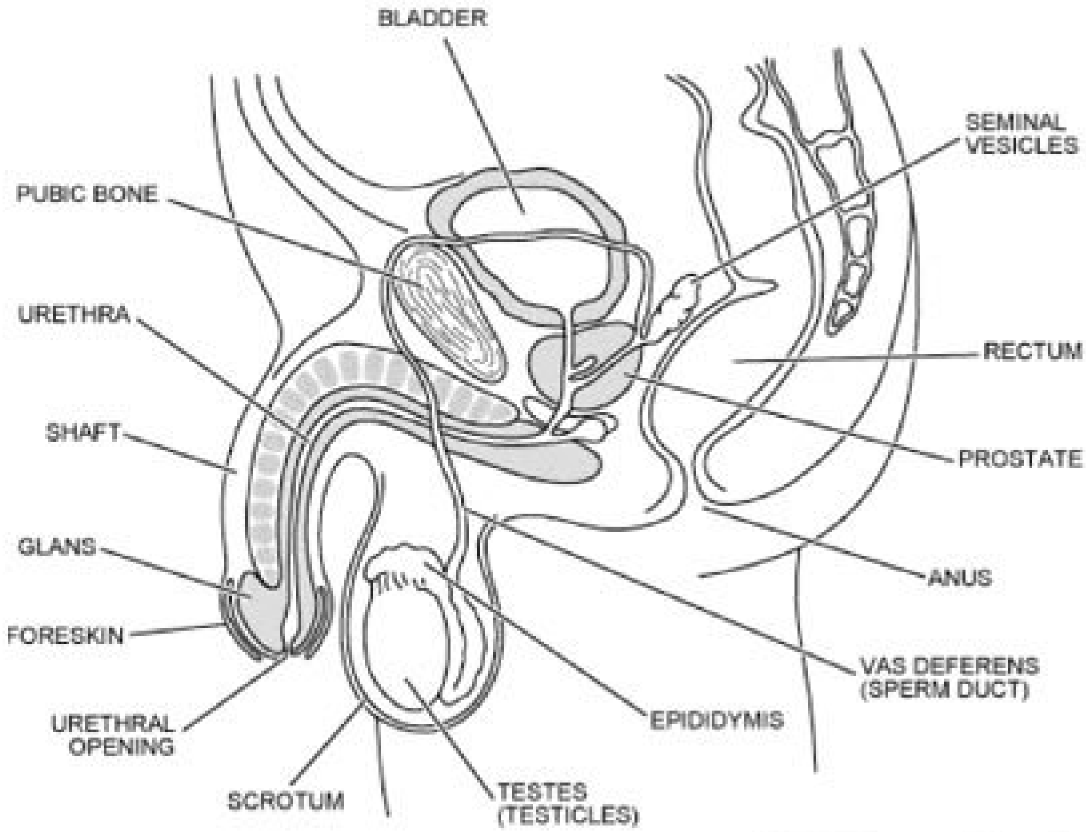
After studying this section you should be able to:
Describe the structure and function of the testes in scrotum
Outline the atructure and function of the spermatic cords
Explain the process of e Jaculation
List the main changes occurring at puberty in the male

Introduction:

The male reproductive system is located in the pelvis region (Figure 1). It includes a pair of **testes** along with **accessory ducts, glands** and the **external genitalia** The testes are situated outside the abdominal cavity within a pouch called **scrotum**. The scrotum helps in maintaining the low temperature of the testes (2–2.5 o C lower than the normal internal body temperature) necessary for spermatogenesis. In adults, each testis is oval in shape, with a length of about 4 to 5 cm and a width of about 2 to 3 cm. The testis is covered by a dense covering. Each testis has about 250 compartments called **testicular lobules**. Each lobule contains one to three highly coiled **seminiferous tubules** in which sperms are produced. Each seminiferous tubule is lined on its inside by two types of cells called **male germ cells** (*spermatogonia*) and **Sertoli cells** (Figur 1). The male germ cells undergo meiotic divisions finally leading to sperm formation, while Sertoli cells provide nutrition to the germ cells. The regions outside the seminiferous tubules called interstitial spaces, contain small blood vessels and **interstitial cells** or **Leydig cells**. Leydig cells synthesis and secrete testicular hormones called androgens. Other immunologically competent cells are also present.

The male sex accessory ducts include **rete testis, vasa efferentia**, **epididymis** and **vas deferens** (Figure 3.1b). The seminiferous tubules of the testis open into the vasa efferentia through rete testis. The vasa efferentia leave the testis and open into epididymis located along the posterior surface of each testis. The epididymis leads to vas deferens that ascends to the abdomen and loops over the urinary bladder. It receives a duct from seminal vesicle and opens into urethra as the ejaculatory duct. These ducts store and transport the sperms from the testis to the outside through urethra. The urethra originates from the urinary bladder and extends through the penis to its external opening called **urethral meatus**.

The penis is the male external genitalia. It is made up of special tissue that helps in erection of the penis to facilitate insemination. The enlarged end of penis called the glans penis is covered by a loose fold of skin called **foreskin**. The male accessory glands include paired **seminal vesicles**, a **prostate** and paired **bulbourethral** glands. Secretions of these glands constitute the seminal plasma which is rich in fructose, calcium and certain enzymes. The secretions of bulbourethral glands also help in the lubrication of the penis.



FUNCTION OF THE MALE REPRODUCTIVE SYSTEM

1.Main Reproductive Functions

i) spermatogenesis (formation of male gametes in the form of sperm)
— exocrine function (release of newly formed sperm into specialized ducts)
— combining of sperm with supporting fluid to form semen
ii) performance of the male sexual act
— delivery of sperm contained within semen into the female reproductive tract in a location which allows them to access the mature ova
— this is an integrative function in that it integrates endocrinological, physiological, and behavioural systems
iii) hormone regulation of reproductive functions
— endocrine function (release of substances into body: not into ducts)

— production and release of the following hormones: gonadotropin releasing hormone (GnRH),
follicle-stimulating hormone (FSH), luteinizing hormone (LH), interstitial cell-stimulating hormone (similar to LH), testosterone inhibin.

2. Non-Reproductive Functions

i) control of accessory sex organs through hormonal production and release
ii) effects on growth and metabolism of the body (again, through hormonal production and release)

Spermatogenesis is the formation of sperm.
Sertoli cells & spermatocytes (developing sperm cells)
— Sperm cells originate in the epithelial layers of the tubules and develop and migrate inwards along Sertoli cells towards the lumen of the tubule.
— The process of spermatogenesis begins in puberty.

1. Infant males are born with **spermatogonia**, which are diploid sex cells.
2. Once the male reaches puberty the spermatogonia undergo mitosis and give rise to **primary spermatocytes**.
3. The primary spermatocytes go through the first meiotic division to produce two **secondary spermatocytes**.
4. The second meiotic division of the secondary spermatocytes produces four **spermatids**.
5. The spermatids go through **spermiogenesis** in order to develop a head and tail.
6. The spermatids differentiate into **spermatozoa**, the mature male sex cell.

— the process of formation of mature sperm from spermatogonium takes 74 days (average)
— the continuous process producing up to 120 million spermatozoa per day

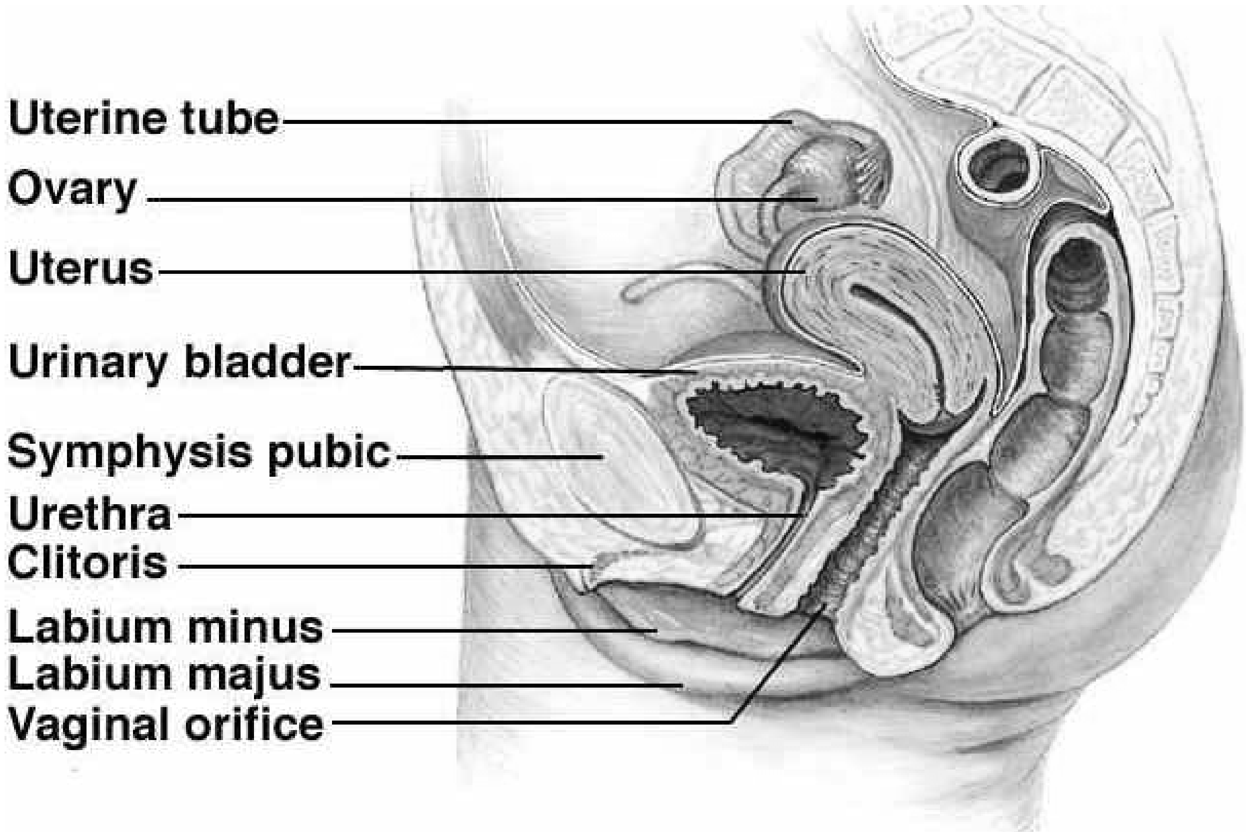
15.2 FEMALE REPRODUCTIVE SYSTEM

Learning out come

After studying this section you should be able to:
Describe the main structures comprising the external genitalia
Discuss the process of ovulation and hormones that control it
Describe the structure and function of the female brest
Outline the changes that occur in the female at puberty,including the physiology of menstruation

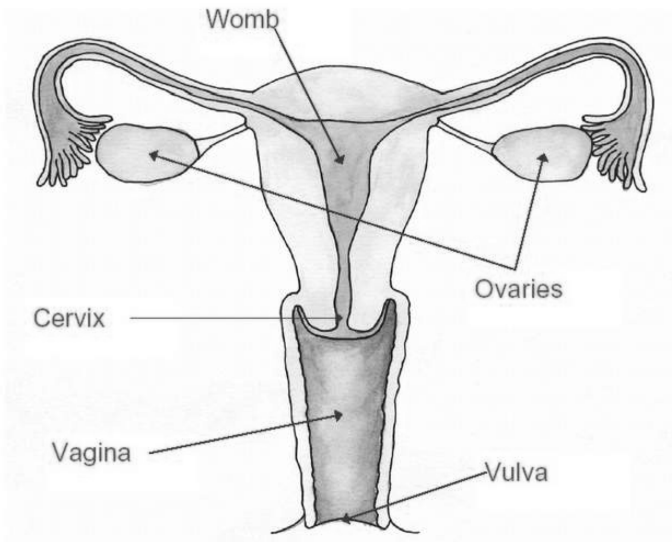
Introduction:

The female reproductive system consists of a pair of **ovaries** along with a pair of **oviducts, uterus, cervix, vagina** and the **external genitalia** located in pelvic region (figure 2)These parts of the system along with a pair of the **mammary glands** are integrated structurally and functionally to support the processes of ovulation, fertilisation, pregnancy, birth and child care.



Ovaries are the primary female sex organs that produce the female gamete (ovum) and several steroid hormones (ovarian hormones). The ovaries are located one on each side of the lower abdomen (Figure 3). Each ovary is about 2 to 4 cm in length and is connected to the pelvic wall and uterus by ligaments. Each ovary is covered by a thin epithelium which encloses the ovarian stroma. The stroma is divided into two zones – a peripheral cortex and an inner medulla.

The oviducts (fallopian tubes), uterus and vagina constitute the female accessory ducts. Each fallopian tube is about 10-12 cm long and extends from the periphery of each ovary to the uterus, the part closer to the ovary is the funnel-shaped **infundibulum**. The edges of the infundibulum possess finger-like projections called **fimbriae**, which help in collection of the ovum after ovulation. The infundibulum leads to a wider part of the oviduct called **ampulla**. The last part of the oviduct, **isthmus** has a narrow lumen and it joins the uterus.



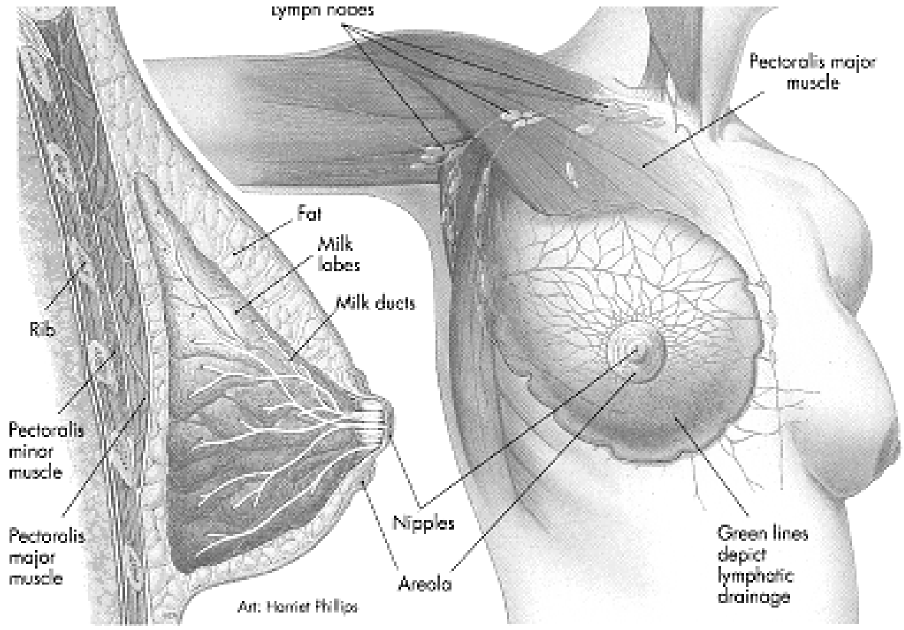
The uterus is single and it is also called **womb**. The shape of the uterus is like an inverted pear. It is supported by ligaments attached to the pelvic wall. The uterus opens into vagina through a narrow cervix. The cavity of the cervix is called **cervical canal,** which along with vagina forms the birth canal. The wall of the uterus has three layers of tissue. The external thin membranous **perimetrium,** middle thick layer of smooth muscle, **myometrium** and inner glandular layer called **endometrium** that lines the uterine cavity. The endometrium undergoes cyclical changes during menstrual cycle while the myometrium exhibits strong contraction during delivery of the baby.

The female external genitalia include mons pubis, labia majora, labia minora, hymen and clitoris (Figure 2). **Mons pubis** is a cushion of fatty tissue covered by skin and pubic hair. The **labia majora** are fleshy folds of tissue, which extend down from the mons pubis and surround the vaginal opening. The **labia minora** are paired folds of tissue under the labia majora. The opening of the vagina is often covered partially by a membrane called **hymen**. The **clitoris** is a tiny finger-like structure which lies at the upper junction of the two labia minora above the urethral opening. The hymen is often torn during the first coitus (intercourse). it can also be broken

- by a sudden fall or jolt,
- insertion of a vaginal tampon,
- active participation in some sports like horseback riding, cycling, etc.

In some women the hymen persists even after coitus. In fact, the presence or absence of hymen is not a reliable indicator of virginity or sexual experience.
A functional mammary gland is characteristic of all female mammals. The mammary glands are paired structures (breasts) that contain glandular tissue and variable amount of fat. The glandular tissue of each breast is divided into 15-20 **mammary lobes** containing clusters of cells called alveoli (Figure 4). The cells of alveoli secrete milk, which is stored in the cavities (lumens) of

alveoli. The alveoli open into mammary tubules. The tubules of each lobe join to form a **mammary duct**. Several mammary ducts join to form a wider mammary ampulla which is connected to **lactiferous duct** through which milk is sucked out.

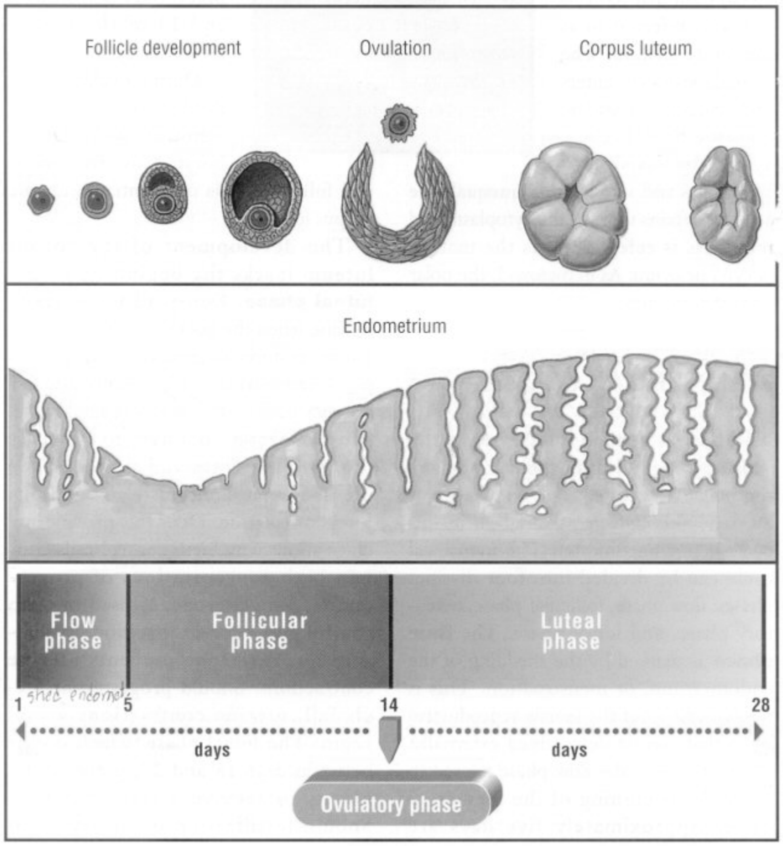


Oogenesis:

The process of formation of a mature female gamete is called **oogenesis** which is markedly different from spermatogenesis. Oogenesis is initiated during the embryonic development stage when a couple of million gamete mother cells (**oogonia**) are formed within each fetal ovary; no more oogonia are formed and added after birth. These cells start division and enter into prophase-I of the meiotic division and get temporarily arrested at that stage, called **primary oocytes**. Each primary oocyte then gets surrounded by a layer of granulosa cells and then called the **primary follicle .**A large number of these follicles degenerate during the phase from birth to puberty. Therefore, at puberty only 60,000-80,000 primary follicles are left in each ovary. The primary follicles get surrounded by more layers of granulosa cells and a new theca and called **secondary follicles**. The secondary follicle soon transforms into a tertiary follicle which is characterised by a fluid filled cavity called **antrum**. The theca layer is organised into an inner theca interna and an outer theca externa.. The secondary oocyte retains bulk of the nutrient rich cytoplasm of the primary oocyte. The tertiary follicle further changes into the mature follicle or **Graafian follicle** The secondary oocyte forms a new membrane called **zona pellucid** surrounding it. The Graafian follicle now ruptures to release the secondary oocyte (ovum) from the ovary by the process called **ovulation**.

MENSTRUAL CYCLE:

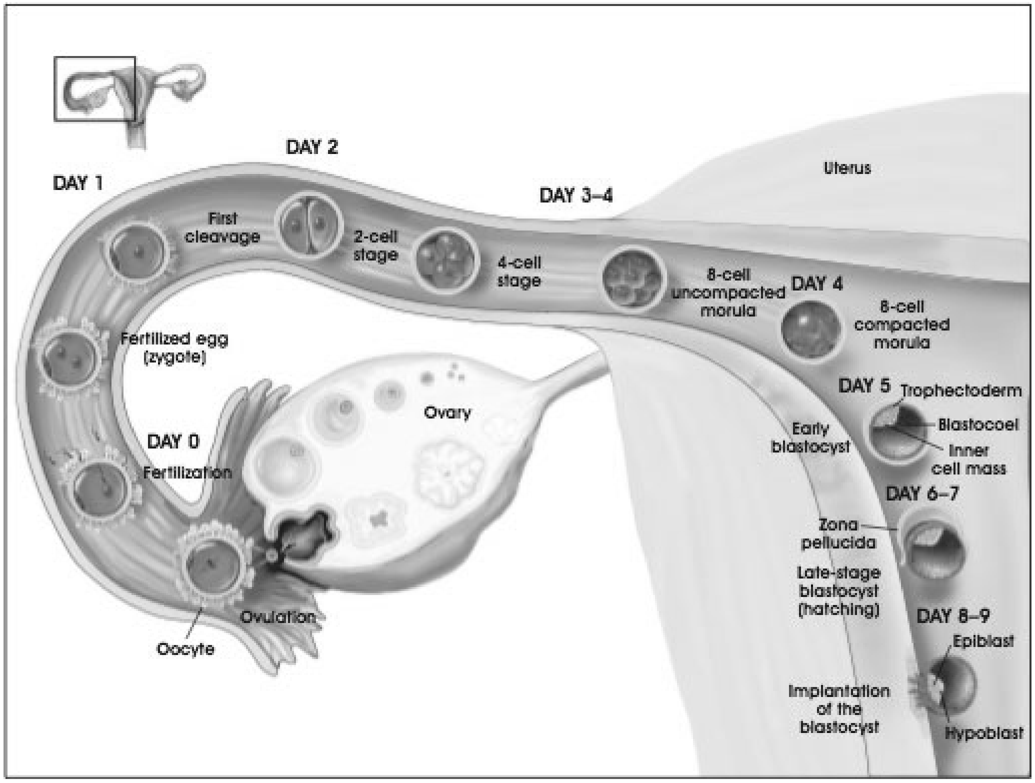
The reproductive cycle in the female primates is called menstrual cycle. The first menstruation begins at puberty and is called **menarche**. In human females, menstruation is repeated at an average interval of about 28/29 days, and the cycle of events starting from one menstruation till the next one is called the **menstrual cycle**. One ovum is released (ovulation) during the middle of each menstrual cycle. The major events of the menstrual cycle are shown in Figure. The cycle starts with the menstrual phase, when menstrual flow occurs and it lasts for 3-5 days. The menstrual flow results due to breakdown of endometrial lining of the uterus and its blood vessels which forms liquid that comes out through vagina. Menstruation only occurs if the released ouvm is not fertilised. Lack of menstruation may be indicative of pregnancy. However, it may also be caused due to some other underlying causes like stress, poor health etc. The menstrual phase is followed by the follicular phase. During this phase, the primary follicles in the ovary grow to become a fully mature Graafian follicle and simultaneously the endometrium of uterus regenerates through proliferation. These changes in the ovary and the uterus are induced by changes in the levels of pituitary and ovarian hormones (Figure). The secretion of gonadotropins (LH and FSH) increases gradually during the follicular phase, and stimulates follicular development as well as secretion of estrogens by the growing follicles. Both LH and FSH attain a peak level in the middle of cycle (about 14th day). Rapid secretion of LH leading to its maximum level during the mid-cycle called LH surge induces rupture of Graafian follicle and thereby the release of ovum (**ovulation**).



The ovulation (ovulatory phase) is followed by the luteal phase during which the remaining parts of the Graafian follicle transform as the **corpus luteum** (Figure 3.9). The corpus luteum secretes large amounts of progesterone which is essential for maintenance of the endometrium. Such an endometrium is necessary for implantation of the fertilized ovum and other events of pregnancy. During pregnanacy all events of the menstrual cycle stop and there is no menstruation. In the absence of fertilisation, the corpus luteum degenerates. This causes disintegration of the endometrium leading to menstruation, marking a new cycle. In human beings, menstrual cycles ceases around 50 years of age; that is termed as **menopause**. Cyclic menstruation is an indicator of normal reproductive phase and extends between menarche and menopause.

FERTILISATION AND IMPLANTATION

During copulation (coitus) semen is released by the penis into the vagina (insemination). The motile sperms swim rapidly, pass through the cervix, enter into the uterus and finally reach the junction of the isthmus and ampulla (ampullary-isthmic junction) of the fallopian tube (Figure). The ovum released by the ovary is also transported to the ampullary-isthmic junction where fertilisation takes place. Fertilisation can only occur if the ovum and sperms are transported simultaneously to the ampullaryisthmic junction. This is the reason why not all copulations lead to fertilisation and pregnancy. The process of fusion of a sperm with an ovum is called **fertilisation**.During fertilisation, a sperm comes in contact with the *zona pellucida* layer of the ovum (Figure) and induces changes in the membrane that block the entry of additional sperms. Thus, it ensures that only one sperm can fertilise an ovum. The secretions of the acrosome help the sperm enter into the cytoplasm of the ovum through the zona pellucida and the plasma membrane. This induces the completion of the meiotic division of the secondary oocyte. The second meiotic division is also unequal and results in the formation of a **second polar body** and a haploid ovum (ootid). Soonthe haploid nucleus of the sperms and that of the ovum fuse together to form a diploid **zygote**. *How many chromosomes will be there in the zygote?* One has to remember that the sex of the baby has been decided at this stage itself. Let us see how? As you know the chromosome pattern in the human female is XX and that in the male is XY. Therefore, all the haploid gametes produced by the female (ova) have the sex chromosome X whereas in the male gametes (sperms) the sex chromosome could be either X or Y, hence, 50 per cent of sperms carry the X chromosome while the other 50 per cent carry the Y. After fusion of the male and female gametes the zygote would carry either XX or XY depending on whether the sperm carrying X or Y fertilised the ovum. The zygote carrying XX would develop into a female baby and XY would form a male (you will learn more about the chromosomal patterns in Chapter 5). *That is why, scientifically it is correct to say that the sex of the baby is determined by the father and not by the mother!* The mitotic division starts as the zygote moves through the isthmus of the oviduct called **cleavage** towards the uterus (Figure) and forms 2, 4, 8, 16 daughter cells called **blastomeres**. The embryo with 8 to 16 blastomeres is called a morula (Figure). The morula continues to divide and transforms into blastocyst (Figure) as it moves further into the uterus. The blastomeres in the blastocyst are arranged into an outer layer called **trophoblast** and an inner group of cells attached to trophoblast called the **inner cell** mass. The trophoblast layer then gets attached to the endometrium and the inner cell mass gets differentiated as the embryo. After attachment, the uterine cells divide rapidly and covers the blastocyst. As a result, the blastocyst becomes embedded in the endometrium of the uterus (Figure). This is called **implantation** and it leads to pregnancy.



PREGNANCY AND EMBRYONIC DEVELOPMENT

After implantation, finger-like projections appear on the trophoblast called **chorionic villi** which are surrounded by the uterine tissue and maternal blood. The chorionic villi and uterine tissue become interdigitated with each other and jointly form a structural and functional unit between developing embryo (foetus) and maternal body called **placenta** (Figure). The placenta facilitate the supply of oxygen and nutrients to the embryo and also removal of carbon dioxide and excretory/waste materials produced by the embryo. The placenta is connected to the embryo through an umbilical cord which helps in the transport of substances to and from the embryo. Placenta also acts as an endocrine tissue and produces several hormones like **human chorionic gonadotropin** (hCG), **human placental lactogen** (hPL), **estrogens, progestogens,** etc. In the later phase of pregnancy, a hormone called **relaxin** is also secreted by the ovary. Let us remember that hCG, hPL and relaxin are produced in women only during pregnancy. In addition, during pregnancy the levels of other hormones like estrogens, progestogens, cortisol, prolactin, thyroxine, etc., are increased severalfolds in the maternal blood. Increased production of these hormones is essential for supporting the fetal growth, metabolic changes in the mother and maintenance of pregnancy. Immediately after implantation, the inner cell mass (embryo) differentiates into an outer layer called **ectoderm** and an inner layer called **endoderm**. A **mesoderm** soon appears between the ectoderm and the endoderm. These three layers give rise to all tissues (organs) in adults. It needs to be mentioned here that the inner cell mass contains certain cells called **stem** cells which have the potency to give rise to all the tissues and organs.

The human pregnancy lasts 9 months. In human beings, after one month of pregnancy, the embryo's heart is formed. The first sign of growing foetus may be noticed by listening to the heart sound carefully through the stethoscope. By the end of the second month of pregnancy, the foetus develops limbs and digits. By the end of 12 weeks (first trimester), most of the major organ systems are formed, for example, the limbs and external genital organs are well-developed. The first movements of the foetus and appearance of hair on the head are usually observed during the fifth month. By the end of 24 weeks (second trimester), the body is covered with fine hair, eye-lids separate, and eyelashes are formed. By the end of nine months of pregnancy, the foetus is fully developed and is ready for delivery.

PARTURITION AND LACTATION

The average duration of human pregnancy is about 9 months which is called the gestation period. Vigorous contraction of the uterus at the end of pregnancy causes expulsion/delivery of the foetus. This process of delivery of the foetus (childbirth) is called **parturition**. Parturition is induced by a complex neuroendocrine mechanism. The signals for parturition originate from the fully developed fetus and the placenta which induce mild uterine contractions called **foetal ejection reflex.** This triggers release of oxytocin from the maternal pituitary. Oxytocin acts on the uterine muscle and causes stronger uterine contractions, which in turn stimulates further secretion of oxytocin. The stimulatory reflex between the uterine contraction and oxytocin secretion continues resulting in stronger and stronger contractions. This leads to expulsion of the baby out of the uterus through the birth canal – parturition. Soon after the infant is delivered, the placenta is also expelled out of the uterus. The mammary glands of the female undergo differentiation during pregnancy and starts producing milk towards the end of pregnancy by the process called **lactation**. This helps the mother in feeding the newborn. The milk produced during the initial few days of lactation is called **colostrum** which contains several antibodies absolutely essential to develop resistance for the new-born babies. Breast-feeding during the initial period of infant growth is recommended by doctors for bringing up a healthy baby.

15.3 Summary

- The gonads (testes and ovaries) produce gametes (sperm and eggs) as well as sex hormones. The male sex hormone is testosterone and the female sex hormones are estrogen and progesterone.
- The male reproductive strategy is to produce millions of sperm and deliver them to the female. On the other hand, the female usually produces only one mature egg per month and is responsible for nourishing and protecting the developing embryo and later fetus.

- The male reproductive system consists of the testes, held outside the body in the scrotum, a series of ducts (the epididymis, vas deferens, and urethra), accessory glands (the prostate gland, seminal vesicles, and bulbourethral glands), and the penis.
- The development of sperm, spermatogenesis, occurs continually in the seminiferous tubules of the testis. They are stored and mature in the epididymis and leave the body through the vas deferens and urethra during ejaculation.
- Semen is produced by the accessory glands neutralizing the passageway of the sperm, providing them with an energy source and causing uterine contractions.
- Male reproductive processes are regulated by a negative feedback loop involving FSH and LH from the anterior pituitary gland, GnRH from the hypothalamus, and testosterone and inhibin from the testis.
- The female reproductive system consists of the ovaries that produce eggs and the female hormones, estrogen and progesterone, the oviducts, uterus, which supports implantation of and the development of the embryo, vagina, and external genitalia.
- In women, the mammary glands produce milk.
- The ovarian cycle involves egg production that began during fetal development of the woman and ovulation that usually releases one egg each month from puberty until menopause.
- Hormones that regulate the ovarian and uterine cycles involve a negative feedback loop of FSH, estrogen, LH, and progesterone. If fertilization occurs, the young embryo produces HCG which can be detected by pregnancy tests and which maintains the corpus luteum.
- At menopause, both the uterine and ovarian cycles stop resulting in a drop in progesterone and estrogen levels.
- Possible problems with the female reproductive system include premenstrual syndrome, menstrual cramps, endometriosis, vaginitis, and pelvic inflammatory disease.
- The human sexual response is the sequence of events occurring during sexual intercourse including excitement (period of increased arousal), plateau (continued arousal), orgasm (climax and ejaculation), and resolution (the return to normal functioning).

Self assessment questions:

1. Explain gametogenesis in female.
2. List the secondary sexual characters in male and females.
3. What is ovulation?explain its hormonal control.
4. Write briefly about corpous luteum.
5. Discuss the physiological changes during pregnancy.
6. Mention the primary organs of sex in males and females.
7. list the functions of oestrogen and progesterone.
8. What are the stages of pregnancy.