Dr.P.B.Reddy's TEXT BOOK OF ANIMAL PHYSIOLOGY

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Dr.P.B.Reddy's

TEXT BOOK
OF
ANIMAL PHYSIOLOGY

(For Indian Universities)

ISBN : 978-93-84124-37-3

By

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Dedicated to
My Wife and Children
Apoorva and Aman

Dr.P.B.Reddy's
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FOREWORD

The promise of the recent trends in biological research is to understand the integrated function of animals and human biological systems in order to improving health of human being. The study of animal physiology is recently stimulated by the development of medical sciences as it holds many chemical and physical principles. Since the discovery of the cell structure and tissues, the science of physiology has undergone rapid development. It includes the study of vital activities in cells, tissues and organ processes such as, contractility of muscle tissue, coordination through nervous system, feeding, digestion, respiration, circulation, reproduction and hormone secretion. Virtually, every specialized field in the biological functions involves some consideration of the physiological aspect.

Making a wonderful book in Animal Physiology more relevant and even more appealing in the Indian context is challenge and of course, an opportunity.

I was glad when I heard that Dr.P.B.Reddy was going to turn his attention to accept this challenge and to write a book on animal physiology.

This is a book for all Zoologists and medical students who are passionate to study of the normal functioning of animals and human body organs during life and of the actions by which life is maintained and transmitted.

This text book is not for a casual reader. Dr.P.B.Reddy will take you in fascinating journey. This book is carefully written and explored the various physiological processes in human and compared with other animal groups. More light is focused on human physiology and medicine. I hope biologist including medical students take the time to discover or appreciate the hard work of Dr. Reddy.

Although some will read the book cover to cover (not at one sitting), while others may found as reference book as it covered the broad array of topics with suitable diagrams and tables at suitable place.

Finally I would like to say that 'Some books are to be tasted, others are swallowed and some few to be chewed and digested' (Francis Bacon). A part from the tasting, swallowing, chewing and digesting, the contents of this book can be absorbed and assimilated with delight. I am sure that the book would be welcomed by one and all.

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PREFACE

In my 25 years as a teacher, I have always enjoyed teaching Physiology. It was because of my love for the subject and constant inspiration from my students that I could come up with 'Text Book of Physiology. This book attempts to summarize the current state of knowledge about the functional organization of the human body and compared with other animals. I have devoted every bit of mine in presenting this book in line with the curriculum of Indian Universities. This text book meant to set a new standard for animal physiology books with its focus on animal diversity. The book also includes the most up-to-date research on various branches of animal physiology, methods and models, with vertebrate and invertebrate examples. I have tried my very best by putting onwards my experience as a teacher in this book.

Few important features of this text book are;

1. It provides basic principles of physiology in a simple and easy language.
2. Well labeled diagrams, graphs, flowcharts and tables have been incorporated.
3. Important terms and matter has been highlighted by using bold letters.
4. Recent updated developments in the subject have been included.
5. The text in this book has been presented in a manner that student can attempt either objective or essay type questions easily.
6. Clinical aspects of related topics were discussed which may be even useful for medical students.

I am thankful to Dr.G.R.Gangle and Dr.R.K.Gujetiya who inspired me to initiate this project. I express my sincere thanks and deep appreciation to all my colleagues in the Govt.P G college, Ratlam, M.P. Special thanks are due to Dr. Milind Dange, Head, Department of Zoology who kindly spared me from

all departmental activities, thus enabling me to complete this project. I extend my heartfelt thanks to Prof. Aayaz Siddique, Prof. Alka Kulshrestha, and Prof..Shehela Ishaque for their suggestions time to time. I am grateful to Dr.D.B.Ratnakar of M/s IMRF publications, Vijayawada, A.P.India for making all efforts in bringing out this text book promptly and in an excellent form.

In spite of great care taken by me and publisher team, some errors may have escaped from our notice. We shall appreciate if such errors are brought to our notice. There will be always being some scope for further improvement. I will request all the readers to evaluate the material and offer their valuable suggestions.

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INTRODUCTION

It is always interesting and surprising that how the different components of living organisms adjust to maintain a constant internal environment. It is the basic concern of physiology and known as homeostasis. Physiology is the subdivision of biology that deals with the various functions of living organisms. This scientific branch covers a big diversity of functions, ranging from the cellular and the interaction of organ systems which maintain for the smooth running of the highly complex biological mechanisms. The branch mainly concerned with the differences in the vital processes in different species of organisms, particularly with a view to the adaptation of the processes to the specific needs of the species, to revealing the evolutionary relationships among different species.

Animal (or mammalian) physiology is the oldest branch of this science. It dates back to at least 420 B.C. and the time of Hippocrates, the father of medicine. Modern physiology first appeared in the seventeenth century when scientific methods of observation and experimentation were used to study the circulation of blood in the body. In 1929, American physiologist W. B. Cannon coined the term homeostasis to describe one of the most basic concerns of physiology: The advancement of recent technological progress, ranging from the simple microscope to ultra-high-technology computerized scanning devices, contributed to the growth of physiology. No longer confined to investigating the functioning components of life that could be observed with

the naked eye, physiologists began to investigate into the most basic life forms, like bacteria. They could also study organisms' basic molecular functions, such as the electrical potentials in cells that help control heart beat.

Like cell biology, many branches of physiology are better known by other names, including biochemistry, biophysics, functional biology and endocrinology. Scientists also observe and investigate how certain body systems, like the circulatory, respiratory, and nervous systems, work independently and together to maintain life. Ecological physiology, on the other hand, reveals how animals developed or evolved specific biological mechanisms to cope with a particular environment. An example is the quality of dark skin, which provides protection against harmful rays of the Sun for humans who live in tropical climates. Cellular physiology, or cell biology, focuses on the structures and functions of the cell. Animal physiology cannot be studied in isolation, as physiological processes are controlled by signaling molecules and responses flow down at cellular, biochemical and molecular levels. Behavior also affects physiology of the organism. Physiology is a branch of science that explores the similarities and differences between living things and how they function. Comparative physiology is another branch of physiology which reveals the functional processes of different living organisms. The discipline itself incorporates many divergent scientific fields, including evolution, environmental studies, and archaeology.

Hence a combination of need and curiosity gave rise to comparative physiology. Physicians needed new ways to treat human patients, so animals that shared many characteristics with humans were a ripe area for research. Ultimately the practical use for comparisons flourished into an overall scientific curiosity concerning the likenesses and divergences among various animal species. Comparative physiologists study and compare a wide range of functions in organisms. Almost any part of an organism's body serves some important use, and nearly all living organisms share basic needs like food, breathing, internal temperature control, and heart sustenance. By studying the processes that drive these needs such as cell-based exchanges and blood circulation researchers can gather a vast amount of comparative information. Proper comparisons can only be achieved when the scientist understands how each organism's physical body allows it to carry out the actions essential for day-to-day living. The physiological component of comparative physiology

may therefore range from studying how organisms use limbs or other appendages to move to how organisms breathe.

Another important aspect of comparative physiology is the relationship between organisms and their environment, or ecophysiology. The same physical setting may exercise very different effects on divergent organisms. A fish, for example, will have a much bleaker outcome in a desert environment than in its home habitat of water. In contrast, a land-dwelling lizard acclimated to harsher climates would be ill-equipped to deal with an aquatic setting due to its anatomical makeup. As such, ecophysiology and its study of aspects of adaptation can offer enhanced understanding of all animal groups in comparative physiology.

One particular area of comparative physiology has received increased attention over time: the use of phylogenic comparative methods. Scientists utilize these methods to examine potential evolutionary relationships between diverse living organisms and to document any significant changes a particular animal group may have undergone since its inception. Researchers may study the physical resemblances between certain organisms or how certain organisms have developed similar functional parts, like lungs or gills for breathing purposes. As a result, the study may uncover common ancestors among different species and solidify an evolutionary link. Examination of fossil remains and other archaeological evidence may also help comparative physiologists understand how an animal group has changed and adapted from ancient times until the present era.

CHAPTER 1
CELLULAR PHYSIOLOGY AND HOMEOSTASIS

Definitions and Features:

- The concept of homeostasis was explained by Claude Bernard in 1865
- The term Homeostasis was obtained from Greek (*homoios*,= similar and *stasis* = standing still
- The word homeostasis was coined by Walter Bradford Cannon in 1926
- The tendency of all living organisms or cell to adjust its internal conditions, such as the chemical composition of its body fluids, so as to maintain health and functioning, regardless of external conditions.
  The maintenance of a stable body temperature in homeotherms is an example of homeostasis.
- Its regulation involves a receptor, a stimulus and an effector

Introduction

Physiology is the study of how the body functions. Cause and effect occurrences are the focus of physiology. Our bodies are kept internally balanced even though our outward atmosphere is always changing. This process of constancy is known as homeostasis. All living organisms depend on maintaining a complex set of interacting metabolic chemical reactions. From the simplest unicellular organisms to the most complex organisms, internal processes operate to keep the conditions within fixed limits to permit these reactions to proceed. Homeostatic processes act at the level of the cell, the tissue, and the organ, as well as for the organism as a whole. Hormones, negative and positive feedback loops, the nervous and endocrine systems all

help to maintain that balance. There are four different types of tissues in the human body. Each tissue is built for a specific function within the body.
Examples:

1. Maintaince of constant body temperature in warm blooded animals
2. Regulation of constant pH of Blood
3. Regulation of glucose level in mammals including man
4. Regulation of water balance in the body
5. Sleeping times

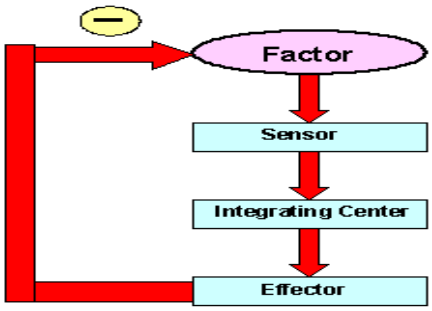
Regulation

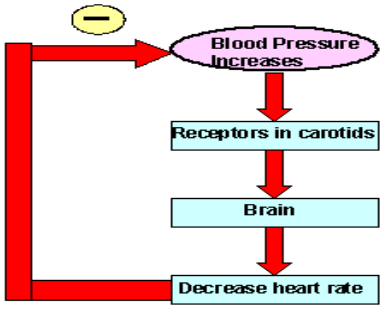
It requires three interdependent components namely a receptor, a stimulus and an effector. The receptor is the sensing component that checks and responds to changes in the environment. When the receptor senses a stimulus, it sends information to a control center. The control center determines an appropriate response to the stimulus. The control center then sends signals to an effector, which can be muscles, organs, or other structures that receive signals from the control center. After receiving the signal, a change occurs to correct the difference by depressing it with negative feedback.

Negative Feedback mechanisms

Most of biological systems, qualitatively different influences can oppose each other. It is the most common and correct method of homeostasis. It consists of reducing the production or activity of any organ or system back to its normal range of functioning. It involves an action that directly opposes a variation from normal limits. An increase or decrease in the variable (ex. blood pressure) causes responses that tend to push the variable in opposite direction (negative)

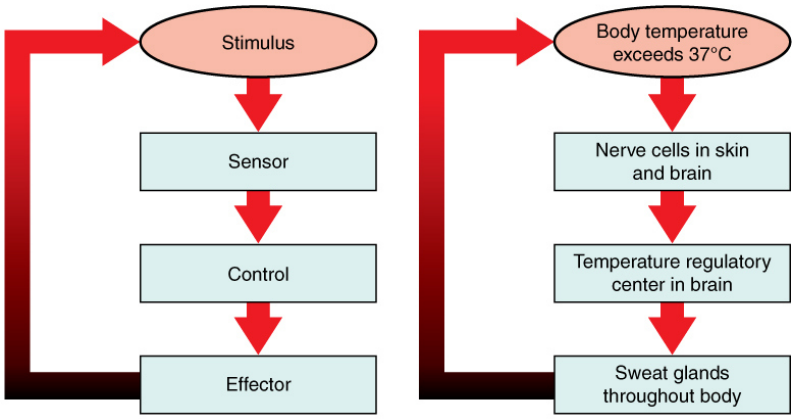
Example1: regulation of blood pressure





Here blood vessels act as the receptors and they communicate this message to the brain. The brain then sends a message to the effectors like heart and blood vessels. The heart rate would decrease as the blood vessels increase in diameter (known as vasodilatation) and opposite would happen when blood pressure decreases by vasoconstriction. These changes would cause the blood pressure to fall back to its normal range.

Example2. Body temperature Control



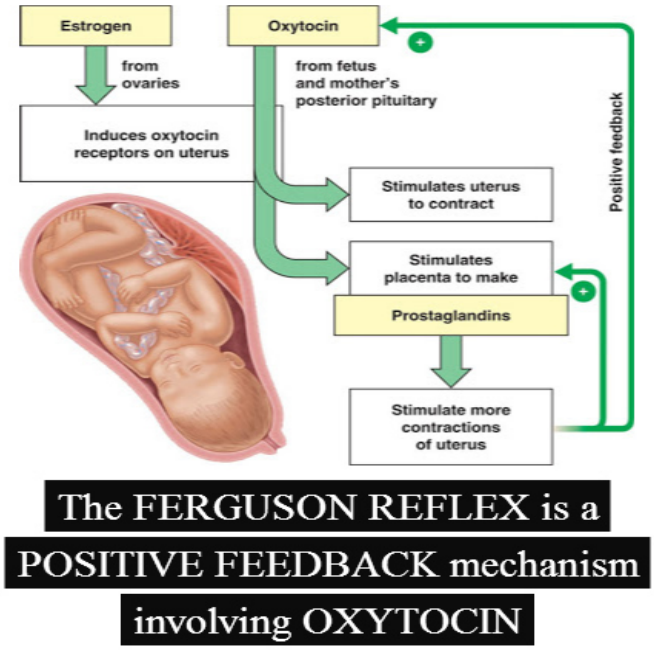
(a) Negative feedback loop (b) Body temperature regulation

The endocrine system releases hormones. Thermo regulatory centre is present in hypothalamus. Even the small variation of normal body temperature brings changes in its function like stimulation of sweat glands that produce more sweat to reduce the temperature or signaling different muscles to shiver to increase body temperature. Both feedbacks are equally important for the healthy functioning of one's body. Complications can arise if any of the two feedbacks are affected or altered in any way.

Positive Mechanisms

Positive feedback is a process in which the body senses a change and activates mechanisms that accelerate or increase that change. This can also aid homeostasis, but in many cases it produces the opposite effect and can be life threatening. It is rarely used by body.

Examples; .Child birth and blood clotting



During child birth the pituitary secretion of oxytocin increase to keep the contractions of uterus as long as needed for the child's birth and the secretion of pituitary is increased by positive feedback, increasing the strength of the contractions.

Homeostatic imbalance

- Many diseases involve a disturbance of homeostasis
- Ageing also causes disturbances in homeostasis. As the organism ages, the efficiency in its control systems becomes reduced. The inefficiencies gradually result in an unstable internal environment that increases the risk of illness, and leads to the physical changes associated with aging
- High core temperature, a high concentration of salt in the blood, or low concentration of oxygen, can produce homeostatic emotions (such as warmth, thirst, or breathlessness), which motivate behavior aimed at restoring homeostasis (such as removing a sweater, drinking or slowing down)

Conclusions

Homeostasis is a concept used throughout this book to explain how the internal environment is maintained at a level favorable to healthy functioning within the body compartments. Homeostatic control depends mainly upon negative feedback mechanisms that act to reverse instability and regulate parameters close to their best possible values. Prevention of parameter variation can be harmful under some circumstances. The promotion of change via positive feedback mechanisms, or through resetting of homeostatic set points, is then of benefit.

Failure of negative feedback processes, appropriate positive feedback responses, or set point resetting or a reduction in their efficiency, leads to homeostatic imbalance marked illness. Homeostasis based on nature nurture interactions therefore provides a working framework for health and health care. Healthcare processes involving assessment, diagnosis, planning, implementing care and reassessment of care are analogous with the natural components of homeostasis and as such are concerned largely with supplementing normal anatomical, biochemical and hence physiological processes in order to restore the homeostatic status (where possible) for the patient.

Further Reading

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CHAPTER 2
BODY WATER AND BODY FLUIDS

Introduction

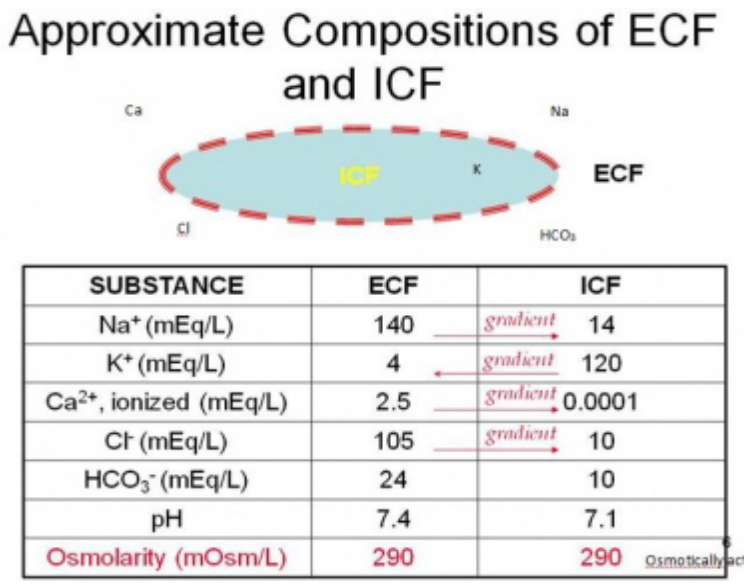
- Water is a universal medium for various biochemical reactions. It is also medium for transportation of nutrients and excretion. It is a helps in heat control, as a lubricant for joints; and for shock absorption.
- In physiology, it is the water that is present in the tissues, the blood, the bones, or somewhere else is known as body water. Not to be confused with Body of water.
- Body water makes up a significant portion of the animal body, both by weight and by volume.
- Water may enter into the body either by drinking or with food. Some amount of this water is retained in animals to perform numerous functions.
- In general it forms 65-75% of the total body weight. However, sometimes it may vary with age, sex and illness.
- The percentage water in the body is regulated by hormones (ADH, aldosterone, angiotensinogen).
- The loss of the body water part of body fluid is specifically termed dehydration.
- Na^+ has a much higher concentration in ECF than intracellular fluid (ICF). In contrast, K^+ has a much higher concentration in ICF than ECF. Therefore, Na^+ loss approximately correlates with fluid loss from extracellular

fluid (ECF) while loss of K^+ correlates with fluid loss from ICF. The water loss may take place by either diffusion or osmosis.

Compartmentalization of body water

According to Netter's Atlas of Human Physiology, body water is divided into the following compartments.

- **Extra cellular fluid (ECF**): It is present in the spaces outside the cell. Extracellular fluid forms 1/3 of body water or 30-35% of body water. Ex. plasma, interestial fluid, Transcellular fluid . Plasma forms 1/5 of extracellular fluid or 20% of body water. Interstitial fluid forms 4/5 of extracellular fluid. Transcellular fluid forms third space and usually ignored in calculations. It is present in inside organs, such as the gastrointestinal, cerebrospinal, peritoneal, and ocular fluids.
- **Intracellular fluid (ICF):** Also known as tissue fluid**.** It is larger in volume and forms 2/3 of body water or 60-70% of body water. Interstitial fluid (or tissue fluid) is a solution that dips and surrounds the cells of multicellular animals. It approximately forms 16% of total body weight. It helps in transport of nutrients and removal of metabolic wastes from the surrounding cells.
-



SUBSTANCE	ECF		ICF
Na^+ (mEq/L)	140	gradient →	14
K^+ (mEq/L)	4	← gradient	120
Ca^{2+}, ionized (mEq/L)	2.5	gradient →	0.0001
Cl^- (mEq/L)	105	gradient →	10
HCO_3^- (mEq/L)	24		10
pH	7.4		7.1
Osmolarity (mOsm/L)	290		290 Osmotically ac

Ionic Composition of Body Fluids:

The following table gives representative values for the primary ionic constituents of the major fluid compartments. The three major compartments of body fluid differ from each other in their ionic composition.

1. The major cation in the ECF is sodium and the major anions are chloride and bicarbonate.
2. The composition of the PV and ISF are very similar because the capillary membranes are highly permeable to water and most solutes. The primary difference in composition between these two compartments is due to the fact that the capillary membranes are nearly impermeable to protein basically confining it to the PV. The higher anionic protein concentration in PV than in ISF causes differences in the distributions of permeable ions; an approximately 5% higher concentration of Na^+ in the plasma relative to the ISF, and a 5% higher concentration of Cl^- and HCO_3^- in the ISF relative to the plasma.
3. This differential distribution of permeable ions across the capillary which occurs because of the presence of an impermeable ion in the capillary lumen is known as the Donnan Equilibrium.
4. The intracellular ionic composition is very different from the ECF but is extremely consistent among all cells of different tissues and species. The major intracellular cation is K^+ which is balanced by anionic molecules including cellular proteins. Bicarbonate, $Na^+$and Cl^- ions are scarce in this compartment.

Electrolyte	Plasma, (mEq/L) [molarity]	Plasma Water (mEq/L) [molality]	Interstitial Fluid (mEq/L)	Intracellular Fluid (mEq/L)
Cations:				
Sodium	142	153	145	10
Potassium	4	4.3	4	160
Calcium	5	5.4	5	2
Magnesium	2	2.2	2	26
Total Cations:	153	165	156	198
Anions:				
Chloride	101	108.5	114	3
Bicarbonate	27	29	31	10
Phosphate	2	2.2	2	100
Sulphate	1	1	1	20
Organic Acid	6	6.5	7	
Protein	16	17	1	65
Total Anions:	153	165	156	198

CHAPTER 3
MEMBRANE TRANSPORT

Background:

The passage of solutes or ions and small molecules through biological membranes is termed as membrane transport. These mechanisms are regulated by a semi permeable unite membrane which is made up of phospholipids bilayer and proteins.

The selective membrane permeability is important feature of plasma membrane. Due to this property it can permit only selected substances through the membrane according to the physiological requirement and type of the cell.

Introduction

In general, the flow of materials from one partition to another can occur in the direction of a concentration or electrochemical gradient. Energy is not required If the transport of substances occurs in the direction of the gradient, that is, in the direction of decreasing potential. However, energy is required if the transport is against the gradient. For example, a classic chemical mechanism for separation that does not require the addition of external energy is dialysis. In this system a semi permeable membrane separates two solutions of different concentration of the same solute. If the membrane allows the passage of water but not the solute the water will move into the compartment with the greatest solute concentration in order to establish an equilibrium in which the energy of the system is at a minimum. This takes place because the

water moves from a high solvent concentration to a low one (in terms of the solute, the opposite occurs) and because the water is moving along a gradient there is no need for an external input of energy.

The nature of biological membranes especially that of its lipids, is amphiphilic, as they form bilayers that

Relative permeability of a phospholipid bilayer to various substances		
Type of substance	**Examples**	**Behaviour**
Gases	CO_2, N_2, O_2	Permeable
Small uncharged polar molecules	Urea, water, ethanol	Permeable, totally or partially
Large uncharged polar molecules	glucose, fructose	Not permeable
Ions	K^+, Na^+, Cl^-, HCO_3^-	Not permeable
Charged polar molecules	ATP, amino acids, glucose-6-phosphate	Not permeable

contain an internal hydrophobic layer and an external hydrophilic layer. This structure makes transport possible by simple or passive diffusion, which consists of the diffusion of substances through the membrane without expending metabolic energy and without the aid of transport proteins. If the transported substance has a net electrical charge, it will move not only in response to a concentration gradient, but also to an electrochemical gradient due to the membrane potential.

Types of transport
It is of two types
Passive transport
Active transport

A: Passive transport:
This type of transport does not require energy. Substance move across the cell membrane along with concentration gradient. It is again two types.
Diffusion
Osmosis

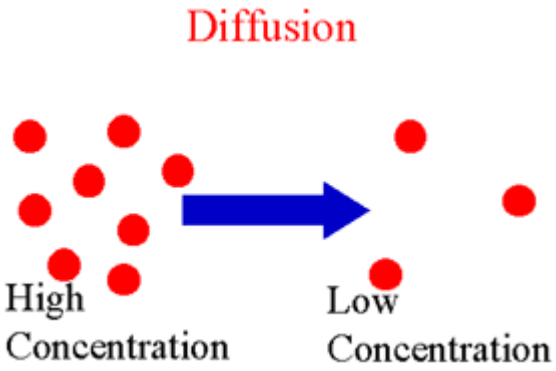
Diffusion

It is a type of passive transport.
Metabolic energy is not required
Molecules move from higher concentration to lower concentration (chemical gradient)
Cations (positive) move to negatively charged areas where as anions (negative) move to the positively charged areas.

Diffusion is again divided into two types
Simple diffusion
Facilated diffusion

Simple diffusion

Spontaneous movement of particles takes place from an area of high concentration to an area of low concentration.
Net diffusion stops when concentration on both sides equal (if crossing a membrane) or when there is a uniform distribution of particles.
Equilibrium is reached

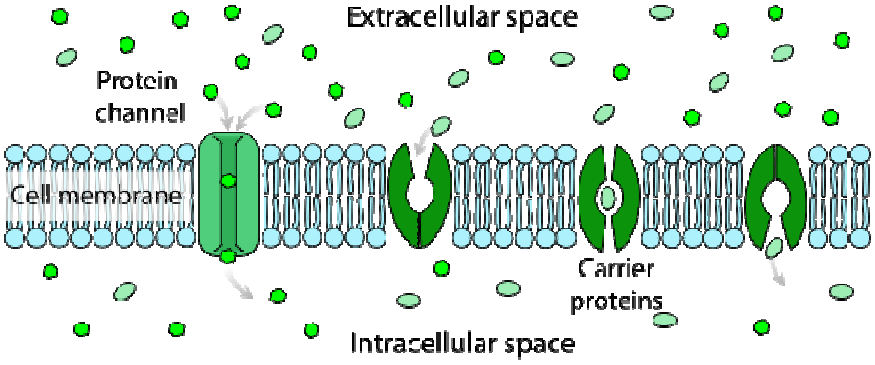


Factors Affecting Diffusion

Diffusion directly through lipid bilayer
Size of the gradient: If the concentration gradient is high, diffusion will be fast.
Temperature: Diffusion will be faster in high temperature.
Size: The permeability of plasma membrane is more with increase in molecular weight. This is the reason why diffuses faster than large proteins.
Lipid solubility: Lipid soluble molecules (ex. alcohols) diffuse rapidly than water soluble molecules (glucose, urea).

Ion channels and specific transporters are required for charged molecules and larger, uncharged molecules.
Ions also utilize ionic channels to cross the plasma membrane. Some channels are always opened while others gated. Gated channels have gates e by voltage or certain ligands.

Facilated diffusion
Allows diffusion of large, membrane insoluble compounds such as sugars and amino acids.
Does not require energy (passive) and rapid than simple diffusion
Highly Selective.
Substance binds to membrane-carrier transport protein.
Binding alters protein conformation, exposing the other surface.
Fully reversible - molecules may enter the cell and leave the cell through the transport protein.
Particles move from areas of high concentration to areas of low concentration.
Movement rate of particles will saturate.
Maximum rate limited by number of transporters.
Once all transporters are operating at 100%, an increase in concentration will not increase rate.



Facilitated diffusion in cell membrane, showing ion channels and carrier proteins

Ex: How to Cheat - Glucose Enters the Cell by Facilitated Diffusion
Glucose binds to transport protein Transporter changers conformation and glucose is released into cell Intracellular glucose is immediately phosphorylated phosphorylated glucose does not diffuse out (remember that

the transport protein is very specific) internal glucose (unphosphorylated) concentration remains low providing large concentration difference for entry

Osmosis

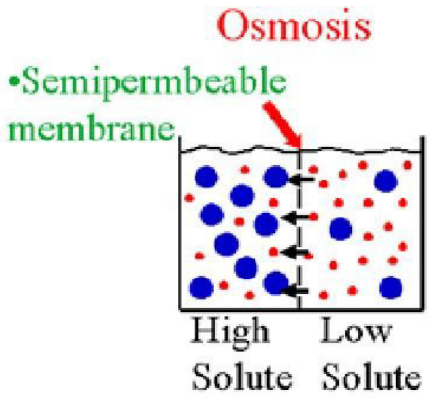
Water is a Polar molecule. Hence many substances dissolve in it. These dissolved substances are termed Solutes, and water is a Solvent. Water molecules gather around molecules of a Solute. But when solute dissolves it lowers the concentration of water. Water Potential measures the concentration of free water molecules. It is a measure of the tendency of these molecules to diffuse to another area. The more free water molecules, the higher the Water Potential.

Water diffuses by Osmosis from a region of high Water Potential to a region of low Water Potential through the Water Potential Gradient. Osmosis can therefore be defined as the diffusion of water from a region of high Water Potential to a region of low Water Potential through a Partially Permeable Membrane.

It is diffusion through a semi permeable membrane

The movement of water molecules from high concentration to low concentration through a semi permeable membrane is known as osmosis

Osmosis is the natural net movement of solvent molecules through a semi permeable membrane into a region of higher solute concentration. It takes place till the equilibrium is established on the two sides. It is a physical process in which any solvent moves across a semi permeable membrane (permeable to the solvent, but not the solute).



Osmosis, the Passive Transport of Water
Osmosis = the diffusion of water across a semi-permeable membrane
Plasma membrane permeable to water but not to solute
Solute = dissolved particle
Solvent = liquid medium in which particles may be dissolved
Water moves from solution with lower concentration of dissolved particles to solution with higher concentration of dissolved particles
Water moves from dilute solution to concentrated solution
Osmotic potential is the total of all dissolved particles

Hypotonic Solution: Solute concentration lower than cell
Less dissolved particles outside of cell than inside of cell
Hypo = less, under (think hypodermic, hypothermia); Tonic = dissolved particles
Water moves into cell from solution
Cell expands (and may burst)

Isotonic Solution: Solute concentration equal to that of cell
No net water movement

Osmosis Produces a Physical Force
Movement of water into a cell can create pressure on plasma membrane
Animal cells will expand and may burst
Some protozoans, like *Paramecium* have contractile vacuoles to remove excess water
We can alter the rate of contractile vacuole function by placing it in increasingly hypotonic solutions
Organisms with a cell wall, such as plants, do not burst
Cell membrane pushes against cell wall
The rigid cell wall resists due to its own structural integrity
These opposing forces create turgidity, which keeps plants upright
If you don't water a plant, it droops (plasmolysis). The watering however reestablishes of turgidity.

B: Active transport

The liquids inside and outside of cells have different substances. Sometimes a cell has to work and use some energy to maintain a proper balance of ions and molecules.

There are thousands of proteins embedded in the cell's plasma membrane. These proteins are specific and positioned to cross the membrane so one part is on the inside of the cell and one part is on the outside.

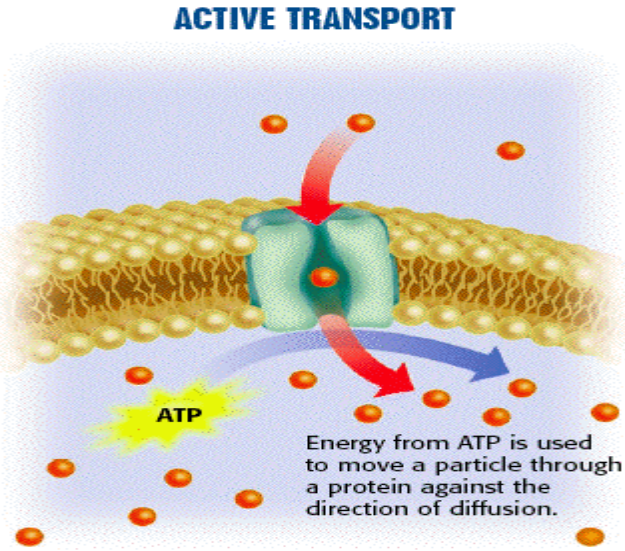
In this type, molecules move across cell membranes from an area of lower concentration toward an area of higher concentration.

It requires energy (ATP) to overcome the influences of diffusion and osmosis.

It requires specific carrier proteins. They contain specific receptors to identify specific molecules.

Examples: 1.sodium-potassium pump during nerve conduction

2. Uptake of glucose in the intestine



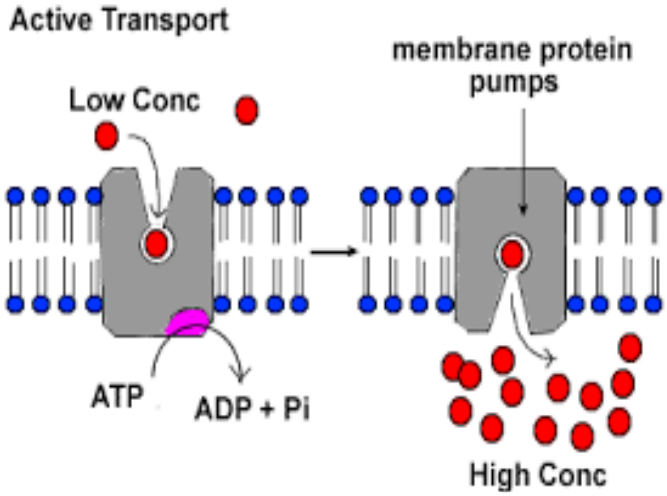


Fig. Showing Active transport of sodium- potassium pump

CHAPTER 4
METABOLISM

The structural make up of all living organisms mainly are made from proteins, carbohydrates and lipids. As these molecules are vital for life, metabolic reactions either focus on making these molecules during the construction of cells and tissues, or by breaking them down and using them as a source of energy. These biochemicals can be joined together to make polymers such as DNA and proteins, essential macromolecules of life.

- The word metabolism aroused from Greek which means change.
- It is the set of life-supporting chemical transformations within the cells of living organisms. These enzyme-catalyzed reactions allow organisms to grow and reproduce, maintain their structures, and respond to their environments.
- It can also refer to all chemical reactions that occur in living organisms, including digestion and the transport of substances into and between different cells.
- The chemical reactions of metabolism are organized into metabolic pathways, in which one chemical is transformed into another chemical through a series of reactions in the presence of enzymes. So, enzymes are crucial to metabolism because they allow organisms to drive desirable reactions. Enzymes also allow the regulation of metabolic pathways in response to changes in homeostasis or to signals from other cells.

- The metabolic system of a particular organism determines which substances is nutritious and which poisonous. For example, some prokaryotes use hydrogen sulfide as a nutrient, while this gas is poisonous to animals.

Key concepts

Metabolic pathways involve biosynthetic processes (anabolism) and the breakdown of molecules (catabolism) to provide energy and building blocks.
Synthetic pathways require the input of energy.
Pathways that break down molecules usually release energy.
Metabolic pathways can have reversible and irreversible steps.
Alternative routes may exist that can bypass steps in a pathway.
A remarkable feature of metabolism is the similarity of the basic metabolic pathways and components between even greatly different species.

For example, the carboxylic acids that are known as the intermediates in the citric acid cycle are present in all known organisms from Escherichia *coli* to elephants.

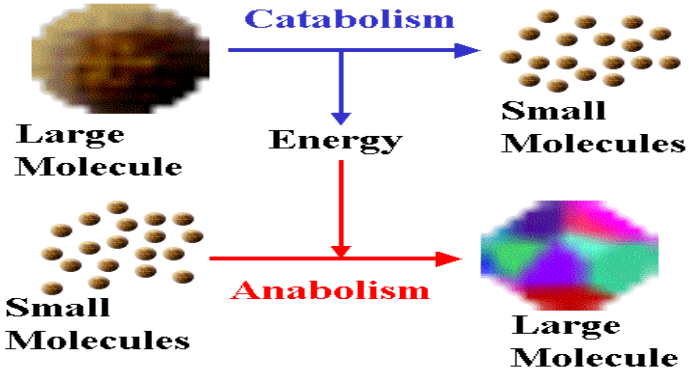


Fig. showing anabolism and catabolism

Example 1: Muscle proteins are made up of myosin and actin. It consists of many amino acids attached to each other by so-called peptide bonds. Proteins are broken down to the individual amino acids in digestion of dietary protein. This is known as catabolism. In this process, energy that had been stored in the protein molecules is liberated. In contrast, when skeletal muscles are being built up (such as during normal growth in childhood, or the hypertrophy that occurs with weight training), this is anabolism. Individual amino acids are

bonded together in specific sequences to form the proteins. Formation of these bonds requires energy that must come from other chemical reactions.

METABOLISM

The food we eat, (carbohydrates, lipids, and proteins), are our only source of energy for doing the biological work of cells. These nutrient molecules have energy stored in the bonds between their atoms

Metabolic uses for nutrients: It is mainly of three types.

- Used immediately for energy for active processes
- Synthesized into structural or functional molecules
- Synthesized as fat or glycogen for later use as energy

OXIDATION-REDUCTION REACTIONS

- **Oxidation** = the removal of electrons from a molecule and results in a decrease in the energy content of the molecule. Because most biological reactions involve the loss of hydrogen atoms, they are called dehydrogenation reactions.
- **Reduction** = the opposite of oxidation; the addition of electrons to a molecule, and results in an increase in the energy content of the molecule.
- An important point to remember in Oxidation-Reduction reactions is that oxidation is usually an energy-releasing reaction.

CARBOHYDRATE METABOLISM

GLUCOSE ANABOLISM

- The conversion of glucose to glycogen for storage in the liver and skeletal muscle is called glycogenesis. The process is stimulated by insulin.
- The conversion of glycogen back into glucose is called glycogenolysis. This process occurs between meals and is stimulated by glucagon and epinephrine.
- Gluconeogenesis is the conversion of protein or fat molecules into glucose. Glycerol from fat can be converted to glyceraldehyde-3-phosphate and some amino acids may be converted to pyruvic acid. Both of these compounds can enter the TCA cycle to provide energy.
- During digestion, polysaccharides are converted to monosaccharides (primarily glucose), which are absorbed through capillaries in villi and transported to the liver via the hepatic portal veins.

- Glucose is the body's preferred source for synthesizing ATP. If cells require immediate energy, glucose is oxidized by the cells to produce ATP.
- Glucose can also be used to form amino acids, which then can be incorporated into proteins.
- Excess glucose can be stored by the liver (25%) and skeletal muscle (75%) as glycogen (how animals store carbohydrate) in a process called glycogenesis.
- If glycogen storage areas are filled up, (they hold about 1.1 pounds of glycogen), liver cells and fat cells convert glucose to glycerol and fatty acids that can be used for synthesis of triglycerides in a process called lipogenesis.

Glucose Catabolism:

- Glucose oxidation is also called aerobic or cellular respiration. It occurs in every cell of the body (except red blood cells because they lack mitochondria), and provide the cells main source of energy.
- The complete oxidation of glucose to CO_2, H_2O results in large amounts of energy (ATP) and occurs in successive stages: glycolysis, formation of acetyl coenzyme A, the tricarboxylic acid cycle and the electron transport system.

LIPID METABOLISM

Most proteins are transported in the blood in combination with proteins as lipoproteins. There are 4 classes of lipoproteins.

- chylomicrons
- VLDL's (very low density lipoproteins)
- LDL's (low density lipoproteins)
- HDL's (high density lipoproteins)

Chylomicrons:

- Form in small intestinal mucosal cells and contain dietary lipids. They enter villi lacteals, are carried into the systemic circulation into adipose tissue where their triglyceride fatty acids are released and stored in the adipocytes and used by muscle cells for ATP production.

VLDL's:

- Transport vehicles that carry triglycerides synthesized in hepatocytes to adipocytes for storage.

LDL's:

- Carry about 75% of total blood cholesterol and deliver it to cells throughout the body. When present in excessive numbers, LDL's deposit cholesterol in and around smooth muscle fibers in arteries.

HDL's:

- Remove excess cholesterol from body cells and transport it to the liver for elimination.

NOTE:

- There are two sources of cholesterol in the body: food we eat, and liver synthesis.
- For adults, desirable levels of blood cholesterol are under 200 mg/dL for total cholesterol; LDL under 130 mg/dL; and HDL over 40 mg/dL. Normally, triglycerides are in the range of 10-190 mg/dL.
- Exercise, diet and drugs may be used to reduce blood cholesterol levels.

Fate of Lipids:

- Some lipid may be oxidized to produce ATP, where each unit of lipid produces TWICE the amount of ATP as an equivalent unit of carbohydrate.
- Some lipids are stored in adipose tissue.
- Other lipids are used as structural molecules or to synthesize essential molecules. Examples include phospholipids of cell membranes, lipoproteins that transport cholesterol, and cholesterol used to synthesize bile salts and steroid hormones.
- Triglycerides are stored in adipose tissue, mostly in the subcutaneous layer.
- Adipose cells contain lipases that hydrolyze fats into glycerol and fatty acids.

LIPID ANABOLISM: Lipogenesis

- Lipogenesis = the conversion of glucose or amino acids into lipids.
- LIPID CATABOLISM: Lipolysis
- Lipolysis = triglycerides are split into fatty acids and glycerol.
- As a part of normal fatty acid catabolism, ketone bodies are formed.
- An excess of ketone bodies (ketosis), may cause acidosis or abnormally low blood pH.

PROTEIN METABOLISM

- During digestion, proteins are hydrolyzed into amino acids, which are then absorbed by the capillaries of villi and enter the liver via the hepatic portal vein.
- Amino acids, under the influence of human growth hormone and insulin, enter the body cells by active transport.
- Inside cells, amino acids are synthesized into protein that function as enzymes, transport molecules, antibodies, clotting chemicals, hormones, contractile elements in muscle fibers and structural elements such as hair. They may also be stored as fat or glycogen or used for energy.

Protein Catabolism:

- Before amino acids can be catabolized, they must be converted to substances that can enter the TCA cycle. These conversions involve deamination, decarboxylation, and hydrogenation.
- Amino acids can be converted into glucose, fatty acids and ketone bodies.

Protein Anabolism:

- Involves the formation of peptide bonds between amino acids to produce new proteins.
- Protein synthesis is stimulated by human growth hormone, thyroxine, and insulin.
- Protein synthesis is carried out on the ribosomes of almost every cell in the body, directed by the cells' DNA and RNA.
- Of the 20 amino acids in your body, 10 are referred to as "essential" amino acids. These amino acids cannot be synthesized by the human body from molecules present within the body. Foods containing these amino acids are "essential" for human growth and must be part of the diet.
- Non essential amino acids CAN be synthesized by body cells by a process called transamination. Once the appropriate essential and nonessential amino acids are present in cells, protein synthesis occurs rapidly.

METABOLISM DURING FASTING OR STARVATION

- Fasting means going without food for many hours or a few days. Starvation implies weeks or months of food deprivation or inadequate food intake.

- Catabolism of stored triglycerides and structural proteins can provide energy for several weeks.
- The amount of adipose tissue determines the lifespan possible without food. The average person has a 1-2 month energy reserve in adipose tissue.
- Initially, during fasting and starvation glucose is used for ATP production. During prolonged fasting, large amounts of amino acids from tissue protein breakdown (primarily skeletal muscle) are released to be converted to glucose in the liver by gluconeogenesis.
- Ketogenesis increases as catabolism of fatty acids rises. The presence of ketones reduces the use of glucose for ATP production which in turn decreases the demand for gluconeogenesis and slows the catabolism of muscle proteins.

HEAT AND ENERGY BALANCE

- Normal body temperature is maintained by a homeostatic balance between heat-producing and heat-losing mechanisms.
- Metabolic Rate = overall rate at which heat is produced
- Basal Metabolic Rate (BMR) = measurement of the metabolic rate under basal conditions
- BMR is the measure of the rate at which the quiet, resting, fasting body breaks down nutrients to liberate energy
- BMR is also a measure of how much thyroxine the thyroid gland is producing, since thyroxine regulates the rate of ATP use and is not a controllable factor under basal conditions.
- Heat is a form of kinetic energy that can be measured as temperature and expressed in units called calories. A calorie is the amount of heat energy required to raise the temperature of 1 gram of water from 14 degrees C to 15 degrees C.
- Body Temperature Homeostasis:
- If the amount of heat production equals the amount of heat loss, a human maintains a constant core temperature of 98.6 degrees F, (37 degrees C).
- Core temperature refers to the body's temperature in body structures below the skin and subcutaneous tissue.
- Shell temperature refers to the body's temperature at the surface (skin and subcutaneous tissue).
- Too high a core temperature kills by denaturing proteins.

- Too low a core temperature causes cardiac arrhythmias that can result in death.

Heat Production:

- Is influenced by metabolic rate and responses that occur when body temperature starts to fall.
- Factors that affect metabolic rate include exercise, hormones, and the nervous system, and body temperature, ingestion of food, age, gender, climate, sleep, and malnutrition.
- Heat conservation mechanisms include vasoconstriction, sympathetic stimulation, skeletal muscle contraction (shivering), and thyroid hormone production.
- The hypothalamus is involved in thermoregulation and several negative feedback loops are involve in raising or lowering body temperature when it is too low or too high.

REGULATION OF FOOD INTAKE

- Two centers in the hypothalamus related to regulation of food intake are the feeding (hunger) center and the satiety center. The feeding center is constantly active but can be inhibited by the satiety center.
- Stimuli that affect the feeding and satiety centers are: glucose, amino acids, lipids, body temperature, distention of the GI tract and the hormone cholecystokinin (CCK).

CHAPTER 5
ANIMAL NUTRITION (nutrine= to nourish)

Background:

- An important necessity of all living organisms is to obtain energy and matter. Energy is essential to drive the metabolic activities.
- The materials required for the growth and metabolism are known as nutrients.
- The process by which the animal obtains these nutrients is known as nutrition.
- Most of the animals are heterotrophs. (hetero= different, trophic= nutrition).
- It means that animals depend on others for their food.

Types of nutrition:

- **Autotrophic nutrition:** In this method, the organism can obtain the food from sun light. Eg. Euglena (photo synthesis) or from chemicals (chemo synthesis) Eg. Bacteria.
- **Heterotrophic nutrition:** In this method, animals depend on other organisms for its food. It is the characteristic feature of animals.

On the basis of nature of food it is of following types.

- Herbivores (Herb=plant, vore= to eat). Their food mainly consists of plant material. Ex. Cow
- Carnivores (Cornis= flesh). Their food mainly consists of flesh. Ex. Tiger.

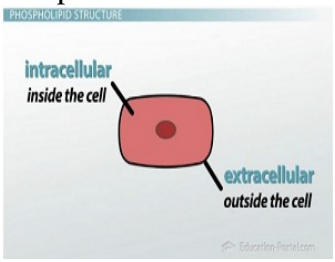
- Omnivores (Omni= all). Their food consists of both plant and animal materials. Ex. Man, Cockroach.
- Detrivores. They mainly feed upon dead organic matter.Ex. Eartworm
- Predators. They obtain the food by hunting and killing the animal. Ex. Tiger, Eagle.
- Scavengers. They mainly feed upon other dead animals.
- Insectivores. They feed on insects. Ex. Manis (ant eater).
- Osmotrophic. They feed on pre digested food by diffusion. Ex.Taenia solium.
- Parasitic. They depend for the food on their host. Ex. Ascaris.
- Larvivorous. They feed upon larvas.Fishes.
- Sanguivorous. They feed upon blood. Ex.Leech,Mosquito
- Coprophagous. Their food consists of faecal matter. Ex.rabbit,Pig

Steps in Nutrition

1. **Ingestion:** Intaking of food
2. **Digestion:** Breaking of complex and large molecules into simple soluble components.
3. **Absorption:** Entry of the digested food from the intestine into blood.
4. **Assimilation:** Reuse of simple components into complex components in the cell. This process occurs according to the necessity of the cell.
5. **Egestion:** This is the final step. The elimination of undigested food as faeces is known as egestion.

Types of Digestion

1. **Intracellular:** It occurs inside the food vacuoles of the cell. Digested food diffused into cytoplasm. It is primitive and less efficient.



2. **Extra cellular:** It occurs outside the cell or gut lumen. It is found in higher animals. Digested materials are absorbed into the cell. It is more complex but efficient.

Malnutrition:

- This is a condition that results from eating a diet in which nutrients are not enough or are too much such that it causes health problems.
- It is often also called as under nutrition.
- Undernourishment is most frequent due to not enough high quality food available to eat. This is related to high food prices and poverty.
- Under nutrition is sometimes used as a synonym of protein–energy malnutrition (PEM).
- Under nutrition includes stunted growth (stunting), wasting, and deficiencies of essential vitamins and minerals.
- Kwashiorkor ('displaced child') is mainly caused by inadequate protein intake. The main symptoms are edema, wasting, liver enlargement, hypo albuminaemia, steatosis, and possibly depigmentation of skin and hair. Kwashiorkor is identified by swelling of the extremities and abdomen.
- Marasmus ('to waste away') is caused by an inadequate intake of protein and energy. The main symptoms are severe wasting, leaving little or no edema, minimal subcutaneous fat, severe muscle wasting, and non-normal serum albumin levels. Marasmus can result from a sustained diet of inadequate energy and protein, and the metabolism adapts to prolong survival. It is traditionally seen in famine, significant food restriction, or more severe cases of anorexia. Conditions are characterized by extreme wasting of the muscles and a thin expression.
- Malnutrition increases the risk of infection and infectious diseases.
- It weakens every part of the immune system.

CHAPTER 6
PHYSIOLOGY OF DIGESTION

Background:

- Digestion is the breakdown of food into smaller components that can be more easily absorbed and assimilated by the body.
- Based on how food is broken down it is divided into two types.
- Mechanical digestion: It occurs mainly in buccal cavity. It refers to the physical breakdown of large pieces of food into smaller pieces by chewing.
- Chemical digestion: The breakdown of large pieces of food into smaller pieces with help of enzymes is known as chemical digestion.
- The major part of digestion takes place in the small intestine. The large intestine primarily serves as a site for fermentation of indigestible matter by gut bacteria and for reabsorption of water from digests before excretion.

Digestion is a multistage process and involves following steps.

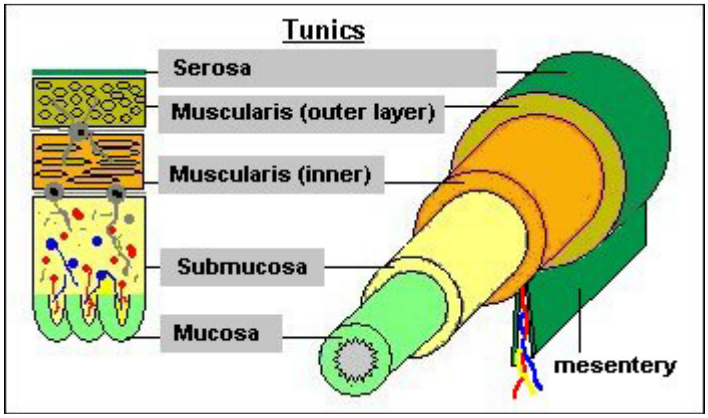
1. Ingestion: Intake of the food into the mouth or entry of food in the digestive system.
2. Digestion: mastication and the mixing of the water, acids, bile and enzymes in the stomach and intestine to break down complex molecules into simple molecules.
3. Absorption: The simple molecules (nutrients) from the digestive system enter into the circulatory and lymphatic capillaries through osmosis, active transport, and diffusion.

4. Egestion; Removal of undigested materials from the digestive tract through defecation.
5. The Gastrointestinal Tract (GIT) is responsible for the breakdown and absorption of various foods and liquids needed to continue life. The GI tract starts with the mouth and proceeds to the esophagus, stomach, small intestine (duodenum, jejunum, ileum), and then to the large intestine (colon), rectum, and terminates at the anus.

Layers of Gastrointestinal Tract (GIT):

The GI tract is composed of four layers or also known as Tunics. Each layer has different tissues and functions. From the inside out they are called: mucosa, sub mucosa, muscularis mucosa, and serosa.

- **Mucosa**: It is inner most layer. It helps in absorption and secretion of mucus. It is composed of simple columnar epithelium. Specialized goblet cells are present to secrete mucus. It is folded to form Villi and Micro Villi.
- **Submucosa**: It is relatively thick, highly vascular, and serves the mucosa. The absorbed elements that pass through the mucosa are picked up from the blood vessels of the submucosa. The submucosa also has glands and nerve plexuses.
- **Muscularis mucosa**: It is responsible for segmental contractions and peristaltic movement in the GI tract. It is composed an inner circular and outer longitudinal layer of smooth muscle. These muscles cause food to move and churn with digestive enzymes down the GI tract.
- **Serosa**: It is outer and a protective layer. It is composed of a vascular connective tissue and simple squamous epithelium. It secretes lubricating serous fluid.



Accessory organs:

Salivary glands

- They are associated with mouth and buccal cavity.
- They produce saliva which keeps buccal cavity moist.
- In man3 types of salivary glands are present. But in Rabbit it is of 4 types.
- (a) Sublingual: Smallest and present beneath the tongue.
- (b)Parotid: Largest and present in the cheek region near the ear.
- (c).Sub maxillary: Present towards posterior end of the lower jaw.
- They are exocrine glands that produce saliva which begins the process of digestion with amylase or ptyalin.
- Saliva secretion is controlled by Autonomic nervous system (ANS).
- pH of saliva =6.7-6.8 (slightly acidic).
- Salivary amylase or ptyalin is the main enzyme that acts upon starch.
- Lysozyme is also present in saliva which kills harmful bacteria.

2. Tongue or Lingue

- It is muscular structure present in the floor of buccal cavity.
- It is made up of skeletal muscles.
- Manipulates food for chewing/swallowing.
- Main taste organ, covered in taste buds

3. Teeth:

- Present in the buccal cavity and attached to the both jaws.
- Ecto mesodermal in origin.
- They are thecodont, heterodont and diphydont type.
- Help in chewing and mastigation of food.

4. Liver

- It is the largest gland of the body.
- Glissions's capsules are present in it.
- Cells are hexagonal.
- Endodermal in origin.
- In man it is bilobed while in rabbit it is 5 lobed.
- Produces and excretes bile required for emulsifying fats. Some of the bile drains directly into the duodenum and some is stored in the gall bladder. Biles make the media alkaline.
- Helps metabolize proteins, lipids, and carbohydrates.

- Urea, chief end product of mammalian metabolism, is formed in liver from amino acids and compounds of ammonia.
- Breaks down insulin and other hormones.
- Produces coagulation factors.
- Stores Vitamin A and D.
- Removes dead RBC.
- It is haemopoitic organ in embryo.
- Heparin is secreted by liver only. It is anticoagulant.
- Protein, carbohydrate and alcohol metabolism takes place in liver only.
- Deamination, detoxification, lipogenesis and lipogenolysis take place in liver only.
- Plasma proteins like albumin and globulin are formed here.
- Blood clotting factor fibrinogen is produced from liver only.

5. Gallbladder

- Bile storage. It brings the emulsification of fats.
- Help in the absorption of Vitamin K. and other fat soluble vitamins.

6. Pancreas

- The second largest gland. It is mixed gland (both exocrine and endocrine).
- Endodermal in origin.
- Secretes pancreatic juice with pH 7.5-8.1.
- Exocrine functions: Digestive enzyme secretion.
- Stores zymogens (inactive enzymes) that will be activated by the brush boarder membrane in the small intestine when a person eats protein (amino acids).
- Trypsinogen – Trypsin: digests protein.
- Chymotypsinogen – Chymotrypsin: digests proteins.
- Carboxypeptidases: digests proteins.
- Lipase-lipid: digests fats.
- Amylase: digests carbohydrates.
- Endocrine functions: Hormone secretion.
- Somatostatin: inhibits the function of insulin. Produced if the body is getting too much glucose.
- Glucagon: stimulates the stored glycogen in the liver to convert to glucose. Produced if the body does not have enough glucose.

- Insulin: made in the beta cells of the Islets of Langerhans of the pancreas. Insulin is a hormone that regulates blood glucose.

7. Vermiform appendix

- There are a few theories on what the appendix does.
- Vestigal organ
- It is made up of lymphatic tissue and help in immunity.
- Helps maintain gut flora.
- Cellulose digesting bacteria vom pyrella is present in it.

Enzyme	Produced In	Site of Release	pH Level
Carbohydrate			
Salivary amylase	Salivary glands	Mouth	Neutral
Pancreatic amylase	Pancreas	Small intestine	Basic
Maltase	Small intestine	Small intestine	Basic
Protein Digestion:			
Pepsin	Gastric glands	Stomach	Acidic
Trypsin	Pancreas	Small intestine	Basic
Peptidases	Small intestine	Small intestine	Basic
Nucleic Acid			
Nuclease	Pancreas	Small intestine	Basic
Nucleosidases	Pancreas	Small intestine	Basic
Fat Digestion:			
Lipase	Pancreas	Small intestine	Basic

Process:

- The human gastrointestinal tract (GIT) is around 9 meters long.
- Food digestion physiology varies between individuals and upon other factors such as age, type of the food and size of the meal.
- The process of digestion normally takes between 24 and 72 hours.
- It includes three different phases known as cephalic phase, gastric phase, and intestinal phase.
- **Cephalic phase**: The cephalic phase occurs at the head region. Thought and smell of food stimulate the cerebral cortex which is transferred to

the hypothalamus and medulla oblongata. Then after it is routed through the vagus nerve and release of acetylcholine. Gastric secretion at this phase rises to 40% of maximum rate.

- **Gastric phase:** It takes 3 to 4 hours. It is stimulated by expansion of the stomach. Presence of food in stomach and decrease in pH stimulates the secretion of gastric juices.
- **Intestinal phase:** It has two parts, the excitatory and the inhibitory. Partially digested food fills the duodenum. This triggers intestinal gastrin to be released. Enterogastric reflex inhibits acetylcholine of vagus. Pyloric sphincter get tighten to prevent more food from entering, and inhibits local reflexes.

Process:

- Digestion begins in the mouth with the secretion of saliva and its digestive enzymes. Food is converted into a bolus by the mechanical mastication and swallowed into the esophagus.
- From here it enters the stomach through the action of peristalsis. Gastric juice contains hydrochloric acid and pepsin. It can damage the walls of the stomach but mucus is secreted for protection. In the stomach further release of enzymes break down the food further and this is combined with the churning action of the stomach.
- The partially digested food enters the duodenum as a thick semi-liquid (paste like) chime. In the small intestine, the larger part of digestion takes place and this is helped by the secretions of bile, pancreatic juice and intestinal juice. The intestinal walls are lined with villi and microvilli. It helps to improve the absorption of nutrients by increasing the surface area of the intestine.
- Peristalsis is slower in the large intestine. So the passage of food is slower to enable fermentation by the gut flora. Here water is reabsorbed and waste material stored as faces to be removed by defecation via the anal canal and anus.

Common stomach and intestinal disorders:

- **Appendicitis**: Appendicitis is the inflammation of the appendix. Abdominal pain, loss of appetite, fever, and vomiting are the common symptoms are. Kids and teenagers are the most common victims of appendicitis. It must be corrected by surgery.

- **Celiac Disease**: In this type digestive system is damaged by the response of the immune system to a protein called gluten. This protein is found in rye, wheat, and barley, and also in foods like breakfast cereal and pizza crust. People with celiac disease experience abdominal pain, diarrhea, bloating, exhaustion, and depression when they eat foods with gluten in them. They also have difficulty digesting their food.
- **Diverticulitis**: Diverticulitis is a common disease of the bowel in the large intestine. It involves the formation of inflamed pouches (diverticula) on the outside of the colon. Bacterial infection may takes place in diverticulitis. If the infection spreads to the lining of the abdominal cavity (peritoneum), this can cause a potentially fatal peritonitis. The inflamed diverticula can cause narrowing of the bowel, leading to an obstruction. Sometimes the affected part of the colon can adhere to the bladder or other organ in the pelvic cavity and cause a fistula, or abnormal communication between the colon and an adjacent organ.
- **Gastritis and Peptic ulcers**: The stomach and the duodenum are resistant to irritation because of the HCL secretion by the stomach. But sometimes bacteria called Helicobacter pylori or the chronic use of drugs or certain medications, weakens the mucous layer of GIT. This can cause irritation and inflammation of the lining of the stomach, which is called gastritis, or cause peptic ulcers, which are holes or sores that form in the lining of the stomach and duodenum and cause pain and bleeding. Medications are the best way to treat this condition.
- **Gastrointestinal Infections**: Gastrointestinal infections can be caused by bacteria such as Campylobacter, Salmonella, E. coli, or Shigella. They can also be caused by viruses or by intestinal parasites like amoebiasis and Giardiasis. The most common symptoms of gastrointestinal infections. Abdominal pain and cramps, Diarrhea, and vomiting.
- **Inflammatory Bowel Disease**: Inflammatory bowel disease is the chronic inflammation of the intestines. There are two major types, *ulcerative colitis* and *Crohn's disease* and indeterminate colitis. Ulcerative colitis usually affects just the rectum and large intestine, while Crohn's disease can affect the whole gastrointestinal tract from mouth to anus along with some other parts of the body. Patients with these diseases also suffer from extra intestinal symptoms including joint pain and red eye, which can signal a flare of the disease. These diseases are treated with medications.

- **Polyp**: A polyp is an abnormal growth of tissue (tumor) projecting from a mucous membrane. If it is attached to the surface by a narrow elongated stalk it is said to be pedunculated. If no stalk is present it is said to be sessile. Polyps are commonly found in the colon, stomach, nose, urinary bladder and uterus. They may also occur elsewhere in the body where mucous membranes exist like the cervix and small intestine.

Disorders of the pancreas, liver, and gallbladder

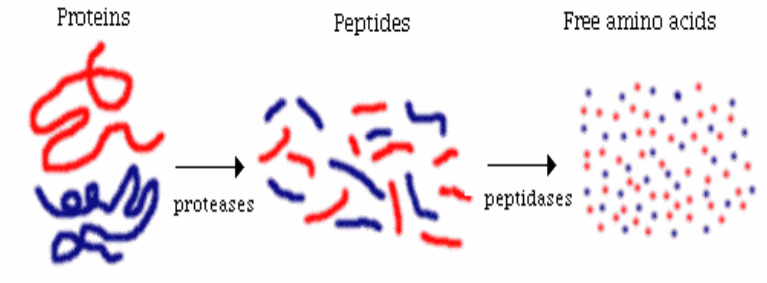
They affect the ability to produce enzymes and acids that aid in digestion. Examples of these disorders are:

- **Cystic Fibrosis**: It is a chronic and inherited illness. It causes the production of abnormally thick mucus which blocks the duct or passageways in the pancreas. It prevents the entry of digestive fluids into the intestines. People with this disorder take supplements and digestive enzymes to help manage their digestive problems.
- **Hepatitis**: The inflammation of liver is known as hepatitis. It is caused by virus. Viral hepatitis, like hepatitis A, B, and C, is extremely contagious. Hepatitis A, which is a mild form of hepatitis, can be treated at home, but more serious cases that involve liver damage, might require hospitalization.
- **Cholecystitis**: Acute or chronic inflammation if the gallbladder causes abdominal pain. 90% of cases of acute cholecystitis are caused by the presence of gallstones. The actual inflammation is due to secondary infection with bacteria of an obstructed gallbladder, with the obstruction caused by the gallstones.
- **Cholestasis**: Cholestasis is the blockage in the supply of bile into the digestive tract. It can be "intrahepatic" (the obstruction is in the liver) or "extra hepatic" (outside the liver). It can lead to jaundice, and is identified by the presence of elevated bilirubin level that is mainly conjugated.
- **Constipation**: The trouble in having bowel movements is known as constipation. The stool become hard making it difficult to pass and causing a person to strain. Peristalsis is slower. When the waste products go through the intestine most of the water and salt are reabsorbed. One can become constipated if too much water is absorbed, or if waste products move too slowly. Not getting enough fluids, a low fiber diet, age, not being physically active, depression, stress and pregnancy can all be causes of constipation.

Breakdown into Nutrients

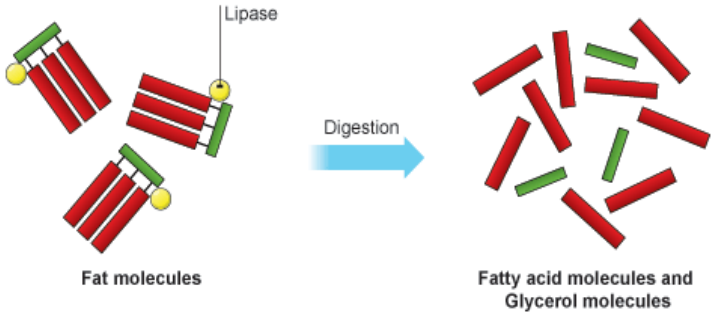
Protein digestion

- Protein digestion occurs in the stomach and duodenum in which 3 main enzymes.
- Pepsin is secreted by the stomach and trypsin and chymotrypsin secreted by the pancreas.
- Exopeptidases and dipeptidases convert proteins and poly peptides into amino acids.
- The digestive enzymes are mostly secreted as their inactive precursors known as zymogens. For example, trypsin is secreted by pancreas in the form of trypsinogen, which is activated in the duodenum by enterokinase to form trypsin. Trypsin then breaks proteins to smaller polypeptides.



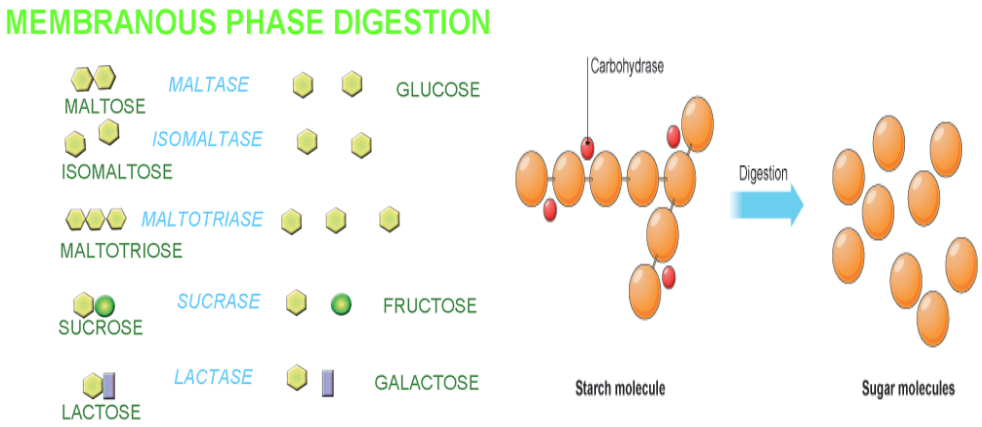
Fat digestion

- Digestion of some fats can begin in the mouth. But fats are mainly digested in the small intestine
- Small amount of salivary lipase breaks down some short chain lipids into diglycerides.
- The presence of fat in the small intestine stimulates the release of pancreatic lipase from the pancreas and bile.
- Bile from the liver helps in the emulsification of fats and absorption fatty acids. Complete digestion of one molecule of fat (a triglyceride) results in 3 fatty acid molecules and one glycerol molecule.



Carbohydrate digestion

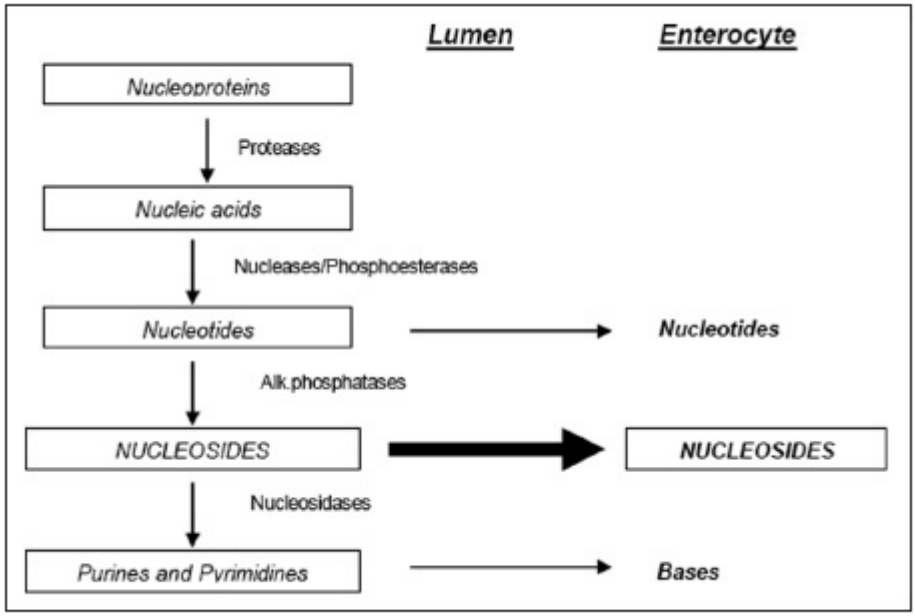
- Dietary starches are composed of glucose units.
- During digestion, bonds between glucose molecules are broken by salivary and pancreatic amylase, resulting in progressively smaller chains of glucose. This results in simple sugars glucose and maltose (2 glucose molecules) that can be absorbed by the small intestine.
- Lactase is an enzyme that breaks down the disaccharide lactose in to glucose and galactose which can be absorbed by the small intestine.
- Sucrase is an enzyme that breaks down the disaccharide sucrose, commonly known as table sugar. This enzyme breakes the sucrose in to fructose and glucose. They are readily absorbed by the small intestine.



DNA and RNA digestion

- Nucleic acids (DNA and RNA) are biological molecules that are essential to almost all biological processes in the body.

- Digestion takes place in the small intestine as protease and nuclease enzymes (DNAase and RNA ase from pancreas) break the nucleoproteins and then nucleotides down into smaller parts.
- Most of them being absorbed into the cells of the gut as nucleosides with over 90% of them being absorbed.



Digestive hormones

There are at least five hormones that aid and regulate the digestive system in mammals. There are few variations across the vertebrate group.

- Gastrin : Secreted by the gastric glands of stomach. Stimulates the glands to secrete inactive pepsinogen. Secretion of gastrin is stimulated by the presence of food in the stomach. The secretion is inhibited by low pH.
- Secretin: Produced in the duodenum and signals the secretion of sodium bicarbonate in the pancreas. It stimulates the bile secretion in the liver. This hormone responds to the acidity of the chyme.
- Cholecystokinin (CCK): Produced in the duodenum and stimulates the release of digestive enzymes in the pancreas. Also stimulates the emptying of bile in the gall bladder. This hormone is secreted in response to fat in chyme.

- Gastric inhibitory peptide (GIP): Also produced in the duodenum and decreases the stomach mixing in turn slowing the emptying in the stomach. Another function is to induce insulin secretion.
- Motilin Produced in the duodenum. Increases the gastrointestinal motility and stimulates the production of pepsin.

CHAPTER 7
RESPIRATORY SYSTEM

Background

- Various metabolic processes of an organism require energy.
- Energy can be obtained from the food which we eat.
- The nutrients like proteins, carbohydrates and lipids contain energy in their chemical bonds.
- This chemical energy can be released by the oxidation in the cells. So it is a catabolic process.
- For the oxidation of food materials oxygen is required. It results the production of water, CO_2 and energy.
- Carbon dioxide is acid and toxic to tissues. Hence it is important to expel from the body.
- So, the respiration is a process which involves exchange of environmental oxygen and body's carbon dioxide.

Types of Respiration (on the basis of contact)

In general it is of two types

1. Direct Respiration :

- It is present in lower organisms.
- Body wall or surface is thin.
- Exchange of gases takes place directly.

- There is no blood.
- Exchange takes place on the body surface by diffusion.

2. Indirect Respiration:

- Here, there is no direct contact between the body cells and surrounding water or air.
- The body wall is thick.
- It is common in higher animals.
- Exchange of gases takes place through blood transport system.

Types of Respiration (on the basis of oxygen presence)

3. Aerobic Respiration:

- It occurs in the presence of oxygen.
- Food is completely oxidized.
- End products are $CO_{2,\ water}$ and large amount of energy.
- Such organisms are known as aerobes.
- Examples: Euglena, man

4. Anaerobic Respiration:

- It occurs in the absence of oxygen.
- Food is incompletely oxidized.
- End products are ethyl alchohol or lactic acid and less amount of energy.
- Such organisms are known as anaerobes.
- Examples: Taenia, skeletal Muscle tissue.
- Mammalian RBCs show anaerobic respiration as they lack mitochondria.

Organs of Respiration in Animal Kingdom:

- Protozoa: Body surface.
- Porifera: Body surface (canal system).
- Coelenterata: Body surface.
- Helminthes: Mostly anaerobes. Body surface.
- Annelida: Skin (cutaneous respiration).
- Arthropoda: Trachea, gills, ctenidium, book lungs.
- Mollusca: ctenidium, pulmonary sac (lungs).
- Echinodermata: Tube feet.
- Hemichordata :Gills
- Urochordata: branchial sacs (gills).

- Cephalochordata: Gills
- Fishes: Gills and air bladder.
- Amphibia: Skin, Buccal cavity, Lungs.
- Reptilia: Lungs.
- Birds: Lungs, Air sacs.
- Mammalia: Lungs

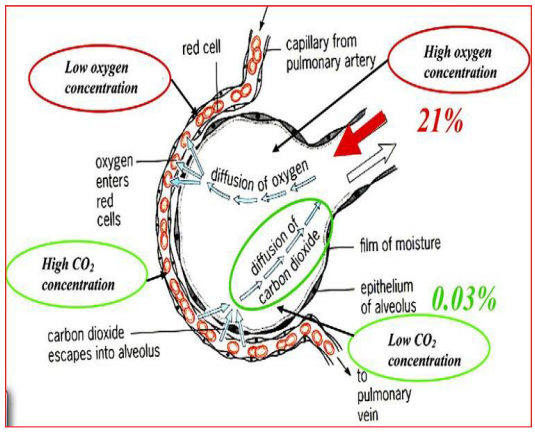
Phases of Respiration

Two phases are present in aerobic respiration.

- **External Respiration or Breathing:** It is the exchange of gases between surrounding medium and respiratory organs. It is a physical process and depends on the principle of diffusion. No energy is required. It do not involve in energy production. Food is not oxidized. Enzymes are not involved.
- **Internal Respiration or Tissue/Cellular Respiration:** The exchange of oxygen and carbon dioxide between the blood and body cells is known as Internal respiration. It is a Physico chemical process. It also depends on the principle of diffusion. It involves in energy production. Food is oxidized. Many enzymes are involved.

Principle of gases Exchange

- The gases exchange is purely physical process and depends on principle of diffusion. Here the flow of the oxygen and carbon dioxide takes place from a region of higher concentration to a region of lower concentration or low partial pressure.
- The partial pressure (Po_2) of oxygen in air or water is about 159nm (760mmHg).It is about 104 mmHg in alveoli and 40mmHg in blood capillaries.
- Therefore, a pressure gradient is created and it is responsible for the diffusion of oxygen from air into the blood and tissues.
- Similarly, the Pco_2 of carbon dioxide in blood capillaries is about 46mmHg. It is 36 mm Hg in alveoli. In air it ranges from 6-10 mmHg.
- This difference in partial pressure is responsible for the diffusion of carbon dioxide from tissue to lungs and to atmosphere.



Characteristics of Respiratory surface

- The external respiration depends upon the principle of diffusion.
- So, for the efficient exchange of gases the respiratory surface must have following characteristics.
- a). It must be thin
- b).It must be permeable for Oxygen and carbon dioxide.
- C) It must be moist.
- It must he highly vascular.
- It must be direct contact with the surrounding medium (water/air).
- It must have larger surface area.
- Presence of respiratory pigment in many animals increases the carrying capacity of gases.
- In Vertebrates, there is a progressive increase in the surface area of the respiratory surface. It increases the efficiency of respiration.

Respiratory system in Mammals (Man).
It is formed of two parts.
I. Respiratory tract
II. Respiratory organs.

Respiratory tract: It has following parts.

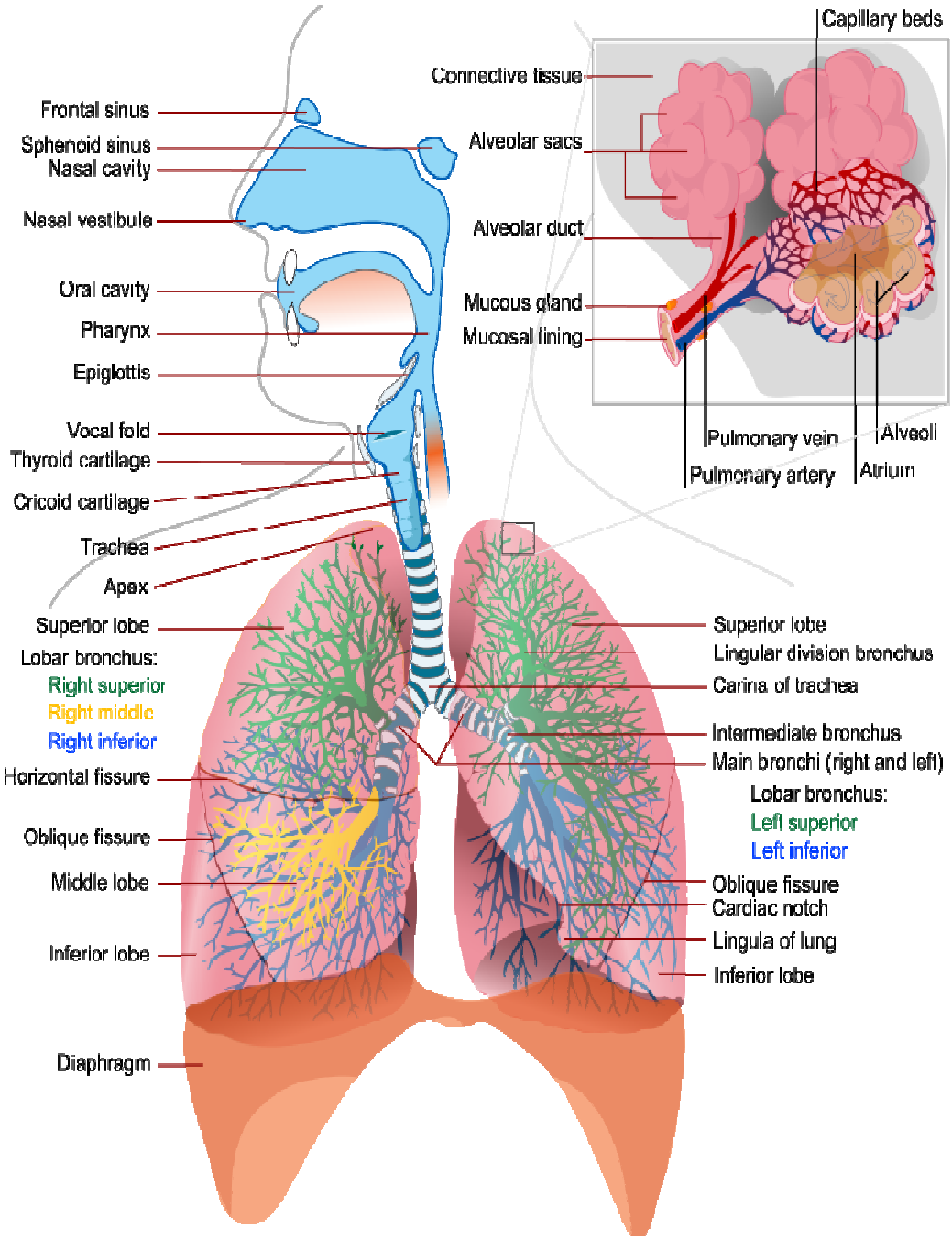
a. **Nostrils:** paired, small and oval apertures present at the lower surface of the nose.
b. **Nasal chambers**: Paired, large chambers. Separated by nasal septum. Anterior part is lined by hair and act as filter to prevent the entry of the dust. Middle part is lined by glandular epithelium and act as air conditioner.

The posterior part is lined by olfactory epithelium (Schneidarian membrane).It helps in smelling.

c. **Internal nares**: Present on the roof of pharynx.
d. **Laryngo pharynx**; Lower part of the pharynx opened into glottis. It closed by epiglottis during the swallowing of the food.
e. **Larynx**; It is thin and tubular. Known as voice box. It is supported by four cartilages. They are 1 cricoid, 1 thyroid and 2 arytenoids. They prevent collapsing the trachea from air pressure.
f. **Trachea:** Also known as wind pipe. Thin walled and tubular. It runs downward through the neck. It is supported by 16-20 dorsally incomplete C shaped cartilaginous rings. It is lined by pseudo stratified and ciliated epithelium.
g. **Bronchi:** Trachea is divided into two primary branches in the thoracic part. They are known as primary bronchi. Each primary bronchus enters in its respective lung. It is also supported by cartilaginous rings. They further divide and redivide to form secondary, tertiary and terminal bronchi. The cartilaginous rings extend up to the tertiary bronchi. They are about tertiary bronchi 10 in number. They further divide to form bronchioles. The final branch is known as terminal bronchiole which is of 0.5 mm in diameter. It opens into alveoli or air sac which is about 0.1 mm in diameter. It is the site of respiration. It is lined by squamous epithelium and glandular. They are about 750 millions of alveoli in the both the lungs which provide 100 sq.m. surface area of respiration. It is about 50 times more than that of skin. Therefore lungs provide much efficient respiratory organs than the skin. Each alveoli itself is known as mini lung.

II. Respiratory organs.

- Lungs are the respiratory organs in mammals including man.
- They are paired, soft, elastic and spongy.
- Present in thoracic cavity one on either side of the heart.
- Covered by two layered pleural membrane. Between these layers pleural cavity is present. It is filled with pleural fluid. It allows free friction less movements of lungs. It also protects the lungs from mechanical shocks.
- Each lung is conical shaped.
- Externally it is divided into lobes by oblique grooves. Left lung is divided into two lobes while right lung is divided into three lobes.
- Internally a network of branches is present. It is known as bronchial intercom. It is formed by the repeated division of primary bronchi.



A schematic view of the human respiratory system.

Mechanism of Breathing:

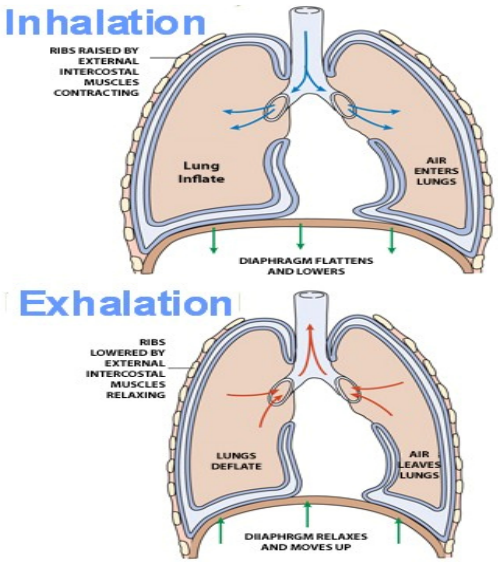
It has two phases. 1. Inspiration

Inspiration:

- The intake of fresh air in the alveoli is known as inspiration.
- It is an active process and involve following muscle contractions.
- **a)**. **Phrenic muscles**: They extend from diaphragm to ribs and vertebral column. When they contract, the diaphragm is flattened. As a result thoracic cavity increases anterio posteriorly.
- **b**).**External Inter costal muscles**: They are 11 pairs present between 12 pairs of ribs. When they contract, ribs are pulled forward, downward and outward. It increases thoracic cavity dorso ventrally and laterally.
- **C). Diaphragm:** It is present in the abdominal cavity. It separates the abdominal and thoracic cavity. It is made up of involuntary muscles and found only in mammals. During inspiration it becomes flat. During expiration diaphragm is relaxed. It is supplied by phrenic nerves.

Expiration:

- It is a passive process.
- Involves the expelling out of air with carbon dioxide.
- External intercoastal muscle relaxed and internal inters coastal muscles assist. Abdominal muscles also assist.
- Ribs fall and diaphragm become dome shaped.
- Thoracic cavity decrease and air is forced out.



Control of Breathing:

- **Conscious control:**
- Conscious control of breathing is common in many forms of meditation, specifically forms of yoga for example pranayama.
- In swimming, cardio fitness, speech or vocal training, one learns to discipline one's breathing, initially consciously but later sub-consciously.
- The conscious breathing can affect the reticular formation in the brainstem which autonomously controls breathing and the cardiovascular system.
- Thus conscious control of breathing and its effect on the cardiovascular system is the mystery behind practices of yoga and meditation.

Unconscious control

- It is controlled by specialized centers in the brainstem.
- When carbon dioxide levels increase in the blood, it reacts with the water in blood, producing carbonic acid. Lactic acid produced by fermentation during exercise also lowers pH.
- The drop in the blood's pH stimulates chemoreceptors in the carotid and aortic bodies as well as those inside the respiratory center in the medulla oblongata. Chemoreceptors send more nerve impulses to the respiration centre in the medulla oblongata and pons in the brain. These, in turn send nerve impulses through the phrenic and thoracic nerves to the diaphragm.

Special Respiratory movements:

- **Cough:** The forcible expiration preceeded by prolonged inspiration. It is a reflex action. Stimulation takes place from trachea to lung. Centre is medulla oblongata. Cough air comes out through the mouth.
- **Sneeze:** It is also a reflex action stimulated by olfactory epithelium. Air is exploded through the mouth.
- **Yawning:** It is prolonged inspiration due to increase of carbon dioxide concentration in lung.
- **Hiccough:** It is a noisy inspiration due to muscular spasm of diaphragm at regular intervals. It occurs due to sudden sucking of air through vocal cords.
- **Branchial Asthma:** It is difficult breathing. More mucus is secreted in alveoli. Occurs due to muscular spasm of smooth muscles of alveoli, bronchioles. Cough start to force out the mucus.

Respiratory Diseases:

- **Common cold:** It is a viral infectious disease of the upper respiratory tract which primarily affects the nose. Symptoms include coughing, sore throat, runny nose, sneezing, and fever which usually resolve in seven to ten days.
- **Pneumonia**: It is an inflammatory condition of the lung affecting primarily the microscopic air sacs known as alveoli. It is usually caused by infection with viruses or bacteria and less commonly other microorganisms, certain drugs and other conditions such as autoimmune diseases. Characterized by a high neutrophil count, e.g. asthma, cystic fibrosis, emphysema, chronic obstructive pulmonary disorder or acute respiratory distress syndrome. symptoms include a cough, chest pain, fever, and difficulty breathing.
- **Restrictive Lung disease**: Restrictive lung diseases are a category of respiratory disease characterized by a loss of lung compliance, causing incomplete lung expansion and increased lung stiffness, such as in infants with respiratory distress syndrome.
- **Tuberculosis**, **MTB**, or **TB**: It is a widespread, and in many cases fatal, infectious disease caused by Mycobacterium *tuberculosis*. Tuberculosis typically attacks the lungs, but can also affect other parts of the body. Symptoms of active TB infection are a chronic cough with blood-tinged sputum, fever, night sweats, and weight loss. Bacillus Calmette-Guérin (BCG) is the most widely used vaccine.

Pulmonary air volumes and Lung capacities:

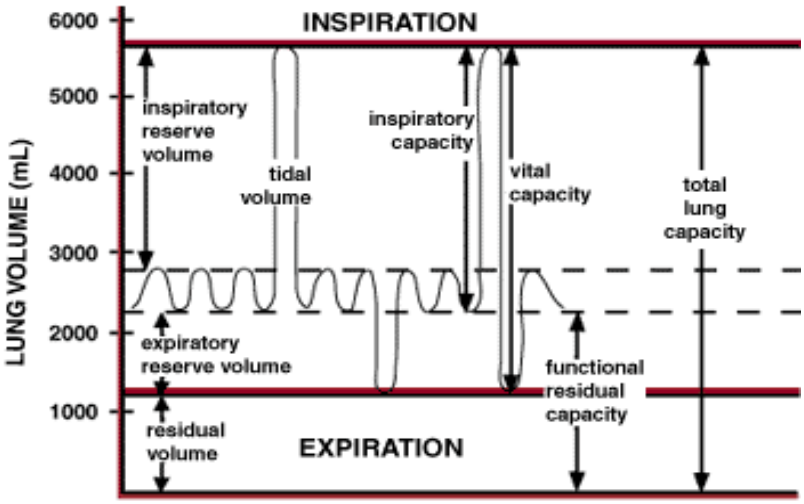
The changes in the volume of air into and out of the lungs can be measured by spirometer or repirometer. The graph showing the changes in the pulmonary volumes and capacities is called as spirogram.

The spirogram has following values:

- **Tidal Volume (TV):** It is the volume of air inspired or expired in each normal breath. It is about 500ml in the average adult man.
- **Inspiratory Reserve Volume (IRV):** It is forced inhalation after normal inspiration. It is also known as complimentary air volume. It is the deepest possible inspiration. It is about 2000-3000 ml.
- **Expiratory Reserve Volume (ERV):** It is forced expiration after normal expiration. It is also known as supplimentay air volume. It is the deepest possible expiration. It is about 1000-1500 ml.

- **Residual Volume (RV):** This is the air that remains in the lungs after forcible expiration. It is about 1200-1400ml.
- **Vital Capacity (VC):** It is the largest possible expiration after largest possible inspiration. It is equal to tidal volume, inspiratory reserve volume and expiratory reserve volume. VC= TV+IRV+ERV. i.e. = 500+3000+1200 =4700ml. The range of vital capacity = 3.5 -4.5 litres in a normal adult man.\
- **Total Lung capacity (TLC):** It is the total amount of air in the lungs after the maximum inhalation. TLC =VC+ RV. It is about 5-6 litres.

All pulmonary volumes and capacities are about 20-25 per cent less in women than in men.



Graph of Pulmonary Volumes

Exchange of gases: Gas exchange is a biological process through which different gases are transferred in opposite directions across a specialized respiratory surface. Gases are constantly required and produced as a by-product of cellular and metabolic reactions. Gases must first dissolve in a fluid in order to diffuse across a membrane. Therefore all gas exchange systems require a moist environment. Therefore, an efficient system for their exchange is extremely important. It occurs in two phases.

- 1. External Respiration or Pulmonary gas exchange.
- 2. Internal Respiration or Gases exchange in Tissues.

1. **External Respiration or Pulmonary gas exchange.**

- It involves the exchange of oxygen of air and carbon dioxide of blood at lung site.
- The pO_2 in alveoli =100mm Hg.
- The pO_2 in venous blood =40 mmHg.
- The difference in partial pressure =60mmHg.
- By this difference O_2 enter in from alveoli to blood.
- Similarly, pCO_2 in alveoli = 40mmHg.
- pCO_2 level in venous blood is = 46 mmHg.
- Difference in pressure gradient =6mmHg.
- By this difference CO_2 diffuse out in alveoli from blood. Diffusing capacity of respiratory membrane is 20 times more to CO_2 than O_2. So, CO_2 diffuse out at faster rate.

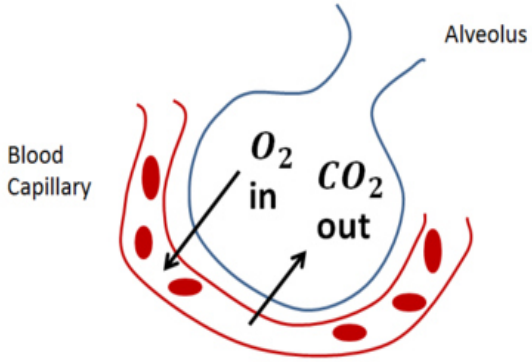


Fig. Gas exchange between a capillary and an alveolus

2. **Internal Respiration or Gases exchange in Tissues.** The oxygenated blood from lungs is carried to the heart which supplies it to the body tissues. The exchange occurs between the oxygen of blood and the carbon dioxide of the body cells.

Transport of oxygen: In lower, smaller and sluggish animals the oxygen requirements are low. So oxygen is mainly transported in dissolved form. But in higher organisms and metabolically active animals more oxygen is required. So, oxygen is mainly transported in bound form with some respiratory pigment. Hence blood transports the oxygen in two ways.

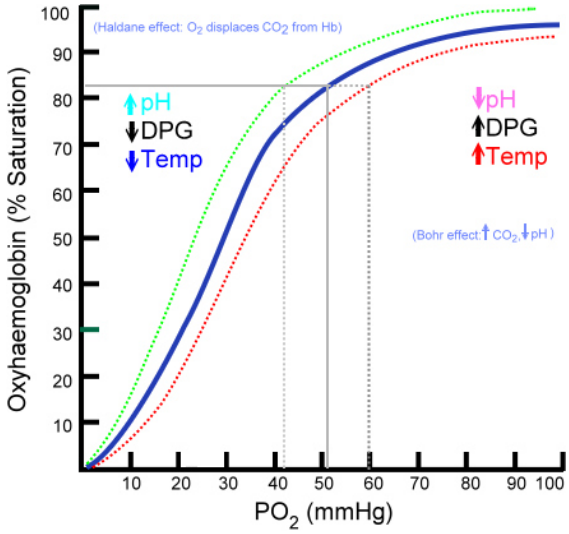
In solution: About 1-3% of oxygen is transported by plasma in dissolved form.

As oxy haemoglobin:

- About 97-99% of oxygen is transported in this form in RBCs.
- Heamoglobin is formed of 4 iron containing porphyrin prosthetic groups attached to a globulin protein.
- Each porphyrin molecule is formed of 4 pyrole rings attached to iron element (Fe^{++}).at the centre.
- Globulin is formed of 4 poly peptide chains (2 alpha and 2 beta chains). Each Fe^{++} can bind one molecule of oxygen to form oxyhaemoglobin.
- So one Heamoglobin molecule can bind up to 4 molecules of oxygen.

Binding of Oxygen to Hemoglobin: Oxygen Saturation (Dissociation) Curve:

- It is also known as oxygen equilibrium curve.
- It expresses the relationship between P_{O_2} and the bound oxygen content.
- Percent saturation is plotted against O_2 tension.
- The hemoglobin molecule has four binding sites for oxygen molecules. Actually, some of the Hb normally in red blood cells cannot bind oxygen (it is either metHb or HbCO) and the experimentally determined oxygen-binding capacity of hemoglobin (C_{Hb}) is 1.34 ml O_2per gram Hb. In 100 ml of blood, there is about 15 g of Hb, so that 100 ml of blood has the capacity to bind 20.1 ml of oxygen. This quantity is called the oxygen-binding capacity of blood (C_B). Note that C_B is proportional to the haematocrit of the blood



Hemoglobin saturation curve.

The curve shows that there is progressive increase in the percent saturation of haemoglobin with the increase in P02 upto a level and becomes constant (30% saturation at 20mm Hg, 75% at 40 mmHg, and 97% about 95 mmHg). So a normal oxygen disassociation curve is sigmoid.

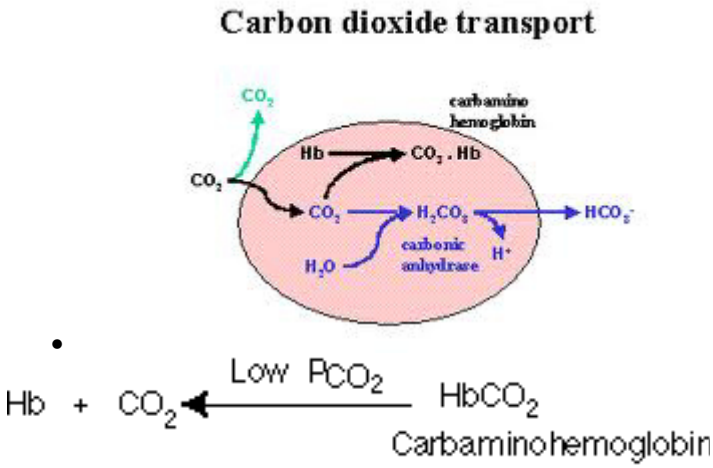
Factors affecting the oxygen disassociation curve:

- **Pc02:** The oxygen disassociation curve turns to right and oxygen binding capacity of haemoglobin is lowered with increase in Pc02.It is known as Bohr's effect.
- **Temperature:** The oxygen disassociation curve turns to right with increase in temperature.
- **pH:** The oxygen disassociation curve turns to right with decrease in pH (acidity).Transport of carbon dioxide: CO_2 is produced in the tissues as an end product of cell respiration. From the cells CO_2 diffuses into blood in exchange with the oxygen of blood. It is transported both by plasma and haemoglobin. Blood transports the CO_2 in three ways:
- **As carbonic acid:** About 7% of CO_2 is transported by this method. Carbonic acid is formed by the diffusion of CO_2 in water. Reaction occurs in the presence of an enzyme carbonic anhydrase in RBCs and stimulated by low Po_2.

$$CO_2 + H_2o \longrightarrow H_2CO_3 \longrightarrow HCO_3^- + H^+$$

The H_2CO_3/HCO_3^- combination acts as the primary buffer of the blood. The hydration of carbon dioxide is a slow process but occurs rapidly in the red blood cells because a high concentration of the enzyme carbonic anhydrase catalyzes the reaction.

- As carbamino haemoglobin: About 10-15 % of carbon dioxide is transported bound to haemoglobin and plasma proteins. Carbon dioxide combines reversibly with haemoglobin to form carbamino haemoglobin. Carbon dioxide does not bind to iron but it binds to amino groups on the polypeptide chains of haemoglobin. Carbon dioxide also binds to amino groups on the polypeptide chains of plasma proteins.
- Carbaminohemoglobin (Tissues) : Of the total carbon dioxide in the blood, 23% binds to the globin portion of the hemoglobin molecule to form carbaminohemoglobin, as written in this equation:



Carbaminohemoglobin forms in regions of high PCO_2, as blood flows through the systemic capillaries in the tissues.

CO_2 Transport: Bicarbonate Ions (Tissues)

- Of the total carbon dioxide in the blood, 75% is converted into bicarbonate ions within the red blood cells, in a sequence of reversible reactions. The bicarbonate ions then enter the plasma.
- In regions with high PCO_2, carbon dioxide enters the red blood cell and combines with water to form carbonic acid. This reaction is catalyzed by the enzyme carbonic anhydrase. The same reaction occurs in the plasma, but without the enzyme it is very slow.
- Carbonic acid dissociates into hydrogen ions and bicarbonate ions. The hydrogen ions produced in this reaction are buffered by binding to hemoglobin. This is written as HHb.

In order to maintain electrical neutrality, bicarbonate ions diffuse out of the red blood cell and chloride ions diffuse in. This is called the chloride shift.

- Within the plasma, bicarbonate ions act as a buffer and play an important role in blood pH control.

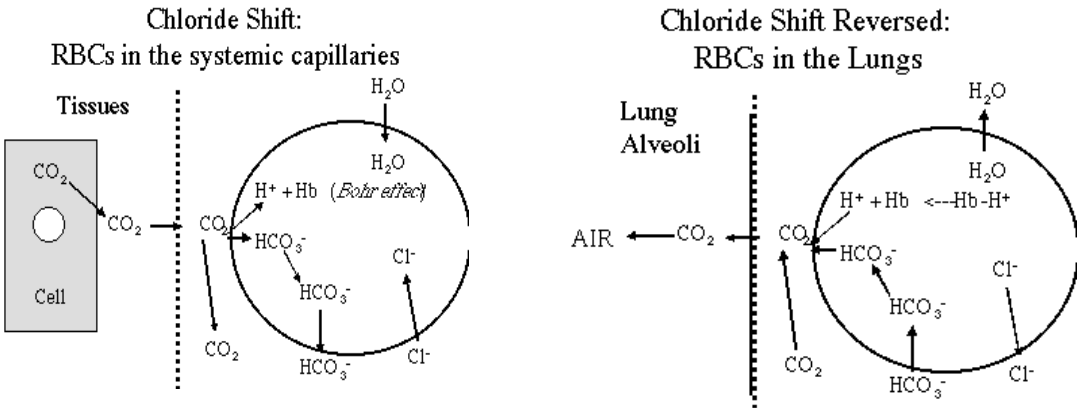
CO_2 Transport: Bicarbonate Ions (Lungs)

- In the lungs, carbon dioxide diffuses out of the plasma and into the alveoli. This lowers the PCO_2 in the blood, causing the chemical reactions to reverse and proceed to the left.

• In the lungs, the bicarbonate ions diffuse back into the red blood cell, and the chloride ions diffuse out of the red blood cell. Recall that this is called the chloride shift.
• The hydrogen ions are released from hemoglobin, and combine with the bicarbonate ion to form carbonic acid.
• Carbonic acid breaks down into carbon dioxide and water. This reverse reaction is also catalyzed by the enzyme carbonic anhydrase.

Hamburger's Phenomenon (Chloride shift):

- CO_2 produced from tissue metabolism enters into RBC. This CO_2 reacts with water and form carbonic acid. This reaction is catalysed by carbonic anhydrase.
- Carbonic acid is buffered by potassium and $KHCO_3$ id formed. The cell membrane of RBC is permeable for K^+ and Na^+ ions but not for Cl^- and $HCO3^-$.
- Cl^- ions enters in RBC and KCL is formed. Now $HCO3^-$ ions become free which come outside and react with Na^+ to form $NaHCO^3$. About 8o% of CO_2 is transported towards respiratory organs in this form.
- Entering Cl^- ions into RBC is known as positive chloride shift. Shifting of Cl^- ions from RBC into plasma is known as negative chloride shift.



CHAPTER 8
THE CARDIOVASCULAR SYSTEM

Background:

- Every cell needs a regular supply of nutrients, oxygen etc. to provide energy for the growth and repair.
- It also needs a constant removal of wastes like $Co_{2,\ ammonia}$, urea etc. Otherwise they become toxic to the body.
- In lower organisms, as they are in direct contact with the surrounding water, exchange of the materials takes place directly between the cell and water.
- But in higher multicellular organisms there is no direct supply of the material. Hence circulatory system is needed.

Functions of Circulatory system:

- Help in the transportation of nutrients like glucose, aminoacids and vitamins.
- Help in the transportation of wastes like ammonia and urea.
- Help in the transportation of respiratory gases.
- Help in the transportation of hormones.
- Help in the transportation of intermediate metabolites like lactic acid.
- Help in the transportation of heat.
- Help in the transportation of water

Circulatory system in Animal kingdom:

- Protozoa: Absent. Protozoans show intra cellular circulation (Cyclosis).
- Porifera: Absent. Canal system is present. Water circulates.
- Cnidarians: Absent.
- Helminthes: Absent. Augmented by parenchyma/mesenchyma
- Annelida: First time closed blood circulatory system is evolved.
- Annelida: Open type blood circulatory system is present.
- Mollusca: Open type blood circulatory system is present.
- Echinodermata: poorly developed.

Types of circulatory system: It is of two types:

1. Open type.
2. Closed type.

Open type:

- It is found in arthropods and molluscans.
- Blood flow in open spaces called sinuses.
- The sinuses join to form haemocoel.
- Blood flow at low velocity and at low pressure.
- There is a direct contact between the cells and blood.
- Respiratory pigment may be present or absent. If present it is dissolved in plasma as RBCs are absent.

Closed type:

- It is found in higher animals including man.
- Blood flow in closed vessels (arteries and veins).
- The sinuses are absent.
- Blood flow at high velocity and at high pressure.
- There is no direct contact between the cells and blood.
- Respiratory pigment is present in RBCs.
- It is more efficient system of circulation.

Circulatory system in Mammals (Man)

It consists of blood, heart and blood vessels.

Heart:

- It is the pumping organ of the body.
- It is thick, muscular and contractile organ.
- It is situated in the middle of the mediastinum behind the breastbone in the chest, at the level of thoracic vertebrae T5-T8.
- It is usually felt to be on the left side because the left heart is stronger, since it pumps to all body parts.
- The pericardium encloses the heart and also attaches to the mediastinum via the pericardia pleura, providing anchorage for the heart. The back surface of the heart lies near to the vertebral column, and the front surface sits deep to the sternum and costal cartilages.
- The venae cavae, and the great arteries, the aorta and pulmonary trunk, are attached to the upper surface of the heart. The lower tip of the heart lies just to the left of the sternum between the junction of the fourth and fifth ribs.
- The shape of the heart is similar to a pinecone, rather broad at the base and tapering to the apex. An adult heart has a mass of 250–350 grams.

Chambers:

- The heart has four chambers, two upper atria, the receiving chambers, and two lower ventricles, the discharging chambers.
- The atria are connected to the ventricles by the atrio ventricular valves and they are separated by the coronary sulcus.
- The right atrium receives deoxygenated blood from the body and the left atrium receives oxygenated blood from the lungs.
- There is an ear-shaped structure in the upper right atrium called the right atrial appendage, or auricle, and another in the upper left atrium, the left atrial appendage. The right atrium and the right ventricle together are sometimes referred to as the *right heart* and this sometimes includes the pulmonary trunk. Similarly, the left atrium and the left ventricle together are sometimes referred to as the *left heart*.
- These are separated by the posterior inter ventricular sulcus. The left heart pumps to the systemic circulation and the right heart pumps to the pulmonary circulation.
- The cardiac skeleton is made of dense connective tissue as collagen and this gives structure to the heart and forms the atrio ventricular septum which separates the right from the left heart, and the fibrous rings which serve as

bases for the four heart valves. The cardiac skeleton also provides an important boundary in the heart's electrical conduction system since collagen cannot conduct electricity.

- The chordae tendinae attach to the atrioventricular valve cusps. The interatrial septum separates the atria and the interventricular septum separates the ventricles. The interventricular septum is much thicker than the interatrial septum, since the ventricles need to generate greater pressure when they contract.

Valves:

- It is four in number. They lie along the same plane.
- The valves ensure unidirectional blood flow through the heart and prevent backflow. Between the right atrium and the right ventricle is the tricuspid valve. The right ventricle receives blood from the right atrium through the tricuspid valve. This consists of three cusps (flaps or leaflets), made of endocardium reinforced with additional connective tissue. Each of the three valve-cusps is attached to several strands of connective tissue, called chordae tendineae (tendinous cords).
- They connect each of the cusps to a papillary muscle that extends from the lower ventricular surface. These muscles control the opening and closing of the valves. The three papillary muscles in the right ventricle are called the anterior, posterior, and septal muscles, which correspond to the three positions of the valve cusps.
- Between the left atrium and left ventricle is the mitral valve or bicuspid valve. It has two cusps which are also attached via chordae tendinae to two papillary muscles projecting from the ventricular wall.
- The semi lunar pulmonary valve is located at the base of the pulmonary artery. This has three cusps which are not attached to any papillary muscles. When the ventricle relaxes blood flows back into the ventricle from the artery and this flow of blood fills the pocket-like valve, pressing against the cusps which close to seal the valve. The semi lunar aortic valve is at the base of the aorta and also is not attached to papillary muscles. This too has three cusps which close with the pressure of the blood flowing back from the aorta.

Right heart

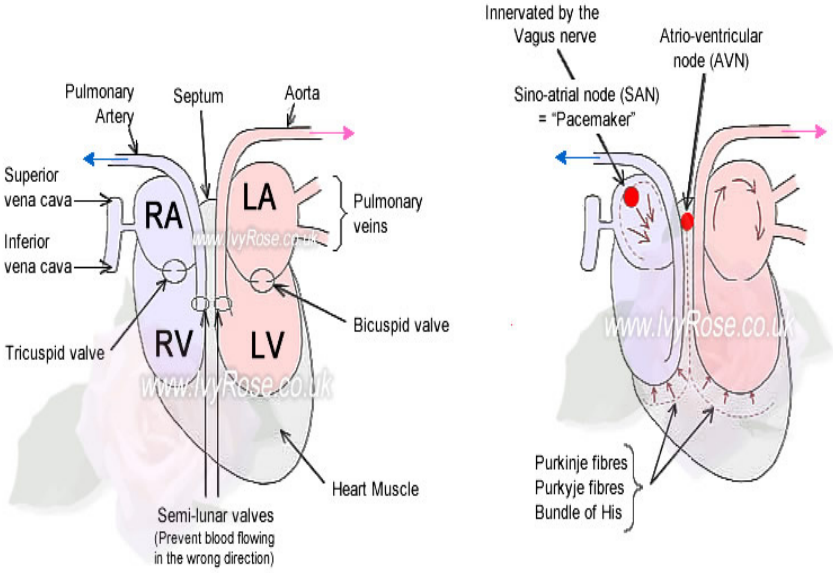
- The two major systemic veins, the superior and inferior venae cava open into the right atrium. The superior vena cava drains the blood from above the diaphragm and empties into the upper back part of the right atrium.
- The inferior cava drains the blood from below the diaphragm and empties into the back part of the atrium below the opening for the superior cava.
- In the wall of the right atrium is an oval-shaped depression is present. It is known as the fossa ovalis, (vestigial) which is a remnant of an opening in the fetal heart known as the foramen ovale.
- The atria receive venous blood on a nearly continuous basis, preventing venous flow from stopping while the ventricles are contracting. While most ventricular filling occurs while the atria are relaxed, they do demonstrate a contractile phase when they actively pump blood into the ventricles just prior to ventricular contraction. The right atrium is connected to the right ventricle by the tricuspid valve.
- When the myocardium of the ventricle contracts, pressure within the ventricular chamber rises. Blood, like any fluid, flows from higher pressure to lower pressure areas, in this case, toward the pulmonary trunk and the atrium. To prevent any potential backflow, the papillary muscles also contract, generating tension on the chordae tendineae. This prevents the flaps of the valves from being forced into the atria and regurgitation of the blood back into the atria during ventricular contraction.
- The walls of the right ventricle are lined with trabeculae carneae, ridges of cardiac muscle covered by endocardium. When the right ventricle contracts, it ejects blood into the pulmonary trunk, which branches into the left and right pulmonary arteries that carry it to each lung. At the base of the pulmonary trunk is the pulmonary semi lunar valve that prevents backflow from the pulmonary trunk.

Left heart

- After gas exchange in the pulmonary capillaries, blood returns to the left atrium high in oxygen via one of the four pulmonary veins. Blood flows nearly continuously from the pulmonary veins.
- Most blood flows passively into the heart while both the atria and ventricles are relaxed, but toward the end of the ventricular relaxation period, the left atrium will contract, pumping blood into the ventricle. This

atrial contraction accounts for approximately 20 percent of ventricular filling. The left atrium is connected to the left ventricle by the mitral valve.

Although both sides of the heart will pump the same amount of blood, the muscular layer is much thicker in the left ventricle compared to the right, due to the greater force needed here. The left ventricle is the major pumping chamber for the systemic circuit. It ejects blood into the aorta through the aortic semi lunar valve.



Physiology

- The heart functions as a pump and acts as a double pump in the cardiovascular system to provide a continuous circulation of blood throughout the body.
- This circulation includes the systemic circulation and the pulmonary circulation. Both circuits transport blood but they can also be seen in terms of the gases they carry.
- The pulmonary circulation collects oxygen from the lungs and delivers carbon dioxide for exhalation. The systemic circuit transports oxygen to the body and returns relatively deoxygenated blood and carbon dioxide to the pulmonary circuit.

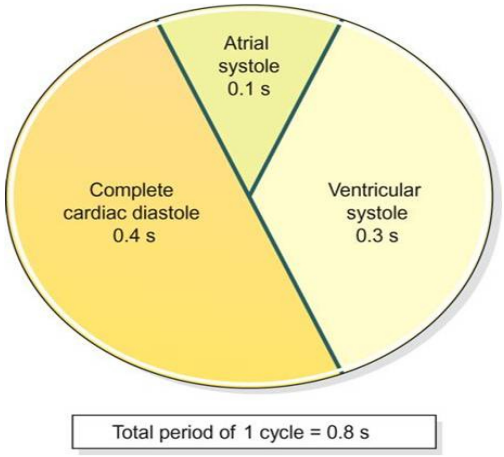
- Blood flows through the heart in one direction, from the atria to the ventricles, and out through the pulmonary artery into the pulmonary circulation, and the aorta into the systemic circulation.
- The pulmonary artery (also trunk) branches into the left and right pulmonary arteries to supply each lung. Blood is prevented from flowing backwards (regurgitation) by the tricuspid, bicuspid, aortic, and pulmonary valves.
- The function of the right heart is to collect de-oxygenated blood, in the right atrium, from the body (via the superior and inferior venae cavae).
- Then it is pumped into the right ventricle through the tricuspid valve and into the pulmonary artery through the semi lunar pulmonary valves.
- In pulmonary circulation carbon dioxide can be exchanged for oxygen in the lungs.
- In the left heart oxygenated blood is returned to the left atrium via the pulmonary vein. It is then pumped into the left ventricle through the bicuspid valve and into the aorta for systemic circulation. Ultimately in the systemic capillaries exchange with the tissue fluid and cells of the body occurs.
- The ventricles are stronger and thicker than the atria, and the muscle wall surrounding the left ventricle is thicker than the wall surrounding the right ventricle.

Cardiac Cycle and Heart Beats

- The rhythmic contraction and relaxation of auricles and ventricles is known as heart beats. Contraction is known as systole while relaxation is known as diastole.
- All the chambers do not beat simultaneously.
- Right and left auricles contract simultaneously while both ventricles also work simultaneously.
- The period between ends of one heart beat to the end of next hear beat is called as cardiac cycle.
- The cardiac cycle is formed of three phases.
- Arterial Systole: It involves contraction of auricles from anterior to posterior side. It takes 0.1 second while diastole is about 0.3seconds.
- Ventricular Systole: It involves simultaneous relaxation of atria and contraction of ventricles. The auriculo ventricular valves close rapidly to prevent the back flow of blood from ventricle to auricles. The rapid closing

of valves produce first sound called "Lubb'. It is also known as systolic sound. Each ventricle pumps out about 70ml blood (stroke volume). Ventricular systole takes about 0.3 seconds.

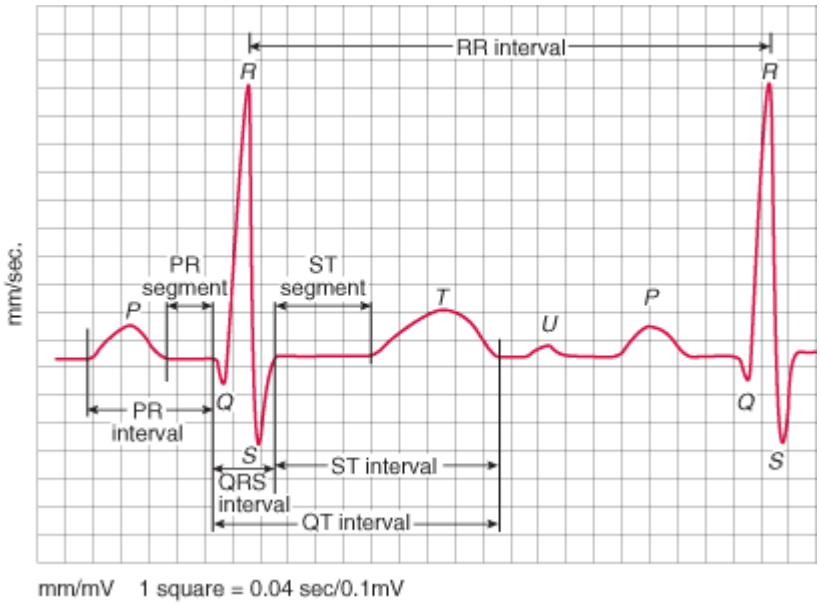
- Joint diastole: Ventricular systole is followed by the ventricular diastole. It is called as joint diastole or complete cardiac diastole. Semi lunar valves close rapidly to prevent back flow of the blood. It produces the second heart sound called 'Dubb'. It takes 0.4seconds. So, the cardiac cycle completed in 0.8 seconds.



Electrocardiography (ECG):

Electrocardiography is the recording of the electrical activity of the heart. Traditionally this is in the form of a trans thoracic (across the thorax or chest) interpretation of the electrical activity of the heart over a period of time. The graphic recording produced by this procedure is termed an electrocardiogram (also ECG or EKG).

An ECG is used to measure the heart's electrical conduction system. It picks up electrical impulses generated by the polarization and depolarization of cardiac tissue and translates into a waveform. The waveform is then used to measure the rate and regularity of heartbeats, as well as the size and position of the chambers, the presence of any damage to the heart.



Electro cardiogram

P wave:

The P wave represents atrial depolarization. It is generally upright. It represents right atrial activity, and the 2nd component represents left atrial activity.

PR interval:

The PR interval is the time between onset of atrial depolarization and onset of ventricular depolarization. Normally, it is 0.10 to 0.20 sec; prolongation defines 1st-degree atrioventricular block.

QRS complex:

The QRS complex represents ventricular depolarization. The Q wave is the initial downward deflection; normal Q waves last < 0.05 seconds. Q wave is considered abnormal if it exceeds. The R wave is the first upward deflection. Taller R waves may be caused by ventricular hypertrophy. The S wave is the 2nd downward deflection if there is a Q wave and the first downward deflection if not. Normally, the QRS interval is 0.07 to 0.10 sec.

QT interval:

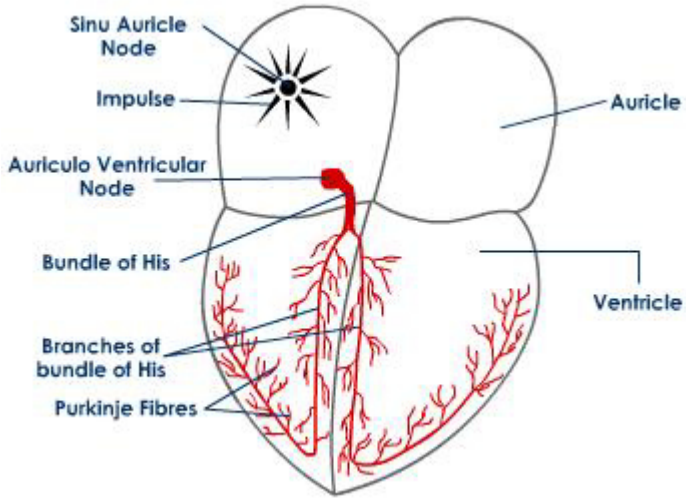
The QT interval is the time between onset of ventricular depolarization and end of ventricular repolarization.

ST segment:
The ST segment represents completed ventricular myocardial depolarization. Normally, it is horizontal along the baseline of the PR (or TP) intervals or slightly off baseline.

T wave:
The T wave reflects ventricular repolarization. It usually takes the same direction as the QRS complex. The T wave is usually smooth and rounded but may be of low amplitude in abnormalities.

U wave:
The U wave appears commonly in patients who have hypokalemia, hypomagnesemia, or ischemia. It is often present in healthy people.

Origin and Conduction of Heart Beat
The cardiac muscles of the heart have the property of excitability and conductivity. When these muscles are stimulated, they get excited and initiate waves of electric potential impulses are conducted along the special cardiac muscle fibres on the wall of the heart chambers.



Origin and Conduction of Heart Beat

- The impulse originates from the SA node. It lies on the right wall of the right auricle below the opening of the vena cava. It is also called pacemaker as it determines the rate of heart beat.
- The impulse originated from the sinu-auricular (SA node) node is picked up and propagated by a special system of tissues present in the heart. The conducting system includes the following components.

a) Auriculo ventricular node
b) Bundle of His (AV Bundle)
c) Purkinje fibres

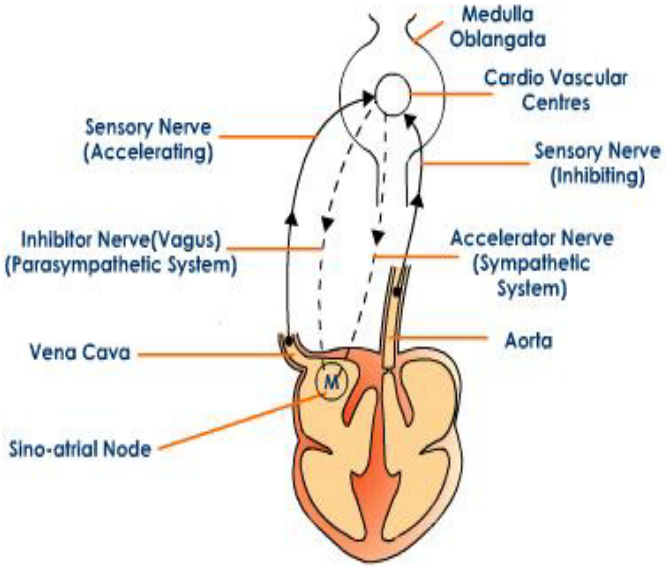
- The impulses arising from the sino auricular node is picked up by the auriculo ventricular node (AV node) located at the posterior right border of the inter auricular septum.
- It functions as a relay station and it transmits the impulses to other parts of the heart through the bundle of His.
- The bundle of His originates from the AV node as a bundle of tissue. Immediately after its origin it divides into 2 branches. These branches run along the inner border of each ventricle and reach the tip of the ventricle and then run upwards along the outer margin of the ventricle. The bundle of His and its branches produce minute branches called Purkinje fibres on the wall of the ventricles.
- During a heart beat, the auricles contract first and the ventricles contract later. This is because there is no muscular continuity between the auricles and the ventricles. The auricles receive the impulses directly from the SA node. The impulses reach the AV node about 0.03 seconds after their origin from the SA node. So the ventricles always contract after the auricles.

Regulation of Heart Beat

The heart beat is controlled by the nervous system, hormones, temperature and pH.

- Nervous control: It is associated with autonomous nervous system.SA node is connected to sympathetic nervous system. It secrets adrenalin or sympathetin which increases the heart beat. However, the inhibitory centre is associated with vagus or para sympathetic nerve fibres. They secrete acetyl choline which decreases the rate of heart beat.
- Hormonal Control: It consists of two hormones known as epinephrine (adrenaline) nor epinephrine (noradrenalin) secreted by medulla of adrenal gland. They can increase and decrease the heart beat as sympathetic and para sympathetic nervous system.
- Temperature: When air temperatures (and the humidity) soar, the heart pumps a little more blood, so pulse rate may increase, but usually no more than five to 10 beats a minute.

- pH: Low pH implies high CO_2 concentration in the blood. The heart will compensate by beating faster to get rid of the CO_2 and bring the blood closer to 7.4



Neurons connecting the heart to the cardiovascular system

Cardiovascular diseases

The causes of cardiovascular disease are diverse but atherosclerosis and hypertension are the most common. In addition, with aging come a number of physiological and morphological changes that alters cardiovascular function and lead to increased risk of cardiovascular disease, even in healthy asymptomatic individuals.

- Atherosclerosis: In this disease, an artery wall thickens as a result of invasion and accumulation of white blood cells (WBCs).Also known as fatty streaks. These accumulations contain living, active WBCs (producing inflammation) and remnants of dead cells, including cholesterol and triglycerides. It also includes calcium and other crystallized materials which form a plaque. The "fatty streaks" reduce the elasticity of the artery walls which eventually increase pulse pressure.
- Hypertension: Hypertension (HTN) or high blood pressure is a chronic medical condition in which the blood pressure in the arteries is elevated. High blood pressure is said to be present if it is often at or above 140/90 mmHg.

- Hypertension is classified as either primary (essential) hypertension or secondary hypertension. About 90–95% of cases are categorized as "primary hypertension" which means high blood pressure with no obvious underlying medical cause. The remaining 5–10% of cases categorized as secondary hypertension is caused by other conditions that affect the kidneys, arteries, heart or endocrine system.

CHAPTER 9
PHYSIOLOGY OF EXCRETION AND OSMOREGULATION

Back ground:

The process of removal of nitrogenous wastes along with excess water and pigments is called excretion. It maintains the homeostasis of the body. Elimination of metabolic waste products accompanying digestion and respiration and/ or maintenance of water and electrolytes is known as excretion.

- Maintain proper internal pH by removing excess acids and bases.
- Eliminate byproducts of nitrogen metabolism.
- Due to catabolism of proteins amino ($-NH_2$) group is released.
- The accumulation of $-NH_2$ group is very toxic.
- So it must be either used in the body or must be expelled out.
- Similarly, water is also formed due to oxidative phosphorylation and pigments are formed by the metabolism of haemoglobin of dead RBCs. Excessive of water is to be expelled to prevent the dilution of fluids.

Excretory organs:

- **Protozoa:** Contractile vacuole, Plasma membrane.
- **Porifera :** Absent. Excretion takes place by canal system.
- **Cnidaria:** Absent. Excretion takes place through body surface.
- **Helminthes:** Flame cells, Proto nephridia. Rennet cells.
- **Annelida:** Nephridia. Chlorogogan cells.

- **Arthropoda:** Malphigian tubules, Coxal glands, Green glands.
- **Mollusca:** Meta nephric kidney, Organs of Bojanus.
- **Echinodermata:** Tube feet.
- **Chordata :** Kidney

Important Nitrogenopus wastes: Different animals expel different nitrogenous wastes like ammonia, urea, uric acid etc.

Ammonia:

- Generally it is formed in aquatic animals.
- Soluble in water and highly toxic.
- Easily diffusible in water media.
- Animals which produce ammonia are known as ammonotelic.
- It is formed by the deamination of proteins.
- One gram of ammonia needs about 300-500ml of water to be expelled out of the body. So this process involves loss of considerable amount of water. That is the reason why ammonotelic excretion is found in aquatic animals.
- Examples: Hydra,Teleosts

Urea:

- It is characteristic of terrestrial animals.
- In higher animals it produced in liver by the deamination process.
- It is known as ornithine cycle.
- Animals which produce urea are known as ureotelic.
- One gram of urea needs about 50ml of water to be expelled out. So it is suitable for terrestrial mode of life with tendency to conserve water. Example. Man, Elasmobranch fish.

Uric acid:

- It is characteristic of animals where conservation of water is needed.
- Uric acid is formed in liver.
- It is formed due to absence of arginase enzyme.
- Animals which excrete uric acid are known as uricotelic.
- It is found in birds, insects and desert animals.
- It is formed from ammonia and purines (adenine and guanine) in liver and kidney. In human beings uric acid is formed by the catabolism of purines.
- It is less soluble in water. One gram of uric acid needs 10 ml of water to be expelled out. Besides it is less toxic and can remain in the tissues for long period. So excretion of uric acid is of greater advantage to land animals.

Other wastes:

- Tri-methyl amine- oxide: Soluble in water. Ex. Bony fishes.
- Guanine: By spider.
- Hippuric acid: mammals, formed by the combination of glycine.
- Ornithinic acid: Birds.
- Creatine: Derivative of creatine phosphate. Ex.mammals.
- Allontoin: Embryonic waste.
- Carbon dioxide: End product of respiration.
- Bilirubin: Toxic bile pigment formed in liver by dead RBCs.

Excretory system of Man:

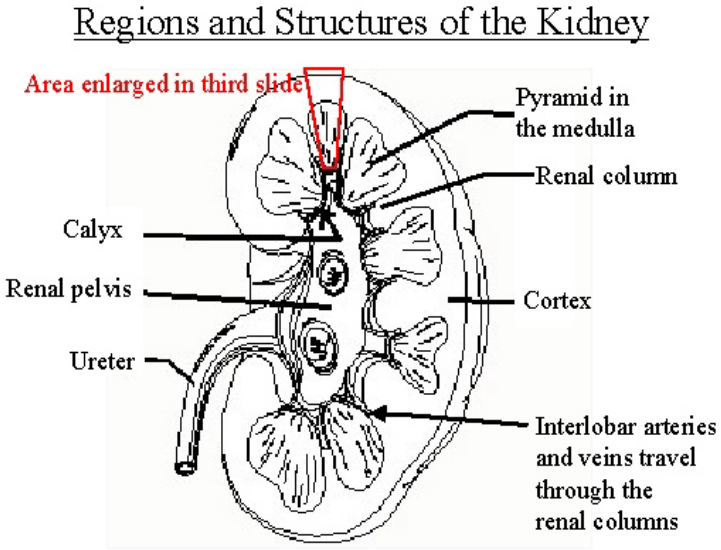
It is formed of

I. One pair of kidneys.
II. One pair of ureters.
III. A urinary bladder.
IV. A urethra.

Kidneys:

- They are the major excretory organs of man and other vertebrates.
- They are paired, large sized, bean shaped, dark red and present in upper part of the abdominal cavity one on either side of the vertebral column just below the diaphragm.
- Located between the last thoracic vertebra and the third lumbar vertebra. They are protected by the last 2 ribs. The kidneys are covered by the peritoneum in the front and on the side and they rest against the abdominal muscles. Their position is slightly asymmetrical, the left kidney being a little higher than the right.
- Each kidney is bean shaped. The outer surface is convex and the inner surface is concave. The inner surface has a deep notch called hilus.
- The kidney is divided into 2 regions, an outer region called renal cortex and the inner region termed renal medulla. The medulla is subdivided into conical masses, the renal pyramids, each having a broad base towards the cortex and a narrow end called renal papilla towards the pelvis. The renal papilla projects into the wide funnel - like structure called the pelvis. The pelvis leads into the ureter between the pyramids. The cortex extends into the medulla as renal column of Bertin.

- Internally each kidney is formed of about one million uriniferous or renal tubules or nephrons. They are embedded in renal fat called renal facia. It forms a shock - absorbing cushion and the renal fascia fixes the kidney to the abdominal walls. They help in urine formation.



Ureters:

- They are paired, long, narrow, muscular and tubular structures.
- Each ureter arises from the hilus of the kidney.
- They run backwards and open into urinary bladder.
- These are lined by transitional epithelium.
- They conduct the urine from kidneys to urinary bladder.

Urinary bladder:

- It is large, thin walled, distensible, pear shaped sac present in the pelvic region of the abdominal cavity.
- It is lined by smooth muscles and transitional epithelium.
- It temporarily stores the urine.

Urethra:

- It is muscular and tubular.
- In female it is about 4cm long and opens directly outside through vaginal orifice.

- In man, it joins the ejaculatory duct to form urino gential canal which passes through the penis. It is about 20 cm long and common passages for both urine and semen.

Structure of a Nephron (Uriniferous tubule):

Nephron is the basic structural and functional unit of the kidney. Its chief function is to regulate the concentration of water**.** A nephron consists of a twisted tubule closed at one end, open at the other with a network of associated blood vessels. Each kidney of man is formed of about one million nephrons.

Each nephron has a length of about 3 cm. It is differentiated into 4 regions having different anatomical features and different physiological roles.

Nephron:

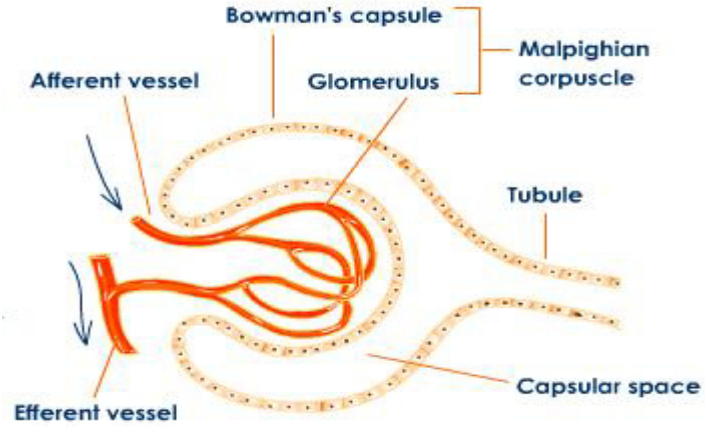
The 4 regions are:

(a) Bowman's capsule

(b) Proximal convoluted tubule (PCT)

(c) Loop of Henle

(d) Distal convoluted tubule (DCT)



(a) Bowman's Capsule

- These were first reported by M.Malphigi (1966).
- It is a large double walled cup.
- It lies in the renal cortex.
- It contains a tuft of capillaries called glomerulus.

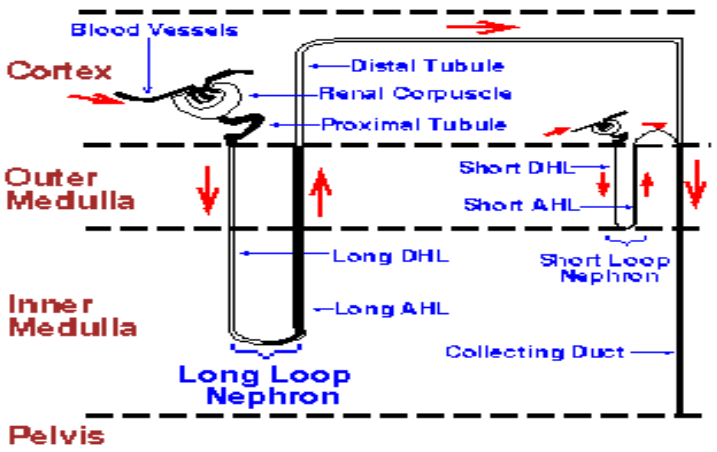
- The space between the two walls of the Bowman's capsule is continuous with the lumen of the next part of the nephron.
- The Bowman's capsule and the glomerulus together constitute the renal corpuscle or Malpighian body.

(b) Proximal convoluted tubule (PCT):

- It starts from the neck of the Bowman's capsule and it is highly convoluted.
- It lies in the renal cortex.
- The wall consists of a single layer of columnar cells bearing a lot of microvilli on the surface.

(c) Loop of Henle:

- It is a V/U shaped segment of the nephron.
- It is located in the renal medulla.
- It consists of two straight parallel limbs known as a descending limb and an ascending limb.
- Descending limb is a continuation of the PCT and enters into the renal medulla and an ascending limb which reenters the renal cortex and joins the DCT.
- It is short or absent in other vertebrates like reptiles.



(d) Distal convoluted tubule (DCT):

- It is greatly twisted like the PCT and lies in the renal cortex.
- The terminal relatively short part of the DCT is called the collecting tubule.
- It opens into the collecting duct.

- It is lined by cuboidal epithelium.

The collecting ducts receive the collecting tubules of several nephrons. They pass into the renal medulla and join each other forming large ducts of Bellini which pass through renal pyramids. Renal papillae open into minor calices which open in larger major calices (4-5 in number). Major calices finally open in a funnel shaped pelvis. Pelvis opens into ureter.

Renal blood supply

Each kidney is supplied by renal artery. Inside the kidney it divides into a number of major branches. Each artery again divides into many afferent arterioles. It enters into Bowman's capsule to form glomerulus. Blood from glomerulus is drained by the efferent arteole. Affrent arteriole is wider than efferent arteriole. This is responsible for glomerular hydro static pressure (GHP).

Physiology of Urine formation:

It occurs in three steps.

Ultra filtration:

- Filtration under high pressure of GHP. Bowman's capsule acts as ultra filters.
- When blood flows through glomerular capillaries all substances are filtered (except blood cells and plasma proteins).
- GHP is about 70mm Hg. It is due to wider afferent and narrow efferent arteriole. But it is resisted by osmotic pressure of blood (BCOP) and cells of Bowman's capsule (CHP).
- BCOP= Blood Colloidal Osmotic Pressure is due to the presence of plasma proteins (albumin). It is about 30 mm Hg.
- CHP= Capsular Hydrostatic pressure. It is due to the pre existing fluid in Bowman's capsule. It is about 20 mmHg.
- So the Effective filtration Pressure (EFP) is equal to
- EFP= GHP-(BCOP+CHP) = 70- (30+20) =20mm Hg. It is also known as Net filtration rate (NFR).
- What so ever filtered in Bowman's capsule is known as nephric filtrate or glomerulus filtrate. It contains both useful and non useful substances.
- Nephric filtrate =Blood- Blood cells+proteins.

Reasons for rapid filtration:

- Blood and the cavity of Bowman's capsule is separated by two very thin membranes.
- Capillaray wall has many fine pores (50-1000 nm in diameter).
- Podocytes of Bowman's extend upto capillaries.
- Affrent arteriole is wider than efferent arteriole.

Selective Reabsorption:

- Nephric filtrate is moved in the nephron towards collecting tubule.
- During this passage all useful and selective substances are reabsorbed. So, it is called as selective reabsorbtion.
- It takes place in PCT+ Loop of Henle+ DCT.
- All glucose and amino acids reabsorb.
- Most of the electrolyte reabsorbed.
- 96% of water reabsorbed.
- Na^+, glucose, amino acid are reabsorbed by active transport.
- Water and Cl^- are reabsorbed by passive transport.
- Glucose, water, amino acid, vitamin C and some salts are reabsorbed in large quantities. They are known as High Thresh hold substance.
- Urea, uric acid are reabsorbed in low amount. They are known as low thresh hold substances.
- Substances like SO_4, and creatine are not reabsorbed. They are known as non thresh hold substances.
- Na^+ ions are more in decending limb.
- Ascending limb is impermeable to water but Na^+ ions are reabsorbed.
- Reabsorbtion of water takes place in DCT under the influence of ADH hormone.
- What so ever enter into the collecting tubule is known as urine.

Tubular secretion:

- It is supporting and supplementary mechanism.
- It is mainly aided by the glandular cells of DCT.
- Cells of tubule remove non thresh hold substances and foreign materials from the blood.
- Most of the K^+ is eliminated in exchange of Na^+.

As a result of these three processes the waste are changed into urine.

Urine composition:

- It is pale yellow in color due presence of a pigment called urochrome. It is formed by the haemoglobin of dead RBCs.
- It is acidic in nature and has pH 6.1- 6.5.
- It has a faint aromatic odour. The bad smell is due degradation of urea into ammonia by microbes.
- Daily output of urine in normal person is 1.5 1.8 litres.
- Chemically it consists of 95-96% water, urea 2%, uric acid 0.2%, ammonia 0.25%, and creatine 0.5% and salts 1%.

Conduction of Urine:

- The urine produced in the nephrons is passed into the collecting tubule which opens into ducts of Bellini.
- They converge towards hilus and pass through renal pyramids, minor calices, major calices, pelvis and ureters.
- Ureters conduct the urine into urinary bladder by peristalsis.
- When urinary bladder is full of urine a reflex is initiated which cause contraction of smooth and abdominal muscles.
- This drives the urine out of the body through urethra.
- The passing out of urine is called micturition.

Counter-current mechanism:

Mammals including man and birds secrete hypertonic urine. This ability is due to presence of counter- current mechanism. It is a main adaptation of land vertebrates for the conservation of water. By this mechanism, the kidneys regulate the osmotic pressure of blood by regulating the water level of blood plasma. It is called as osmoregulation. There are two counter- current mechanisms operating inside the kidney. 1. Vasa rectae 2.Henle's Loop.

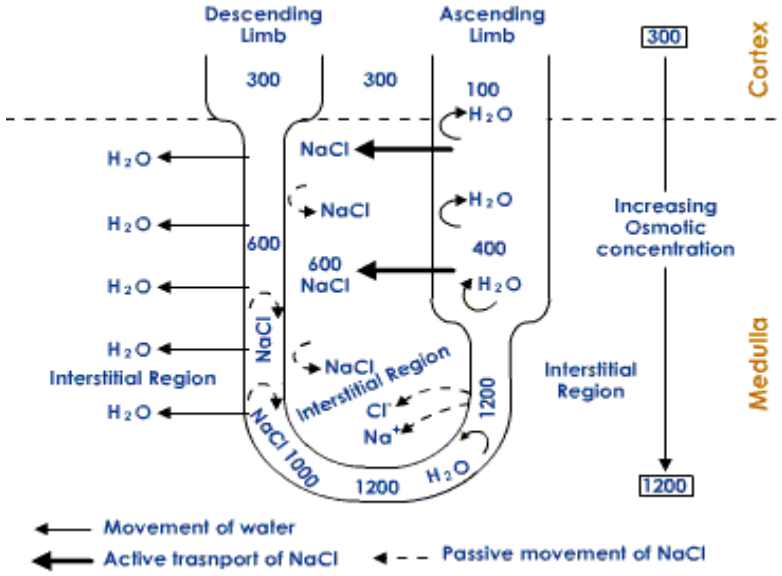
1. Vasa rectae:

- Inside the renal medulla, the efferent arteriole forms a peri tubular capillary network around the tubules. It is called as vasa rectae.
- Only 1-2% of total renal blood flows through vasa rectae.
- The blood flows in opposite directions in two limbs of vasa rectae.
- Blood entering the medulla in descending limb comes very close to outgoing blood in ascending limb. When blood flows towards medulla, Na+ and Cl- diffuse in the blood from interestial fluid but it is reversed when blood flows towards cortex.

- This checks the loss of Na+ and Cl^- from the medulla and maintains the high concentration of these ions in deeper parts of medulla.

2. Henle's Loop:

- Nephric filtrate flows in opposite directions of Henle's loop.
- Large amount of Na+ is actively transported from nephric filtrate into interestial fluid through the wall of ascending limb. It is followed by passive transport of Cl-.It increases the concentration of Na+ and Cl- in medulla.
- Some of Na+ and Cl- passively diffuse into the decending limb.
- Na+ and Cl- from the decending limb reach ascending limb through loop of Henle.
- This cyclic movement of Na+ and Cl- is called counter current mechanism. It increases Na+ and Cl- concentration in renal medulla which help to reabsorbtion of water from glomerular filtrate.
- There is no water reabsorption in ascending limb because its wall is impermeable to water. Water reabsrption mainly occurs in collecting tubules. It is aided by ADH or vasopressin.

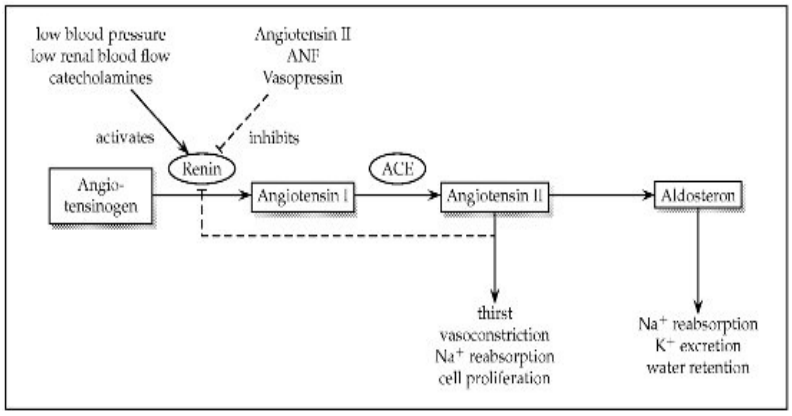


Counter current mechanism

Role of renin-angiotensin system (RAS) in osmoregulation:

- The renin-angiotensin system (RAS) or the renin-angiotensin-aldosterone system (RAAS) is a hormone system that regulates blood pressure and water (fluid) balance.

- When renal blood flow is reduced, juxtaglomerular cells in the kidneys activate their prorenin and secrete renin directly into circulation.
- Plasma rennin then carries out the conversion of angiotensinogen released by the liver to angiotensin I. Angiotensin I is subsequently converted to angiotensin II by the enzyme angiotensin-converting enzyme found in the lungs.
- Angiotensin II is a potent vaso-active peptide that causes blood vessels to constrict, resulting in increased blood pressure. Angiotensin II also stimulates the secretion of the hormone aldosterone from the adrenal cortex.
- Aldosterone causes the tubules of the kidneys to increase the reabsorption of sodium and water into the blood. This increases the volume of fluid in the body, which also increases blood pressure.
- If the renin-angiotensin-aldosterone system is abnormally active, blood pressure will be too high. There are many drugs that interrupt different steps in this system to lower blood pressure.



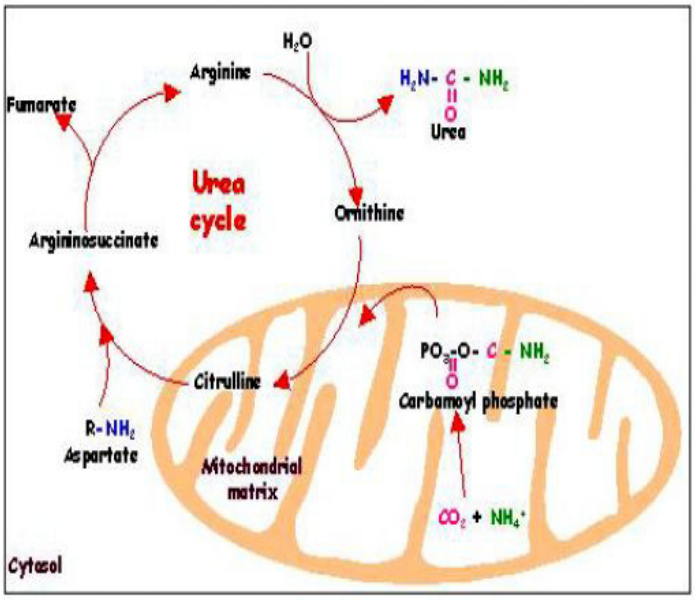
Urea cycle:

Unlike glucose, there is no storage form of amino acids. Amino acids are degraded into free ammonia (NH4+) and the carbon skeleton. Living organisms excrete excess nitrogen as ammonia, uric acid, and urea. The urea cycle is also known as the Ornithine cycle. It is a cycle of biochemical reactions occurring in many animals that produces urea ($(NH_2)_2CO$) from ammonia (NH_3). This cycle was the first metabolic cycle discovered (Hans Krebs and Kurt Henseleit, 1932), five years before the discovery of the TCA cycle. In mammals, the urea cycle takes place primarily in the liver, and to a lesser extent in the kidney.

- The urea cycle takes place in the mitochondria and the cytosol.
- There are four enzymes involved, three of which are cytosolic and one is mitochondrial.
- In the mitochondria, carbamoyl phosphate is catalyzed by carbamoyl phosphate synthetase (CPS I). Carbamoyl phosphate is formed by condensing and activating bicarbonate and ammonia. Two ATP is also required. It is the first acquirement of nitrogen.
- The carbamoyl group of carbamoyl phosphate is transferred to ornithine giving citrulline. The reaction is catalyzed by ornithine transcarbamoylase.
- Citrulline is then transported out to the cytosol. Now in the cytosol, citrullyl-AMP is formed. Adding aspartate displaces AMP to form argininosuccinate, where urea's second nitrogen is acquired. It is catalyzed by argininosuccinate synthetase.
- Arginine, urea's immediate precursor, is then made by the removal of fumarate from argininosuccinate catalyzed by argininosuccinase.
- In the final reaction, urea is formed by cleaving off the carbon backbone of arginine by arginase. Ornithine is also made, which is transported back into the mitochondria.
- Fumarate from argininosuccinate is converted to aspartate for reuse in the argininosuccinate synthetase reaction. The formation of urea costs more than three high energy bonds. The urea cycle ultimately yield 6 ATPs.

Reactions of the urea cycle

Step	Reactants	Products	Catalyzed by	Location
1	$NH_3 + HCO_3^- + 2ATP$	carbamoyl phosphate + $2ADP + P_i$	CPS1	mitochondria
2	carbamoyl phosphate + ornithine	citrulline+ P_i	OTC	mitochondria
3	citrulline + aspartate + ATP	argininosuccinate + AMP + PP_i	ASS	cytosol
4	argininosuccinate	Arg + fumarate	ASL	cytosol
5	Arg + H_2O	ornithine + urea	ARG1	cytosol



Regulation of the Urea Cycle

- Urea catabolism is regulated on two levels. During prolonged starvation, muscle proteins are broken down to supply energy, therefore production of urea increases significantly. The enzymes involved in the urea cycle are also synthesized at higher rates.
- In the short term, CPS I is allosterically regulated.

CHAPTER 10
CONTROL AND CO ORDINATION: PHYSIOLOGY OF NERVOUS SYSTEM

Background:

- The nervous system is the part of an animal's body.
- It coordinates its voluntary and involuntary actions and transmits signals between different parts of its body.
- Nervous system first arose in cnidarians about 550 to 600 million years ago.
- In most animal species it consists of two main parts, the central nervous system (CNS) and the peripheral nervous system (PNS).
- The CNS contains the brain and spinal cord. The PNS consists mainly of nerves, which are enclosed bundles of the long fibers or axons that connect the CNS to every other part of the body.
- The PNS includes motor neurons, mediating voluntary movement.
- The autonomic nervous system, comprising the sympathetic nervous system and the parasympathetic nervous system. It regulates involuntary functions, and the enteric nervous system, which functions to control the gastrointestinal system.

Evolution of nervous system:

- Nervous systems are found in most multicellular animals, but vary greatly in complexity.

- Nervous system is absent in unicellular protozoans and multicellular sponges, placozoans, and mesozoans.
- The nervous systems of the radially symmetric organisms' ctenophores and cnidarians which consist of a diffuse nerve net.
- In most animal species have a nervous system containing a brain, a central cord and nerves radiating from the brain and central cord.
- The size of the nervous system ranges from a few hundred cells to around 100 billion cells (humans).
- The central nervous system functions to send signals from one cell to others or from one part of the body to others and to receive feedback. Malfunction of the nervous system can occur as a result of genetic defects, physical damage due to trauma or toxicity, infection or simply of ageing.

History:

- Scientists of the 19th century studied the propagation of electrical signals in whole nerves (i.e., bundles of neurons) and demonstrated that nervous tissue was made up of cells, instead of an interconnected network of tubes or a reticulum.
- The 20th century was a golden era for electrophysiology. In 1949, Alan Hodgkin and Bernard Katz refined Bernstein's hypothesis by considering that the axonal membrane might have different permeabilities to different ions. They demonstrated the crucial role of the sodium permeability for the action potential.
- In 1952, voltage clamp technique was used to determine the dependence of the axonal membrane's permeabilities to sodium and potassium ions on voltage and time, from which they were able to reconstruct the action potential quantitatively.
- The sodium–potassium pump was identified in 1957.
- Hodgkin and Huxley correlated the properties of their mathematical model with discrete ion channels that could exist in several different states, including "open", "closed", and "inactivated". Their hypotheses were confirmed in the mid-1970s and 1980s by Erwin Neher and Bert Sakmann.

Anatomy of a neuron

- Several types of cells support an action potential, such as plant cells, muscle cells, and the specialized cells of the heart. However, the main excitable cell

is the neuron which also has the simplest mechanism for the action potential.

- Neurons are electrically excitable cells.
- It is composed of one or more dendrites, a single soma (cell body), a single axon and one or more axon terminals.
- Dendrites are cellular projections whose primary function is to receive synaptic signals. Their projections are designed to capture the neurotransmitters released by the pre synaptic neuron.
- They have a high concentration of ligand-gated ion channels. These processes have a thin neck connecting a bulbous protrusion to the dendrite. This ensures that changes occurring inside the spine are less likely to affect the neighboring spines.
- The dendrites extend from the soma, which houses the nucleus, and many of the "normal" eukaryotic organelles.
- The surface of the cell body is populated by voltage activated ion channels. These channels help transmit the signals generated by the dendrites.
- Emerging out from the soma is the axon hillock. This region is characterized by having a very high concentration of voltage-activated sodium channels. In general, it is considered to be the spike initiation zone for action potentials.
- Multiple signals generated at the spines, and transmitted by the soma all converge here. Immediately after the axon hillock is the axon. This is a thin tubular protrusion traveling away from the soma.
- The axon is insulated by a myelin sheath. Myelin is composed of either Schwann cells (in the peripheral nervous system) or oligo dendrocytes (in the central nervous system).
- Although glial cells are not involved with the transmission of electrical signals, they communicate and provide important biochemical support to neurons.
- To be specific, myelin wraps multiple times around the axonal segment, forming a thick fatty layer that prevents ions from entering or escaping the axon. This insulation prevents significant signal decay as well as ensuring faster signal speed. This insulation, however, has the restriction that no channels can be present on the surface of the axon. There are, therefore, regularly spaced patches of membrane, which have no insulation. These nodes of Ranvier can be considered to be "mini axon hillocks", as

their purpose is to boost the signal in order to prevent significant signal decay.

- At the extreme end axon divided into several axon terminals called pre synaptic terminals or synaptic boutons. They contain synaptic vesicles which produce neurotransmitters.

Properties of Nerve fibre:

1. **Excitability:** When nerve fibre is stimulated by a stimulus, it comes in a state of local excitation. The stimulus may be physical (heat, cold, pressure, etc) mechanical or chemical or electrical in nature.
2. **All or None principle:** The amplitude of an action potential is independent of the amount of current that produced it. In other words, larger currents do not create larger action potentials. Therefore, action potentials are said to be all-or-none signals, since either they occur fully or they do not occur at all. The frequency of action potentials is correlated with the intensity of a stimulus. This is in contrast to receptor potentials, whose amplitudes are dependent on the intensity of a stimulus.
3. **Differential permeability:** The cell membrane of neuron separates the cytoplasm from extra cellular fluid (ECF).Both extra cellular fluid (ECF) and cytoplasm (neuroplasm) has different properties. Inside the neuron is electro negative while in ECF (outside of neuron) is relatively electro positive. The potential difference in un excited nerve fibre is called Resting Membrane Potential (RMP) and nerve is said to be polarized nerve fibre.
4. **Conductivity:** When nerve fibre is stimulated by an adequate stimulus the polarity of neuron is reversed. The new potential difference is called 'action potential'. The nerve is said to be depolarized nerve fibre. The action potential is transmitted from site of its origin along the length of the nerve fibre in a particular direction. This property is known as conductivity.
5. **Refractory period:** After an excitation, nerve fibre undergoes a recovery period in which it regains its original ionic distribution and prepares itself for the next stimulation. The period of recovery is called as 'refractory period'. It is about 4 milli seconds. In this phase nerve fibre is not able to give response to any stimulus.
6. **Summation:** Nerve fibre fails to evoke the response if applied stimulus less than the threshold stimulus .But if the same stimulus is repeatedly applied for a sufficient number, stimulation occurs by summation, provided their sum is equal to greater than required value.

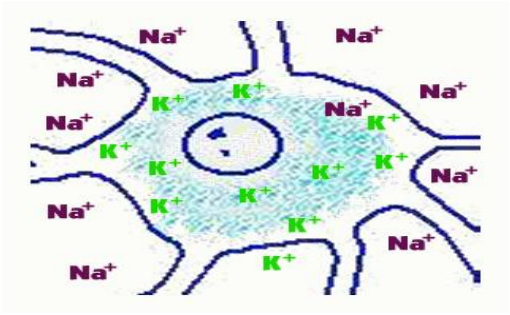
Mechanism of Nerve impulse conduction:

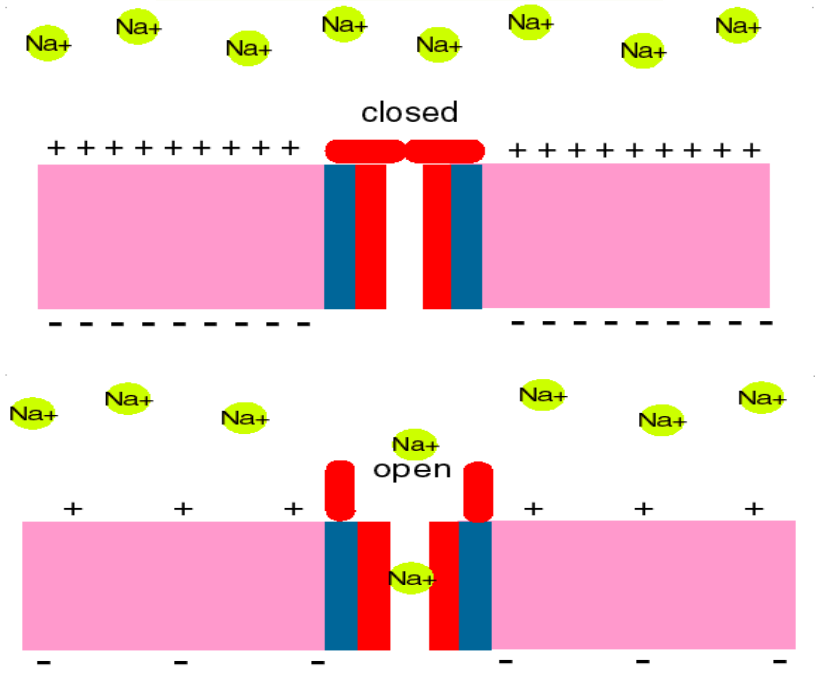
The most accepted theory for nerve impulse conduction was given by Hodgkin and Huxley. This theory states that nerve impulse is an electro chemical event governed by differential permeability of neurolemma. It can be studied under following steps.

- Step I: Generation of nerve impulse.
- Step II.Repolarization of nerve fibre.
- Step III.Propagation of nerve impulse:
- Step IV.Saltatory conduction.
- Step V .Conduction of nerve impulse through a synapse.

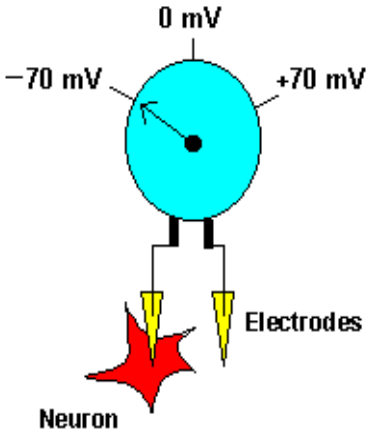
Step I: Generation of nerve impulse:

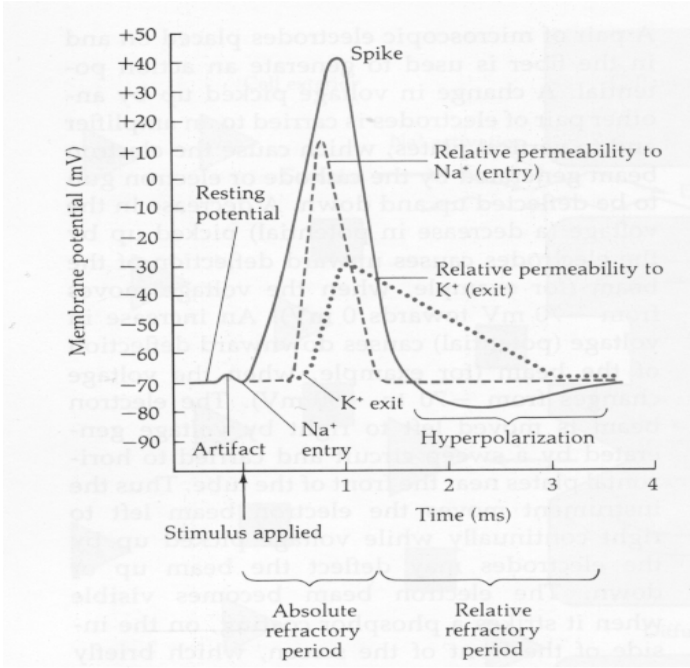
- The cell membrane of neuron separates the cytoplasm from extra cellular fluid (ECF).Both extra cellular fluid (ECF) and cytoplasm (neuroplasm) has different properties. Inside the neuron is electro negative while in ECF (outside of neuron) is relatively electro positive. The potential difference in unexcited nerve fibre is called Resting Membrane Potential (RMP) and nerve is said to be polarized nerve fibre.
- When a nerve fibre is stimulated by an adequate strength it gets excited.
- At the point of stimulation the membrane potential increases. It is more permeable to Na+ than K+.
- Na+ ions diffuse rapidly from outside to intra cellular fluid by active transport. As a result, the neuron becomes electro positive inside. The reversal of polarity across the two sides of membrane is called depolarization. The nerve fibre is known as depolarized nerve fibre. It is electro positive inside and electro negative outside.
- This takes for less than 1/1000 of a second. A nerve fibre can conduct about 1,000 impulses per second.
- When one electrode is placed inside a neuron and the other outside, the voltometer is measuring the difference in the distribution of ions. It is slightly negative in inside than outside.
- During RMP (Resting Membrane Potential) stage nerve fibre has -90 mV negative potential. But in Depolarized nerve fibre the potential increase frist to zero, then rise to +45 to 50+ mV. This newly developed potential difference is called action potential.





- The action potential travels as a wave of depolarization along the length of a nerve fibre in a particular direction is called nerve impulse.
- The nerve cell membrane also contains special passageways for these two ions that are commonly referred to as gates or channels. Thus, there are sodium gates and potassium gates.
- These gates represent the only way that these ions can diffuse through a nerve cell membrane. In a resting nerve cell membrane, all the sodium gates are closed and some of the potassium gates are open. As a result, sodium cannot diffuse through the membrane and largely remains outside the membrane. However, some potassium ions are able to diffuse out.





- Overall, therefore, there are lots of positively charged potassium ions just inside the membrane and lots of positively charged sodium ions plus some potassium ions on the outside. In other words, there is an unequal distribution of ions or a resting membrane potential. This potential will be maintained until the membrane is disturbed or stimulated. Then, if it's a sufficiently strong stimulus, an action potential will occur.

ACTION POTENTIAL

An action potential is a very rapid change in membrane potential that occurs when a nerve cell membrane is stimulated. Specifically, the membrane potential goes from the resting potential (typically -90 mV) to some positive value (typically about +50 mV) in a very short period of time.

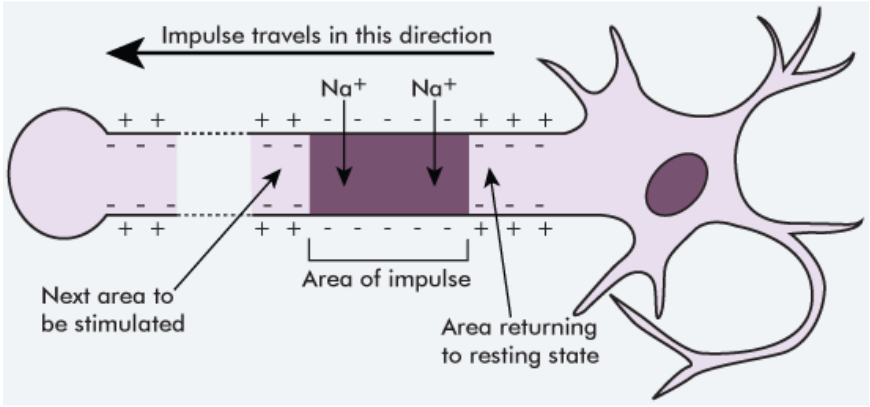
Step II.Repolarization of nerve fibre:

- After the peak action potential (spike potential) the permeability of membrane to Na+ decreases while it becomes more permeable to K+ ions. So K+ ions rapidly diffuse from neuroplasm to extra cellular fluid (ECF) to maintain electrochemical gradient.

- Soon, at this point the membrane regains its original polarity and becomes electro positive on outside and electronegative inside. This is called repolarization and nerve fibre is called repolarized nerve fibre. It has the same polarity as polarized nerve fibre but different ionic distribution.
- It has more K+ outside and more Na+ inside. A repolarized nerve fibre undergoes a refractory period of few milli seconds during which it restores the original ionic distribution. Na+ ions sent out and K+ ions are in by active transport. This returns the membrane to its resting potential.i.e. from +50 mV to -90 mV and neuron is ready to receive another stimulus.

Step III.Propagation of nerve impulse:

- The nerve fibre has the ability to transmit this action potential along the length in a particular direction. It is conducted by local circuits in which a depolarized area causes the depolarization of next area and so on.

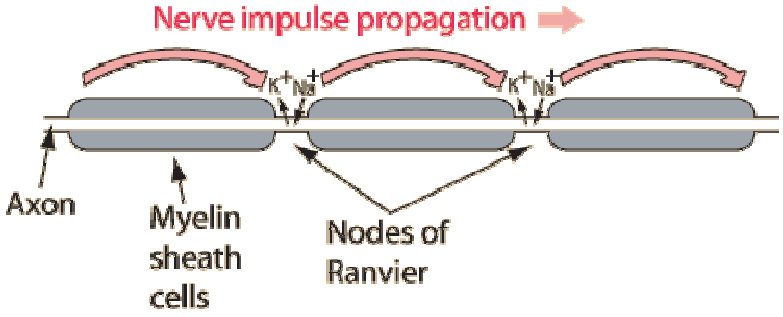


- During this conduction, negative charge present on outer surface of depolarized area attracts the positive charge from outer surface of next polarized area.
- While positive charge present on inner surface of next depolarized area is attracted by the next polarized area. So the depolarized area becomes repolarized and the next polarized area becomes depolarized. This process is repeated and the action potential flows onward as wave of depolarization.

Step IV.Saltatory conduction:

- In non myelinated nerve fibre, the action potential over the membrane all along the length of nerve fibre flows as a wave.

- But in myelinated nerve fibre, the medullaray sheath is impermeable to ions. So action potential occurs only at some points called nodes of Ranvier. So, the action potential is conducted from node to node in a jumping manner. This conduction is 20 times faster than in non myelinated nerve fibre.
- This mode of jumping transmission of nerve impulse is called salutatory conduction.

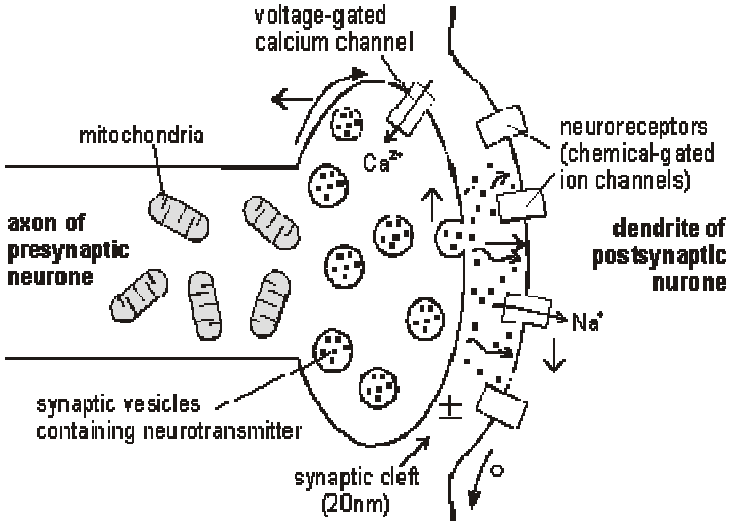


Step V.Conduction of Nerve impulse at Synapse:

- There is no continuity between the neurons. A small space of 200A° is present between neurons. It is known as synaptic cleft.
- The nerve impulses are conducted across the synapse always from axon to Dendron through a chemical (neurotransmitter).So it is also called as chemical transmission.
- When nerve impulse reaches the terminal knobs of the axon, the synaptic vesicles secrete a neuro transmitter (acetyl choline/adrenalin) in the synaptic cleft.

Step VI.Chemoreception:

- In this step, the neurotransmitter is recognized by some special protein molecular sites, called chemoreceptors on the membrane dendrites of the next neuron.
- The chemoreception causes depolarization of the membrane and initiates a new action potential.



Threshold stimulus and potential

- Action potentials occur only when the membrane in stimulated (depolarized) enough so that sodium channels open completely. The minimum stimulus needed to achieve an action potential is called the threshold stimulus.
- If the membrane potential reaches the threshold potential (generally 5 - 15 mV less negative than the resting potential), the voltage-regulated sodium channels all open. Sodium ions rapidly diffuse inward and depolarization occurs.

Refractory periods:

It is of two types.

ABSOLUTE -

- During an action potential, a second stimulus will not produce a second action potential (no matter how strong that stimulus is).
- corresponds to the period when the sodium channels are open (typically just a millisecond or less).

RELATIVE -

- Another action potential can be produced, but only if the stimulus is greater than the threshold stimulus
- corresponds to the period when the potassium channels are open (several milliseconds)
- the nerve cell membrane becomes progressively more 'sensitive' (easier to stimulate) as the relative refractory period proceeds. So, it takes a very

strong stimulus to cause an action potential at the beginning of the relative refractory period, but only a slightly above threshold stimulus to cause an action potential near the end of the relative refractory period

The absolute refractory period places a limit on the rate at which a neuron can conduct impulses, and the relative refractory period permits variation in the rate at which a neuron conducts impulses. Such variation is important because it is one of the ways by which our nervous system recognizes differences in stimulus strength, e.g., dim light = retinal cells conduct fewer impulses per second vs. brighter light = retinal cells conduct more impulses per second.

Conduction Velocity:

- Impulses typically travel along neurons at a speed of anywhere from 1 to 120 meters per second.
- The speed of conduction can be influenced by:
  - the diameter of a fiber
  - the presence or absence of myelin
- Neurons with myelin (or myelinated neurons) conduct impulses much faster than those without myelin.
- Schwann cells (or oligodendrocytes) are located at regular intervals along the process.
- Fat (myelin) acts as an insulator. So membrane coated with myelin will not conduct an impulse. So, in a myelinated neuron, action potentials only occur along the nodes and, therefore, impulses 'jump' over the areas of myelin. Jumping from node to node in a process called saltatory conduction (with the word saltatory meaning 'jumping'):

Types of neurotransmitters:

1- Excitatory: Neurotransmitters that make membrane potential less negative (via increased permeability of the membrane to sodium) and, therefore, tend to 'excite' or stimulate the postsynaptic membrane.

2 – Inhibitory: Neurotransmitters that make membrane potential more negative (via increased permeability of the membrane to potassium) and, therefore, tend to 'inhibit' (or make less likely) the transmission of an impulse. One example of an inhibitory neurotransmitter is gamma amino butyric acid (GABA). Medically, GABA has been used to treat both epilepsy and hypertension. Another example of an inhibitory neurotransmitter is beta-endorphin, which results in decreased pain perception by the CNS.

CHAPTER 11
MOVEMENTS AND LOCOMOTION

Background:

- Movement is an important feature of living organism. Both the microbes and macrobes show wide range of movements.
- The movements results in change in location are called locomotion. At cellular level, cytoplasm exihibits streaming movements. Movements of cilia, flagella etc bring locomotion. Locomotion is very important feature of animals. It helps them to go in search of food, shelter, mate etc.

Locomotory organs in Animal Kingdom:

- **Protozoa:** Pseudopodia, flagella, cilia, myonemes.
- **Porifera:** Absent, But myocytes, chaonocytes and amoebocytes perform movement.
- **Cnidaria:** Tentacles, epithelio muscular cells
- **Helminthes:** Crawling movement, First time muscles are present.
- **Annelida:** Setae, suckers.
- **Arthropoda:** Jointed legs.
- **Mollusca:** Muscular feet.
- **Echinodermata:** Tube feet, water vascular system.
- **Chordata: Muscular** organs like, fins in fishes, limbs in amphibian and reptiles, wings in birds and limbs in mammals.

Types of movements:
Human body exhibit three types of movements:

- **(a) Amoeboid movement**: This movement is brought by pseudopodia. Eg: macrophage and leucocytes move with the help of pseudopodia and engulf pathogens.
- **(b) Ciliary movement**: Most of our internal tubular organs are lined by ciliated epithelium. Those which are present in trachea help in removing dust particles. In spinal canal they help in movement of cerebrospinal fluid.
- **(c) Muscular movement:** The muscular tissue help in movement and locomotion. e.g., eye lids, tongue, limbs, blood within blood vessel and heart etc. This movement requires coordination between muscular, skeletal and nervous activities.

Significance:

- It maintains the equilibrium of the body.
- It helps in obtaining the food.
- It collects informations about changes from environment.
- Peristaltic movements help in movements of food and urine.
- Ciliary movements of fallopian tubes, vasa efferentia, trachea and larynx etc help in the movement of eggs, sperms, and dust particles.
- Protect from predators.
- Escaping from unfavorable environmental conditions.

So, both movements of body parts and locomotion are muscular movements. They increase the chances of survival and continuation of race.

Muscles:

The term muscle is derived from the Latin *musculus* meaning "little mouse" perhaps because of the shape of certain muscles or because contracting muscles look like mice moving under the skin.

- Muscle is a soft tissue found in most animals.
- Muscle cells contain protein filaments of actin and myosin to produce force and motion.
- They are primarily responsible for maintaining and changing posture and locomotion.

- They also involve in the movement of internal organs, such as the contraction of the heart and the movement of food through the digestive system via peristalsis.
- Muscle tissues are derived from the embryonic mesoderm.

Types of Muscles

There are three types of muscle fibres.

1. Skeletal or striated or voluntary.
2. Visceral of smooth or involuntary.
3. Cardiac or heart muscles.

1. Skeletal or striated or voluntary:

- Skeletal muscle or "voluntary muscle" is anchored by tendons to bone and is used to effect skeletal movement.
- Show light and dark bands.
- They are multi nucleated.
- They work under the will of organism or central nervous system.
- An average adult male is made up of 42% of skeletal muscle and an average adult female is made up of 36% (as a percentage of body mass).

2. Visceral of smooth or involuntary :

- Smooth muscle or "involuntary muscle" is found within the walls of organs and structures such as alimentary cana
  l, bronchi, uterus, urethra, bladder, blood vessels, and the arrector pili in the skin (in which it controls erection of body hair). Unlike skeletal muscle, smooth muscle is not under conscious control.
- They are uninucleated.
- They do not work under the will of organism. They are innervated with autonomous nervous system.
- Light and dark bands are absent.

3. Cardiac or heart muscles.

- Cardiac muscle (myocardium), is also an "involuntary muscle" but is more similar in structure to skeletal muscle, and is found only in the heart.
- It performs rhythmic contractions.
- Uninucleated.
- Inter calary discs are present.
-

Microanatomy:

- Skeletal muscles are sheathed by a tough layer of connective tissue called the epimysium.
- The epimysium anchors muscle tissue to tendons at each end. It also protects muscles from friction against other muscles and bones.

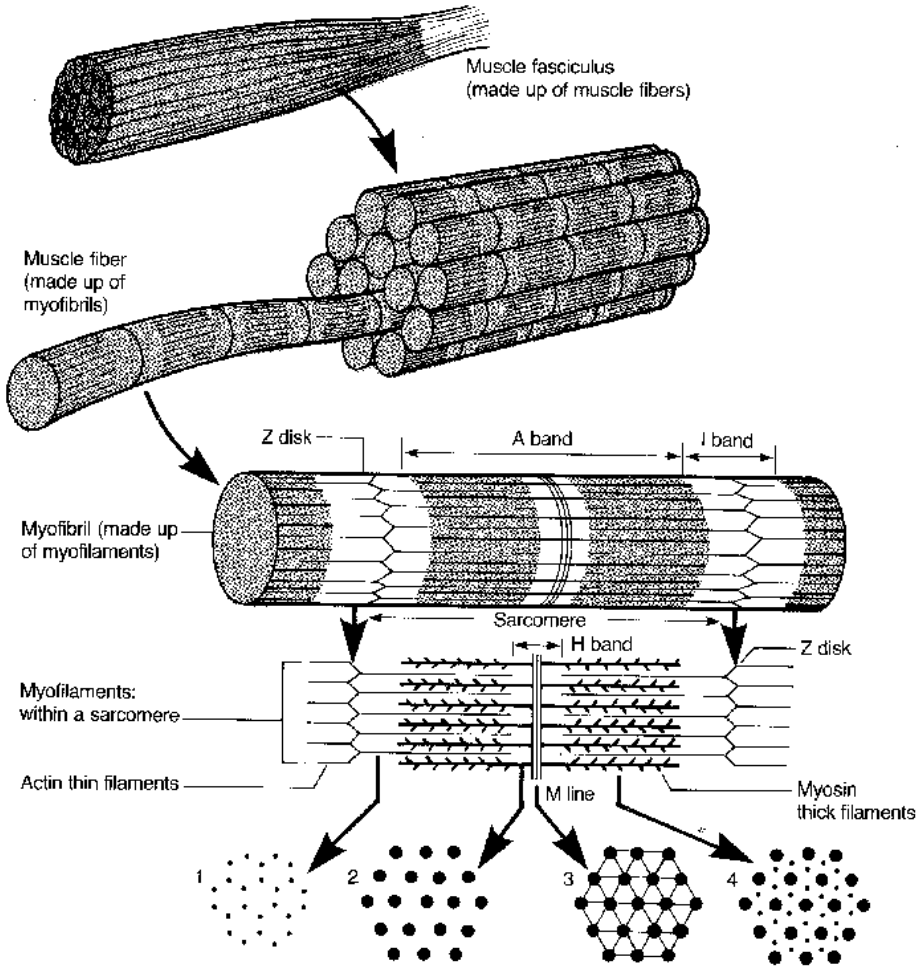


Fig. Diagrammatic breakdown of a typical muscle. Shows how actin thin filaments and myosin thick filaments are arranged to form the myofilaments of a sarcomere, continuing with the formation of myofibrils from many myofilaments.

- Within the epimysium are multiple bundles called fascicles, each of which contains 10 to 100 or more muscle fibers collectively sheathed by a perimysium.
- The threadlike muscle fibers are the individual muscle cells (myocytes), and each cell is encased within its own endomysium of collagen fibers.
- Thus, the overall muscle consists of fibers (cells) that are bundled into fascicles. At each level of bundling, a collagenous membrane surrounds the bundle, and these membranes support muscle function.
- Within the cells of the muscle, bundles of protein filaments are present. They are called as myofibrils.
- Myofibrils are complex strands of several kinds of protein filaments organized together into repeating units called sarcomeres. The striated appearance of both skeletal and cardiac muscle results from the regular pattern of sarcomeres within their cells.
- The filaments in a sarcomere are composed of actin and myosin.

Properties of skeletal muscle fibres:

1. **Excitability:** Skletal muscles can be excited by the impulse of motor nerve.
2. **Conductivity:** They have the ability to coduct the excitation along the length of muscle fibre at the rate of 3-5 meters/second.
3. **All or none rule:** It was first established by the American physiologist Henry Pickering Bowditch in 1871. The all-or-none law is the principle that the strength by which a muscle fiber responds to a stimulus is independent of the strength of the stimulus. If the stimulus exceeds the threshold potential, the muscle fiber will give a complete response, otherwise, there is no response.
4. **Force summation:** It is of two types.

a) **Multiple fiber summation** – When a weak signal is sent by the CNS to contract a muscle, the smaller motor units, being more excitable than the larger ones, are stimulated first. As the strength of the signal increases, more motor units are excited in addition to larger ones, with the largest motor units having as much as 50 times the contractile strength as the smaller ones. As more and larger motor units are activated, the force of muscle contraction becomes progressively stronger. A concept known as the size (sum) principle, allows for a gradation of muscle force during weak contraction to occur in small steps, which then become progressively larger when greater amounts of force are required.

b) **Frequency summation** – For skeletal muscles, the force exerted by the muscle is controlled by varying the frequency at which action potentials are sent to muscle fibers. Action potentials do not arrive at muscles synchronously, and during a contraction, some fraction of the fibers in the muscle will be firing at any given time. In a typical circumstance, when a human is exerting a muscle as hard as he/she is consciously able, roughly one-third of the fibers in that muscle will be firing at once. This 'low' level of contraction is a protective mechanism to prevent damage of the tendon—the force generated by a 95% contraction of all fibers is sufficient to damage the body.

5. **Single muscle twitch:** The single response of muscle fibre to a single stimulus is called muscle twitch. In this a muscle fibre contracts only once on stimulation by a nerve impulse. Time taken in a single muscle twitch in man is 0.1 second.
6. **Tetany:** Tetany arrest is a medical sign consisting of the involuntary contraction of muscles, which may be caused by disease or other conditions that increase the action potential frequency of muscle cells. The state of sustained contraction is called tetany or tetanization**.**
7. **Refractory period:** This is the period in which muscle fibre do not respond to the nerve stimulus of any strength. It is about 0.005 seconds. During this period muscle fibre recovers to regain its original polarity and ionic concentration and prepares itself for next contraction

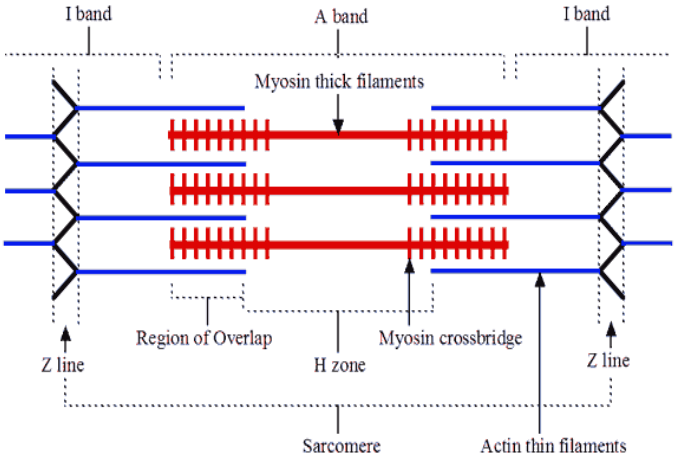
Structure of Myofinril:

- The skeletal muscle fiber is a cell.
- The Sarcolemma is the plasma membrane.
- The Sarcoplasm is the cytoplasm and the sarcoplasmic Reticulum is the endoplasmic reticulum.
- Myofibrils are the cylindrical organelles found inside a muscle fiber.
- The Sarcoplasmic reticulum is responsible for controlling the release of Calcium ions.
- It has multiple inward extensions which form a set of T Tubules (the T stands for transverse)**.**
- Muscles are composed of tubular cells called myocytes or muscle fibers. Muscle fibres contain many chains of myofibrils.
- A myofibri**l** (also known as a muscle fibril) is a basic rod-like unit of a muscle. Myofibrils are composed of thick myosin and thin actin filaments.

- Muscles contract by sliding the thin (actin) and thick (myosin) filaments along each other. Thin filaments consist primarily of the protein actin, coiled with nebulin filaments.
- Thick filaments consist primarily of the protein myosin, held in place by titin filaments. Myosin is responsible for force generation. It is composed of a globular head with both ATP and actin binding sites, and a long tail involved in its polymerization into myosin filaments.
- The protein complex composed of actin and myosin is sometimes referred to as actinomyosin.
- The filaments are organized into repeated subunits along the length of the myofibril. These subunits are called sarcomerer.
- The muscle cell is nearly filled with myofibrils running parallel to each other on the long axis of the cell. The sarcomeric subunits of one myofibril are in nearly perfect alignment with those of the myofibrils next to it. This alignment gives rise to certain optical properties which cause the cell to appear striped or striated. In smooth muscle cells, this alignment is absent, hence there are no apparent striations and the cells are called smooth.

Ultra structure of Myofibril:

- The myofibril shows light and dark bands. Light band is known as I band (isotropic) and Dark band is known as A (an isotropic) band.
- I band consists of thin actin protein filaments while A band contain thick myosin protein filaments. Myosin is a motor protein with a globular head that is critical in muscle movement.
- Thin filaments are composed of many subunits of the globular protein G-actin and several accessory proteins. Each G-actin subunit has 1 ADP/ATP binding site. The main thin filament accessory proteins are tropomyosin and troponin. A pair of tropomyosin molecules is associated with every 7 pairs of G-actin residues along a thin filament.



- The actin filaments of I band is separated by a vertical line called Z line. Similarly A band is also separated by M line.
- The distance between two Z lines is known as macromere. It is the functional unit of muscle contraction. So the macromere contains two Z lines and one M line.
- The gap present between two actin filaments of sarcomere is known as H zone. It disappear when muscle contracts.
- The biochemical basis of muscle activity is related to the enzymatic and physical properties of actin, myosin, and the accessory proteins that constitute the thin and thick filaments.
- The proteins of the thin and thick filaments can be separated into actin, myosin, and 6 accessory proteins. The accessory proteins are a-actinin, b-actinin, tropomyosin, troponin, C protein, and M line protein.

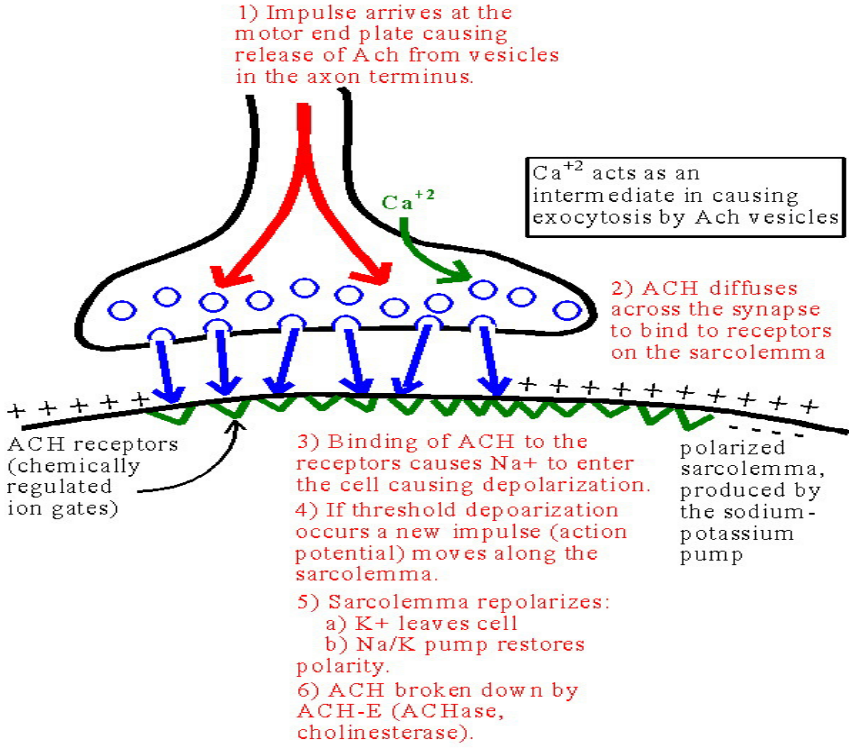
Physiological process of muscle contraction:

The mechanism for muscle contraction evaded scientists for years and requires continued research and updating. The sliding filament theory is now the widely accepted theory for muscle contraction. It was independently developed by Andrew F. Huxley and Rolf Niedergerke and by Hugh Huxley and Jean Hanson in 1954.

Mechanism (sliding filament theory):

For voluntary muscles, all contraction (excluding reflexes) occurs as a result of conscious effort originating in the brain. The brain sends signals, in the form of action potentials, through the nervous system to the motor neuron that innervates several muscle fibers.

1. An action potential originating in the CNS reaches an alpha motor neuron, which then transmits an action potential toward the neuromuscular junction. When it reaches the junction, it causes a calcium ion influx through the voltage-gated calcium channels.
2. The Ca^{2+} influx causes vesicles containing the neurotransmitter acetylcholine to fuse with the plasma membrane, releasing acetylcholine out into the extracellular space between the motor neuron terminal and the neuromuscular junction of the skeletal muscle fiber.
3. The acetylcholine diffuses across the synapse and binds to and activates nicotinic acetylcholine receptors on the neuromuscular junction. Activation of the nicotinic receptor opens its intrinsic sodium/potassium channel, causing sodium to rush in and potassium to trickle out. Because the channel is more permeable to sodium, the charge difference between internal and external surfaces of the muscle fiber membrane becomes less negative, triggering an action potential.



4. The action potential spreads through the muscle fiber's network of T-tubules. Muscle fibre gets depolarized.
5. The depolarization activates L-type voltage-dependent calcium channels (dihydropyridine receptors) in the T tubule membrane in the adjacent sarcoplasmic reticulum.
6. Activated voltage-gated calcium channels physically interact with calcium-release channels to activate them, causing the sarcoplasmic reticulum to release calcium.
7. The calcium binds to the troponin C present on the actin-containing thin filaments of the myofibrils. The troponin then allosterically modulates the tropomyosin.
8. Under normal circumstances, the tropomyosin sterically obstructs binding sites for myosin on the thin filament; once calcium binds to the troponin C and causes an allosteric change in the troponin protein, troponin T allows tropomyosin to move, unblocking the binding sites.
9. ATP binding to the myosin head causes and it is in its low-energy conformation. The active site closes and ATP is hydrolyzed to ADP and Pi. This induces a conformational change (cocking of the head) resulting in myosin weakly binding to actin. This forms a cross-bridge.
10. Pi release results in conformational change that leads to stronger myosin binding, and the power stroke. ADP dissociation leaves the myosin head tightly bound to actin. Binding of a new molecule of ATP to myosin head triggers it to let go of actin and the cycle starts all over again. In the absence of ATP, these state results in muscle rigidity called rigor mortis.
11. Myosin is now bound to actin in the strong binding state. The release of ADP and inorganic phosphate are tightly coupled to the power stroke (actin acts as a cofactor in the release of inorganic phosphate, expediting the release). This will pull the Z-bands towards M line. As a result sarcomere shortens and H zone disappears.
12. ATP binds to myosin, allowing it to release actin and be in the weak binding state. The myosin then hydrolyzes the ATP and uses the energy to move into the "cocked back" conformation
13. The process repeat as long as ATP is available and calcium is freely bound within the thin filaments.
14. While the above steps are occurring, calcium is actively pumped back into the sarcoplasmic reticulum. When calcium is no longer present on the thin filament, the tropomyosin changes conformation back to its previous state

so as to block the binding sites again. The myosin ceases binding to the thin filament, and the contractions cease.

15. The calcium ions leave the troponin molecule in order to maintain the calcium ion concentration in the sarcoplasm. The active pumping of calcium ions into the sarcoplasmic reticulum creates a deficiency in the fluid around the myofibrils. This causes the removal of calcium ions from the troponin. Thus, the tropomyosin-troponin complex again covers the binding sites on the actin filaments and contraction ceases.
16. Physiologically, this contraction is not uniform across the sarcomere; the central position of the thick filaments becomes unstable and can shift during contraction. However the actions of elastic proteins such as Titin are hypothesised to maintain uniform tension across the sarcomere and pull the thick filament into a central position.

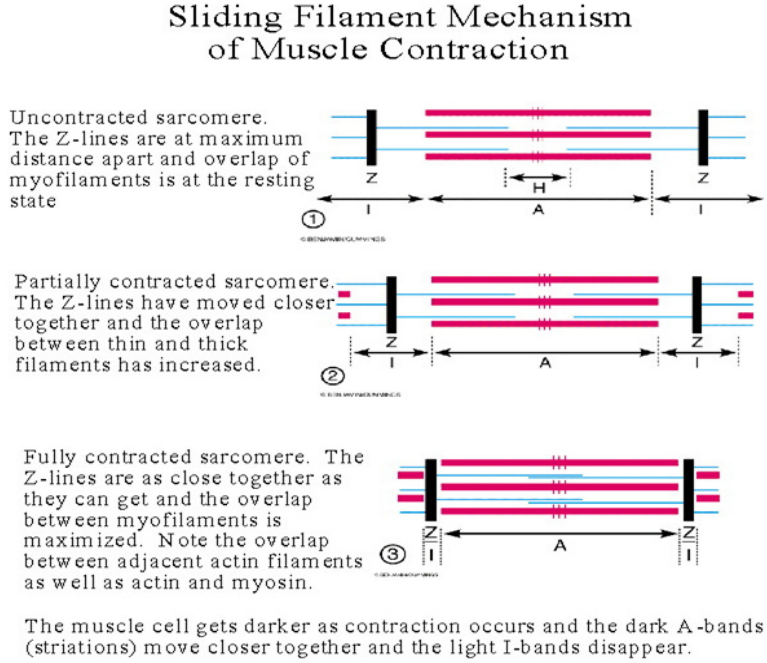


Fig. When sarcomere contracts, the Z lines move closer together, and the I band becomes smaller. The A band stays the same width. At full contraction, the thin and thick filaments overlap.

Energy consumption:

(a) Some ATP is stored in a resting muscle. As contraction starts, it is used up in seconds. More ATP is generated from creatine phosphate for about 15 seconds.

(b) Each glucose molecule produces two ATP and two molecules of pyruvic acid, which can be used in aerobic respiration or converted to lactic acid. If oxygen is not available, pyruvic acid is converted to lactic acid, which may contribute to muscle fatigue.

(c) Approximately 95 percent of the ATP required for resting or moderately active muscles is provided by aerobic respiration, which takes place in mitochondria.Neuromuscular diseases:

- Neuromuscular diseases are those that affect the muscles and/or their nervous control. In general, problems with nervous control can cause spasticity or paralysis, depending on the location and nature of the problem.
- A large proportion of neurological disorders, ranging from cerebro vascular accident (stroke) and Parkinson's disease to Creutzfeldt-Jakob disease, can lead to problems with movement or motor coordination.
- Symptoms of muscle diseases may include weakness, spasticity, myoclonus and myalgia. Diagnostic procedures that may reveal muscular disorders include testing creatine kinase levels in the blood and electromyography (measuring electrical activity in muscles). In some cases, muscle biopsy may be done to identify a myopathy, as well as genetic testing to identify DNA abnormalities associated with specific myopathies and dystrophies.

CHAPTER 12
CONTROL AND COORDINATION: ENDOCRINE SYSTEM

Background:

- Endocrinology is concerned with study of the biosynthesis, storage, chemistry, biochemical and physiological function of hormones and with the cells of the endocrine glands and tissues.
- The endocrine system consists of several glands, all in different parts of the body that secrete hormones directly into the blood rather than into a duct system. Hormones have many different functions and modes of action; one hormone may have several effects on different target organs, and, on the other hand, one target organ may be affected by more than one hormone.
- Endocrine glands are ductless glands and their secretion is known as hormone.
- Along with nervous system it controls and co ordinate the body functions and maintains a homeostasis. So both endocrine and nervous systems collectively called neuro endocrine system.
- T.Addison is known as Father of endocrinology.
- The earliest hormone is insulin.

- The name hormone was given by Starling in 1902.He discovered secretin hormone.

Properties of Hormones:

- They are secreted by endocrine glands.
- They are known as chemical messengers or information molecules.
- They have excitory or inhibitory action on target organs.
- Hormones are released in blood (humoral) and reach the target organs through circulatory system.
- Hormones act by binding to specific receptors in the target organ. Hormones increase cellular activity and work indirectly by activating the genes.
- They coordinate physical, mental and development of secondary sexual characters.
- They maintain homeostasis.
- Chemically they are different in nature.
- They have low molecular weight and act in very low concentration.
- They are non antigenic.
- They are short lived.
- They are quick in action (adrenalin) while some are very slow (estrogens)
- They vary widely in their specificity. For example TSH acts only on thyroid while thyroxine acts on variety of target cells.
- They are used up after their action.

Chemical Nature of Hormones:

Chemically hormones are divided into three categories.

- **Amines**: They are derived from tyrosine amino acid and have amino ($-NH_2$) group. Ex: Epinephrine, nor-epinephrine.
- **Steroids**: These are fat soluble and have sterol group. These are derived from cholesterol group. Ex: corticoids, testosterone, progesterone, estrogens.
- Protein and peptides: These are water soluble and made up of 3-200 amino acids. Ex: STH, TSH, LH, Insulin, ADH etc.

Pheromones or Ectohormones:

- The name pheromone was given Karlson.
- They are secreted upon skin surface.
- They produce characteristic smell.
- Pheromones affect the mutual behavior of the members of the same species.

- These are also known as sex attractants.
- Bomycol was the first pheromone which was studied first.
- Bombycol is the pheromone of silk moth.
- They are volatile in nature and travel with air.
- They help in recognition of its species and enemies.

Types of hormones on the basis of function:

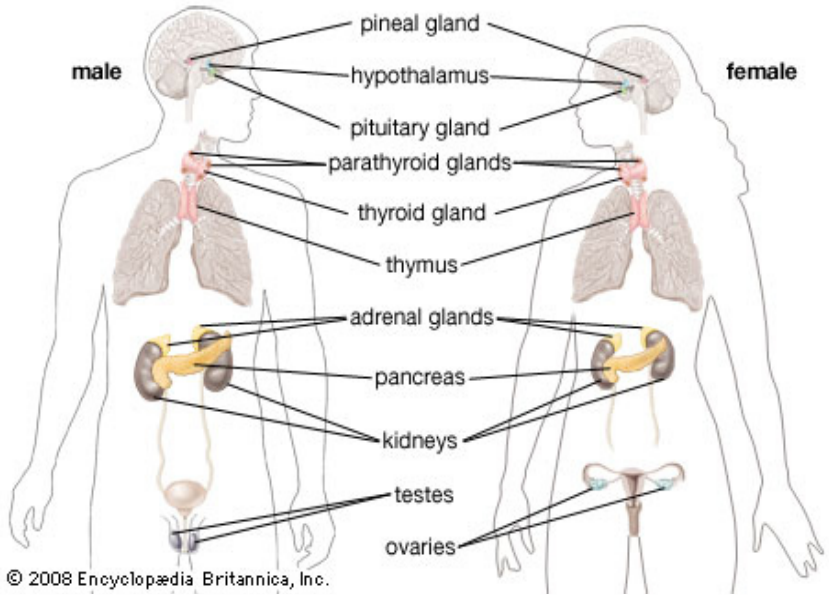
It is of three types.

- **Local Hormones**: Also known as parahormones or tissue hormones. They are secreted at one place and work upon adjacent tissue. They reach by diffusion. Ex. Acetyl choline.
- **Synergistic hormones:** When hormones work together they are known as synergestic hormones. Ex: FSH and LH, Insulin and gluco corticoids.
- **Antagonistic Hormones:** These hormones work against each other. For example Insulin decreases the sugar in the body while glucagon increases.

Endocrine glands in Man:

The number of glands that signal one another in a sequence is called an axis. The typical endocrine glands are given below.

1 Pituitary Gland	2 Thyroid Gland
3 Parathyroid Gland	4 Adrenal Gland
5 Pancreas Gland	6 Ovaries
7 Testes	8 Hypothalamus

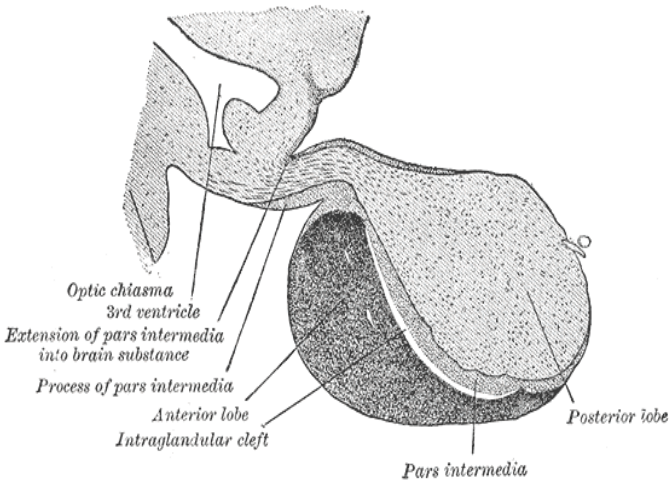


1 Pituitary Gland :

- Also known as the hypophysis.
- The pituitary gland is about the size of a pea weighing 0.5g and is located at the bottom of the hypothalamus at the base of the brain and rests in a small, bony cavity (sella turcica) of sphenoid bone.
- It is covered by a dural fold (diraphragma sellae). It is considered the master gland as it secretes hormones regulating homeostasis. It is functionally connected to the hypothalamus by the median eminence.
- It is composed of three lobes: anterior, intermediate, and posterior. In many animals, these three lobes are distinct. However, in humans, the intermediate lobe is but a few cell layers thick and indistinct; as a result, it is often considered part of the anterior pituitary.

Anterior pituitary:

- Also known as adenohypophysis.
- The anterior pituitary arises from an invagination of the oral ectoderm and forms Rathke's pouch.
- Endocrine cells of the anterior pituitary are controlled by regulatory hormones released by hypothalamus.
- This vascular relationship constitutes the hypothalamo-hypophyseal portal system.
- The anterior pituitary is divided into anatomical regions known as the pars tuberalis, pars intermedia, and pars distalis. It develops from a depression in the dorsal wall of the pharynx (stomal part) known as Rathke's pouch. The pars intermedia is also considered as a separate intermediate lobe.



Hormones of adenohypophysis (Anterior pituitary):

The anterior pituitary synthesizes and secretes hormones. All releasing hormones (-RH) referred to, can also be referred to as releasing factors (-RF).

Somatotrophins:

- It is also known as Human growth hormone (HGH) or growth hormone' (GH) or somatotropin. It is released under the influence of hypothalamic growth hormone-releasing hormone (GHRH), and is inhibited by hypothalamic somatostatin.

Functions: 1.Increased absorption of calcium.
2. Incresead lipolysis.
3. Increased protein synthesis.
4. Increased cell division.

Disorders:

1. Dwarfism: Characterized by retarded growth in children. Occurs due to hypo secretion.
2. Acromicria: Occurs due to hypo secretion in adult. Charecterized by smaller hands, feet and face.
3. Gigantism: Occurs due to hyper secretion in childhood. Characterized by abnormal increased height and long bones
4. Acromegaly: Occurs due to hypersecretion. Abnormal elongation of limbs and lower jaw. Gives gorilla like appearance. Protruding bony ridges over the eyes.

Thyrotrophins:

- Thyroid-stimulating hormone (TSH) is released under the influence of hypothalamic thyrotropin-releasing hormone (TRH) and is inhibited by somatostatin.

Corticotropins:

- Adrenocorticotropic hormone (ACTH), and Beta-endorphin are released under the influence of hypothalamic corticotrophin-releasing hormone (CRH).

Lactotrophins:

- Prolactin (PRL), also known as 'Luteotropic' hormone (LTH), whose release is inconsistently stimulated by hypothalamic TRH, oxytocin, vasopressin,

vasoactive intestinal peptide, angiotensin II, neuropeptide Y, galanin, substance P, bombesin-like peptides (gastrin-releasing peptide, neuromedin B and C), and neurotensin, and inhibited by hypothalamic dopamine.

Gonadotropins:

- Luteinizing hormone (also referred to as 'Lutropin' or 'LH').
- Follicle-stimulating hormone (FSH), both released under influence of Gonadotropin-Releasing Hormone (GnRH)

These hormones are released from the anterior pituitary under the influence of the hypothalamus. Hypothalamic hormones are secreted to the anterior lobe by the hypothalamic-hypophysial portal system.

Intermediate

The intermediate lobe synthesizes and secretes the following important endocrine hormone:

- Melanocyte–stimulating hormone (MSH) or "intermedins".

Posterior pituitary

The posterior pituitary stores and secretes (but does not synthesize) the following important endocrine hormones:

I. Ant diuretic hormone (ADH, also known as vasopressin and arginine vasopressin AVP), the majority of which is released from the supra optic nucleus in the hypothalamus.

Effects:

1. Contraction of smooth muscles of arteriole.
2. Controls the permeability of wall of collecting tubule and DCT.
3. Controls the osmoregulation.
4. Controls the blood pressure.
5. Deficiency causes Diabetes insipidus.

II. Oxytocin (birth hormone): It is released from the paraventricular nucleus in the hypothalamus. Oxytocin is one of the few hormones to create a positive feedback loop.

Effects:

1. Contraction of smooth muscles of myometrium of uterus.
2. It induces child labor contractions during delivery.

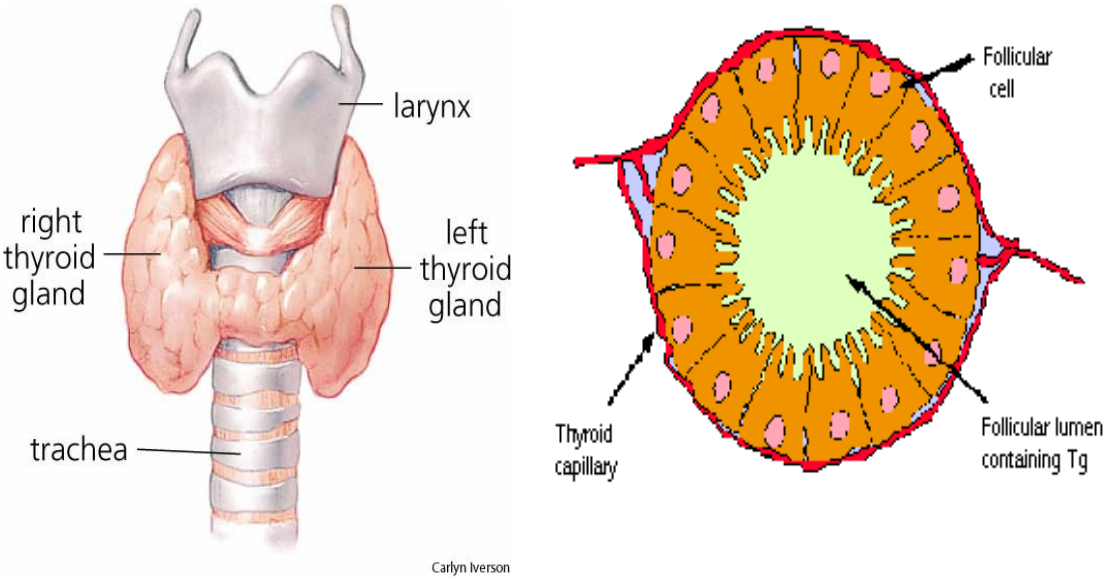
3. Induces milk secretion during sucking. Hence also called as milk ejection hormone.

Functions of pituitary:
Hormones secreted from the pituitary gland help control the following body processes:

- Growth
- Blood pressure
- Some aspects of pregnancy and childbirth including stimulation of uterine contractions during childbirth
- Breast milk production
- Sex organ functions in both males and females
- Thyroid gland function
- The conversion of food into energy (metabolism)
- Water and osmolarity regulation in the body
- Water balance via the control of reabsorption of water by the kidneys
- Temperature regulation
- Pain relief
- Sleeping patterns (pineal gland)

2 Thyroid Gland:

- Located in the neck below the thyroid cartilage.
- It is the largest endocrine gland and weighs about 25 gms.
- Endodermal in origin.
- Present in the ventral side of the trachea.
- It is single lobed in reptile but bilobed in bird and mammals
- Both lobes of thyroid are connected by a transeverse tissue called Isthmus.
- Histologically it consists of 3 million, small, oval or rounded follicles. Each follicle is lined by cuboidal epithelium and surrounded by a gelatinous material called thyroglobulin. In between thyroid follicles parafollicular cells are present. They are scattered in the connective tissue.

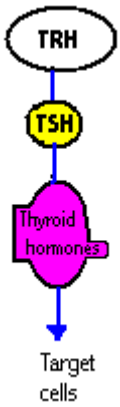


Thyroid gland and thyroid follicle

The thyroid produces its own hormones including thyroxine (T_4) and triiodothyronine (T_3) which regulate the rate of metabolism and affect the growth and functional rate of other systems in the body. T_3 and T_4 secretions are controlled by the TSRH of hypothalamus and TSH of pituitary gland.
The synthesis of thyroxine ($T_{4)\ in}$ the thyroid gland takes place in the follicular cells and involves a number of steps:

1) **The import of iodine into the cell**: The import of iodine across the cell membrane takes place by an active transport mechanism (ATP dependent). The thyroid cells are the only cells in the body that will absorb iodine.
2) **The iodination of tyrosine:** The tyrosine in the thyroid cells is found in thyroglobulin; T_g. Thyroglobulin is a protein which is contained in the lumen of the thyroid cell which includes 140 tyrosines. However only two to five of these tyrosines will be converted to T_3 or T_4. The iodination occurs using thyroid peroxidase enzymes whilst the tyrosine is still attached to the rest of the thyroglobulin by peptide bonds.
3) **The release of the thyroid hormones:** TSH stimulates the release of T_3 and T_4 from thyroglobulin. The ratio of T_4 to T_3 produced in the thyroid is 4:1. Although all the bodies T_4 is produced in the thyroid T_3 can be derived from deiodination of T_4 in other tissues such as the liver or the kidney, this process releases iodide back in to the body. Once released the

thyroid hormones must be transported to the target cells throughout the body. T_3 and T_4 both have poor solubility in water. Hence most of these hormones are bound to a carrier protein such as thyroxine-binding globulin when being transported in the blood. For the hormones to enter the cells, however, they must be free so they are released ready for target cell uptake. Bound forms of T_3 and T_4 remain in the blood.



The rate of uptake into cells determines the rate at which T_3 is produced from T_4 this in turn causes effects such as a change in oxygen consumption and a change in the rate of burning of proteins, carbohydrates and lipids.
The disorders associated with the thyroid tend to be either under or over activity.

Hypothyroidism or under activity:

- An underactive thyroid gland is also known as hypothyroidism. It causes following disorders.
- **Cretinism:** It is a disease of infants. Charecterized by decreased BMR,stunted growth, retarded mental development, low IQ,delayed puberty,pigeion chest (chest bulging forward in sterna region). It may be due to genetic of lack of iodine in the diet.
- **Myxodoema**: It is most common in adults (women). Low BMR, low body temperature, reduced heart rate, low sugar etc. are the main characters. Face and hands become swollen due to deposition of albuminous tissue. It can be corrected by thyroxine administration.
- **Endemic or Simple Goitre**: Occurs due to lack of iodine in the diet. It is non genetic. Characterized by enlargement of thyroid gland. Can be rectified by by adding iodine in the table salt.

- **Hashimoto's Disease**: Also called as auto immune thyroiditis and occurs due to age factor or injury. When thyroxine level is low antibodies are formed which destroy the thyroid gland.

Hyperthyroidism or Over activity:
Over activity of the thyroid is known as hyperthyroidism it is also more common in women than in men and usually occurs in people between twenty and sixty. Hyperthyroidism can make people tired, nervous and irritable and can cause sufferers to have an enlarged thyroid. Patients with disorder will find that despite a large appetite they will lose a lot of weight. A major cause of hyperthyroidism is Graves' disease where antibodies can stimulate the thyroid. Others include an excess of iodine, production of T_3 rather than T_4, pituitary disorders and cancer of the thyroid.

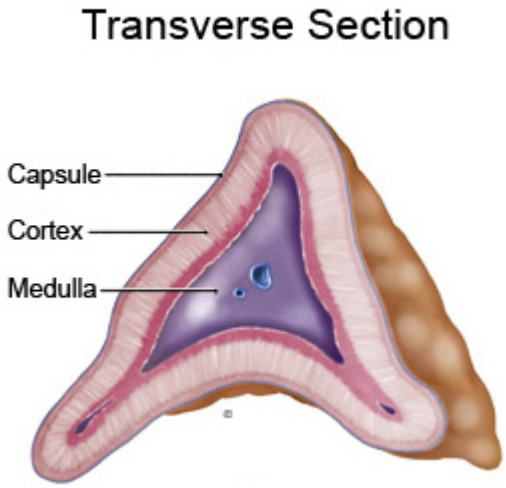
- Exophthalmia goiter: Enlarged thyroid gland, increased BMR, increased heart beat and pulse rate, reduced body weight due to rapid oxidation are the major symptoms. Bulging of eyeballs with starring looks and less blinking is peculiar. It can be corrected by removing a part of the gland.

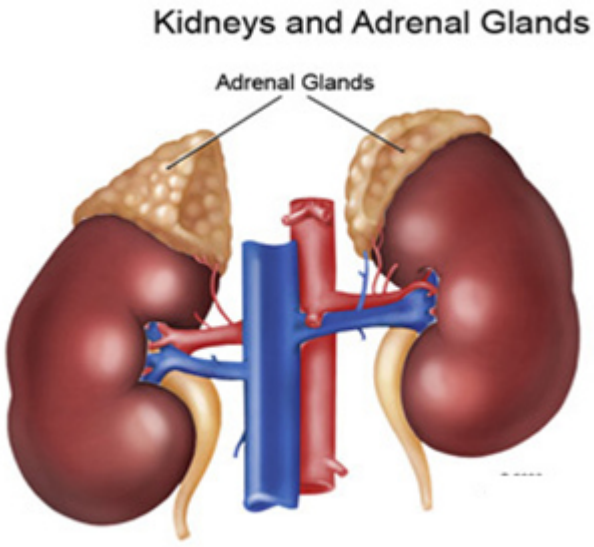
Thyrocalcitonin (TCT): It is long peptide and non iodized hormone secreted by parafollicular cells of thyroid gland. It lowers the calcium level in the blood and increases calcium excretion. It is antagonistic to parathormone. It prevents osteoporosis and increases deposition of calcium on bone. So bones become stronger and longer.

3. Parathyroid:
- Derived from endoderm.
- These are 4 in number and partially embedded in the dorsal surface of thyroid gland.
- They are small and yellow colored.
- The important hormone is a poly peptide parathyroid hormone (PTH) and is regulated by calcium in blood. It is also called as Collip's hormone (After Philips Collip). Its main function is to raise blood calcium level. It is secreted by parathyroid glands, causes bone to release Ca2+ in the kidneys. PTH also stimulates the kidneys to activate vitamin D, promoting intestinal uptake of Ca2+ from food.
- Deficiency causes osteoporosis and bones become week.

4. Adrenal gland (Supra Renal Gland):

- They are paired, yellowish, and star-shaped glands present on the upper surface of the kidneys. It is ecto- mesodermal in origin. The basic function of this gland is to protect the organism against the acute and chronic stress. This has also been popularized as the fight or flight response for medulla and alarm reaction for cortex.

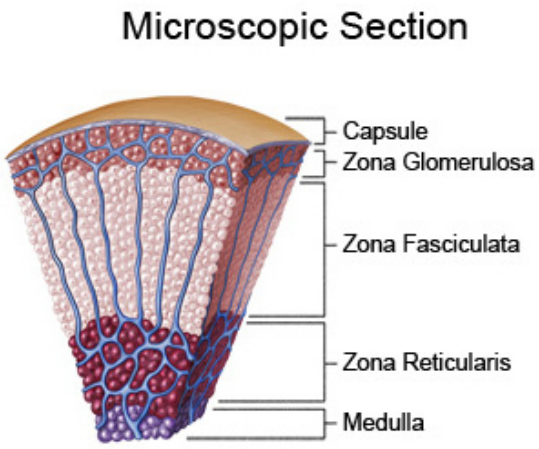




- In humans, the right adrenal gland is triangular in shape, whereas the left adrenal gland is semi lunar in shape. The combined weight of the adrenal glands in an adult human ranges from 7 to 10 grams. They are surrounded by an adipose capsule and renal fascia.
- Each adrenal gland has two distinct structures, the outer adrenal cortex and the inner medulla, both of which produce hormones. The cortex mainly produces cortisol, aldosterone and androgens, while the medulla chiefly produces adrenaline and noradrenaline. The cortex is regulated by ACTH of pituitary hormones.

The adrenal cortex:

- The adrenal cortex is vital to the synthesis of corticosteroid hormones from cholesterol. The source of cortisol and corticosterone synthesis is the hypothalamic-pituitary-adrenal axis. Under normal unstressed conditions, the human adrenal glands produce the equivalent of 35–40 mg of cortisone acetate each day. They also have other functions which include producing androgens (like testosterone) and regulating water and electrolyte concentrations via secretion of aldosterone. The adrenal cortex is regulated by neuroendocrine hormones secreted by the pituitary gland renin-angiotensin system, and hypothalamus.
- The adrenal cortex is meso dermal in origin. It is formed of three distinct regions.1. Zona glomerulosa 2.Zona faciculata 3.Zona fasciculate.



- The three layers of the adrenal cortex are: zona glomerulosa, zona fasciculata, and zona reticularis.
- Zona glomerulosa is the site for production of mineralocorticoids which affect the body's sodium homeostasis.
- Zona fasciculata produces glucocorticoids in humans. Cortisol secretion is simulated by adrenocorticotropic hormone (ACTH) from the anterior pituitary. In the absence of ACTH, zona fasciculata secretes a basal level of cortisol.
- Zona reticularis produces mainly dehydroepiandrosterone (DHEA) and DHEA sulfate.

The adrenal medulla:

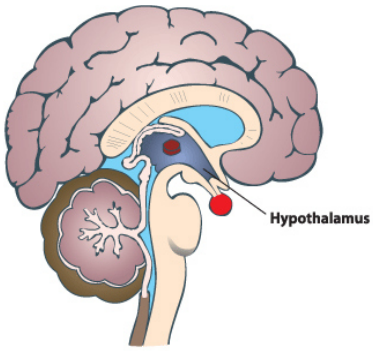
- The adrenal medulla is embedded in the centre of the cortex of each adrenal gland. It is small, making up only about 10 percent of the total adrenal weight.
- The adrenal medulla is composed of chromaffin cells. These cells migrate to the adrenal medulla from the embryonic neural crest. Indeed, the adrenal medulla is an integral part of the sympathetic nervous system, a major subdivision of the autonomic nervous system.
- The sympathetic nervous system and the adrenal medulla are collectively known as the sympatho adrenal system. The chromaffin granules produce the hormones of the adrenal medulla, which include dopamine, nor epinephrine, and epinephrine.
- When stimulated by sympathetic nerve impulses, the chromaffin granules are released from the cells and the hormones enter the circulation by exocytosis.

Diseases of the adrenal glands:

- **Addison's disease**: This is a rare disorder in which the adrenal glands do not produce sufficient amounts of glucocorticoids (mainly cortisol). This can be caused by an autoimmune reaction, by certain infections or by some other rarer causes. It is also called as hypocortisolism.
- **Cushing syndrome**: It is caused by hyper secretion of cortisol. In 1932 American neurosurgeon Harvey Cushing discovered this disease. Abnormal obesity of the face and trunk are peculiar characteristics of this disease.

Hypothalamus:

- The hypothalamus is an integral part of the brain. It is a small cone-shaped structure that projects downward from the brain, ending in the pituitary (infundibular) stalk.



Anterior pituitary Releasing Hormones (RH):

Secreted hormone	Abbreviation	Effect
Thyrotropin-releasing hormone (Prolactin-releasing hormone)	TRH, TRF, or PRH	Stimulate thyroid-stimulating hormone (TSH) release from anterior pituitary (primarily) Stimulate prolactin release from anterior pituitary
Corticotropin-releasing hormone	CRH or CRF	Stimulate adrenocorticotropic hormone (ACTH) release from anterior pituitary
Dopamine (Prolactin-inhibiting hormone)	DA or PIH	Inhibit prolactin release from anterior pituitary
Growth hormone-releasing hormone	GHRH	Stimulate Growth hormone (GH) release from anterior pituitary
Gonadotropin-releasing hormone	GnRH or LHRH	Stimulate follicle-stimulating hormone (FSH) release from anterior pituitary Stimulate luteinizing hormone (LH)release from anterior pituitary
Somatostatin (growth hormone-inhibiting hormone)	SS, GHIH, or SRIF	Inhibit Growth hormone (GH) release from anterior pituitary Inhibit (moderately) thyroid-stimulating hormone (TSH) release from anterior pituitary

- The hypothalamus is located below the thalamus, just above the brainstem.
- The hypothalamus has a central neuroendocrine function, most notably by its control of the anterior pituitary, which in turn regulates various endocrine glands and organs. Releasing hormones (RH) or releasing factors (RF) are produced in hypothalamic nuclei then transported along axons to either the median eminence or the posterior pituitary, where they are stored and released as needed.

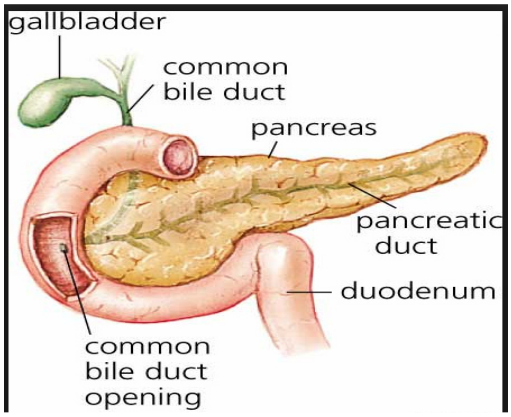
Posterior pituitary Releasing Hormones (RH):

In the hypothalamic-neurohypophyseal axis, neurohypophysial hormones are released from the posterior pituitary, which is actually a prolongation of the hypothalamus, into the circulation.

Secreted hormone	Abbreviation	Effect
Oxytocin	OXY or OXT	Uterine contraction Lactation (letdown reflex)
Vasopressin (antidiuretic hormone)	ADH or AVP	Increase in the permeability to water of the cells of distal tubule and collecting duct in the kidney and thus allows water reabsorption and excretion of concentrated urine

5. Pancreas:

- It is the second largest gland and located in the loop of duodenum.
- It is a mixed gland.
- Endocrine part is formed by islets of langerhans (named after German pathologist Paul Langerhans). It is endodermal and forms only 1-2% of pancreatic tissue.
- Four main cell types exist in the islets. They can be classified by their secretion:
- 1. **α alpha cells**: They secrete glucagon (increase glucose in blood).
- 2. **β beta cells**: They secrete insulin (decrease glucose in blood).
- 3. **Δ delta cells**: They secrete somatostatin (regulates/stops α and β cells).
- **PP cells or γ (gamma) cells**: They secrete pancreatic polypeptide.
- As an exocrine gland, it also plays a pivotal role in the secretion of enzymes which help in digestion. The cells in the pancreas that produce digestive enzymes are called acinar cells.



Disorders:

The hypo secretion mainly causes diabetes mellitus. It is of two types.

- **Diabetes mellitus type 1** (Also known as Juvenile Diabetes): It is a chronic autoimmune disorder in which the immune system attacks the insulin-secreting cells in the pancreas. This causes the patient's blood sugar levels to rise to a dangerous level. To correct this, the patient must take 3+ insulin shots per day.
- **Diabetes mellitus type 2**: It is more common among overweight adults, but has been seen in children also. Unlike Type 1, it can be permanently corrected with weight loss and medicine.

Ovaries

- The ovaries paired and situated in the pelvis with each on opposite sides of the uterus of female reproductive organs.
- It is quite similar to the size and shape of an almond. Ovaries specifically have two functions: they produce eggs and just like the other glands of the endocrine system, they produce female hormones.
- Ovaries secrete estrogen, testosterone and progesterone.
- Estrogen is a steroid and secreted by Graffian follicle. It is responsible for the appearance of secondary sex characteristics for females at puberty and for the maturation and maintenance of the reproductive organs.
- Progesterone prepares the uterus for pregnancy and the mammary glands for lactation. Progesterone functions with estrogen by promoting menstrual cycle changes in the endometrium.

Testes

The testicle is the male gonad in animals. Like the ovaries to which they are homologous, testes are components of both the reproductive system and the endocrine system. The primary functions of the testes are to produce sperm (spermatogenesis) and to produce androgens, primarily testosterone.

The testes produce three main hormones

Hormones of the Testes

Hormone	Produced by	Regulation	Action
Testosterone	Leydig Cells	GnRH from the Hypothalamus causes LH secretion from the Pituitary Gland which stimulates the Leydig Cells.	This hormone controls and maintains the growth and functions of the reproductive organs. It enhances libido and is essential for spermatogenesis.
Inhibin	Sertoli Cells	GnRH from the Hypothalamus causes FSH secretion from the Pituitary Gland which stimulates the Sertoli Cells.	Prevents secretion of further FSH from the Pituitary Gland.
Oestradiol	Sertoli Cells	GnRH from the Hypothalamus causes FSH secretion from the Pituitary Gland which stimulates the Sertoli Cells.	Converted from testosterone, this hormone's function is complex. It may prevent apoptosis of male germ cells.

As young man reaches puberty, his testes actually produce more and more of these hormones. More importantly, these hormones cause boys to have deeper voices, bigger muscles, grow facial and body hair, and stimulate the production of sperm.

Thymus:

- The **thymus** is a specialized organ of the immune system. It is composed of two identical lobes and is located anatomically in the anterior superior mediastinum, in front of the heart and behind the sternum.
- Each lobe of the thymus can be divided into a central medulla and a peripheral cortex which is surrounded by an outer capsule. The cortex and medulla play different roles in the development of T-cells. Hassel's corpuscles (Thymic) are found in thymus.
- Within the thymus, T cells or T lymphocytes mature. T cells are critical to the adaptive immune system, where the body adapts specifically to foreign invaders. Each T cell attacks a specific foreign substance which it identifies with its receptor**.** Each T cell attacks a different antigen**.**
- The thymus is largest and most active during the neonatal and pre-adolescent periods. By the early teens, the thymus begins to atrophy and thymic stroma is mostly replaced by adipose (fat) tissue. Nevertheless, residual T lymphopoiesis continues throughout adult life. Loss of the thymus at an early age through genetic mutation (as in DiGeorge Syndrome) results in severe immunodeficiency and a high susceptibility to infection.

Age	**Mass**
birth	about 15 grams
puberty	about 35 grams
twenty-five years	25 grams
sixty years	less than 15 grams
seventy years	as low as 5 grams

Pineal gland or epiphysis cerebri:

- The pineal gland was originally believed to be a vestigial remnan. It is a small endocrine gland in the vertebrate brain. It produces melatonin, a serotonin derived hormone, which affects the modulation of sleep patterns in both seasonal and circadian rhythms. The production of

melatonin by the pineal gland is stimulated by darkness and inhibited by light. As it is located in the roof of the thalamus it is also called epiphysis.

- It is also known as third eye. René Descartes believed the pineal gland to be the "principal seat of the soul" and viewed it as the third eye.

Placenta:

It is found only mammals (Eutherians). The placenta is an organ that connects the developing fetus to the uterine wall to allow nutrient uptake, waste elimination, and gas exchange via the mother's blood supply. It also fights against internal infection and produces hormones to support pregnancy.

In humans, the placenta also secretes hormones that are important during pregnancy from the syncytial layer of chorionic villi.

- **Human Chorionic Gonadotropin (hCG)**: It can be found in maternal blood and urine as shortly after implantation has occurred, and increases through to the 10-12th week of pregnancy, decreasing to a stable level around the 16-18th week. hCG also ensures that the corpus luteum continues to secrete progesterone and estrogen. hCG suppresses the maternal immunologic response so that placenta is not rejected. hCG is present only during pregnancy because it is secreted by the placenta.
- Human Placental Lactogen (hPL): It promotes mammary gland growth in preparation for lactation in the mother. It also regulates maternal glucose, protein, and fat levels so that this is always available to the fetus. hPL levels increase proportional to placenta size.
- Estrogen: It causes the mother's breasts, uterus and external genitalia to enlarge. Breast enlargement and glandular development is in preparation for lactation and uterine growth to accommodate growing fetus. Estrogen also causes relaxation of ligaments, including the sacro iliac joints and symphysis pubis, which will ease a vaginal birth.
- Progesterone: It is necessary to maintain endometrial lining of the uterus during pregnancy. This hormone prevents preterm labor pains.

Mechanism of Hormone Action

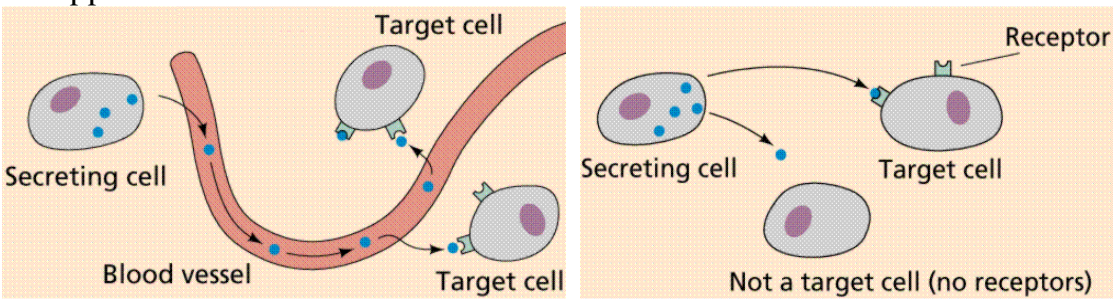
- Hormones are known as first messengers and secreted in response to changes in the environment inside or outside the body. They act on specific organs called target organs. These signals are passed through the blood to arrive at a target organ, which has cells possessing the appropriate receptor.
- Receptors on target cell membranes bind only to one type of hormone. So far more than fifty plus human hormones have been identified. They all act

by binding to receptor molecules. The binding hormone changes the shape of the receptor causing the response to the hormone.

- The blood contains all the hormones but the cells of a target organ can pick up the specific required hormone only and ignore all others.
- It has been found that the target cell has on its surface or in its cytoplasm a specific protein molecule, called a receptor, which can recognize and pick out the specific hormone capable of action in that cell.
- The hormone delivers its message to the target cell by changing the shape of the receptor cell and binds to it. The receptors new shape sets up certain changes in the cell such as alteration in permeability, enzyme activity or gene transcription.
- Hormones may stimulate or inhibit specific biological processes in the target organs to modify their activities thus acting as regulators. There is considerable co-ordination between nerves and hormones. Nerves regulate synthesis and release of some hormones. Sometimes hormones may also influence nerve activities. Thus, hormonal co-ordination plays an important role in regulating body functions.

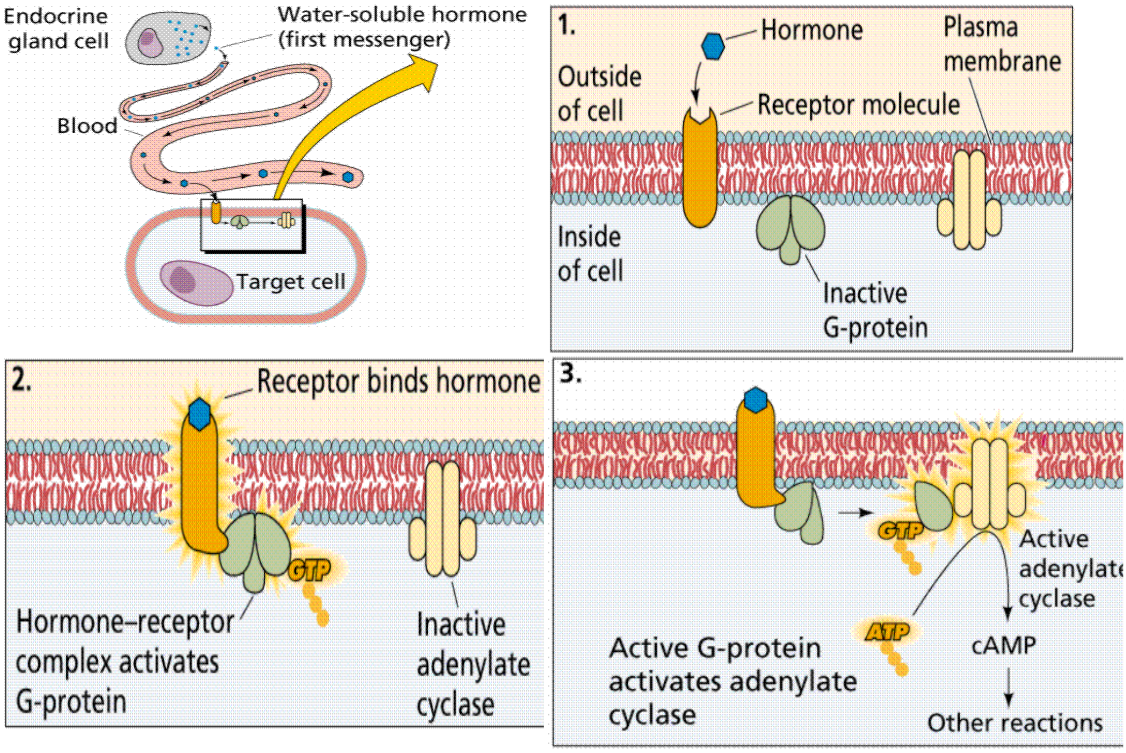
Mechanism

- The hormones are released in very small quantities, yet they can cause widespread responses in cells or tissues all over the body. These responses can be quite specific and selective in different cells.
- All vertebrate hormones belong to one of four chemical groups. They are water soluble or lipid soluble. Peptide and protein hormones are not lipid-soluble. Hence they cannot enter their target cells through the bilipid layer of plasma membrane. Instead, these water-soluble hormones interact with a surface receptor, usually a glycoprotein, and thus, initiate a chain of events within it. The hormone insulin provides a well-studied example of how this happens.



Nonsteroid Hormones (insulin) (Water soluble)

- Nonsteroid hormones (water soluble) do not enter the cell but bind to plasma membrane receptors, generating a chemical signal (second messenger) inside the target cell. Five different second messenger chemicals, including cyclic AMP have been identified. Second messengers activate other intracellular chemicals to produce the target cell response.



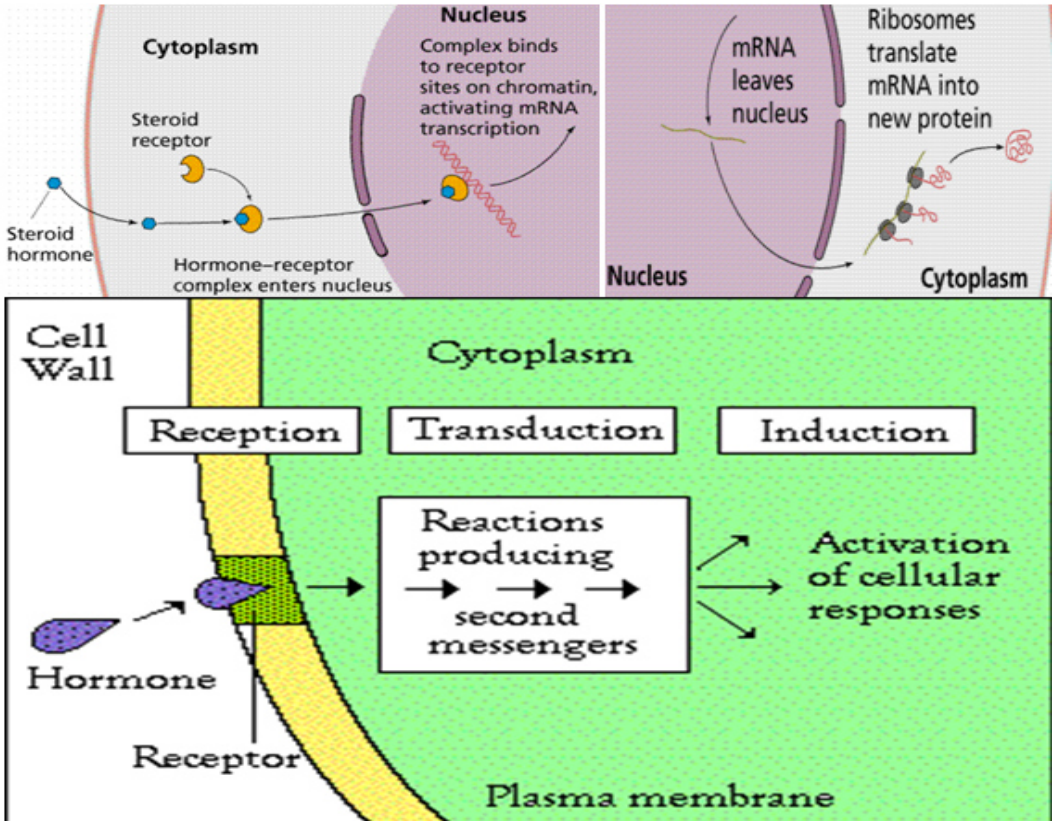
- **Extra cellular Receptors:** The membrane bound receptors of insulin is a hetero tetrameric protein consisting of four subunits, two -subunits protrude out from surface of the cell and bind insulin, and two -subunits that span the membrane and protrude into the cytoplasm. Such receptors range from fewer than 100 in most cells in our body to more than 1, 00,000 in some liver cells.
- **Binding to the receptor:** Binding of insulin to the outer subunits of the receptor causes a conformational change in the membrane spanning -subunits, which is also an enzyme, a tyrosine kinase. The activated -subunits add phosphate groups of specific tyrosine residues located in

cytoplasmic domain of the receptor, as well as a variety of insulin receptor substrates.

- **Second messengers the mediator**: As a result of -subunit activity, a transducer G protein activates enzyme phosphodiesterase. This enzyme makes phosphatidylinositol 4,5-biphosphate (PIP_2) into a pair of mediators inositoltriphosphate (IP_3) and diacylglycerol (DG). In turn, IP_3, which is water-soluble, and so diffuses into cytoplasm, triggers the release of another messenger Ca^{2+} ions from intracellular endoplasmic reticulum activating many calcium-mediated processes. While DG remains in the membrane where it activates an enzyme called protein kinase C, which in turn, activates many other enzymes, such as pyruvate dehydrogenase, and so brings about the physiological effects.
- **Amplification of signal:** Mediators amplify the signal in an expanding cascade of response. A single -subunit of insulin receptor, for example, activates many molecules of DG, and each protein kinase C molecule activated by DG will, in turn, activate many other enzyme molecules. DG and IP_3 are examples of second messengers, intermediary compounds that amplify a hormonal signal and so set into action a variety of events within the affected cell. A variety of events within the affected cell. A variety of hormones use another second messenger, the cyclic form of adenosine monophosphate, (cAMP).
- **Antagonistic effect:** Many cells use more than one second messenger. In heart cells, cAMP serves as a second messenger, speeding up muscle cell contraction in response to adrenaline, while cyclic guanosine monophosphate (cGMP) serves as another second messenger, slowing muscle contraction in response to acetylcholine. It is in this way that the sympathetic and parasympathetic nervous systems achieve antagonistic effect on heartbeat. Another example of antagonistic effect is insulin, which lowers blood sugar level, and glucagons, which raises it.
- **Synergistic effect:** Another type of hormonal interaction is known as synergistic effect. Here, two or more hormones complement each other actions and both are needed for full expression of the hormone effects. For example, the production, secretion and ejection of milk by mammary glands require the synergistic effects of estrogens, progesterone, prolactin and oxytocin.

Steroid Hormones

The second mechanism involves steroid hormones, which pass through the plasma membrane and act in a two step process. Steroid hormones bind, once inside the cell, to the nuclear membrane receptors, producing an activated hormone-receptor complex. The activated hormone-receptor complex binds to DNA and activates specific genes, increasing production of proteins.



CHAPTER 13
ANIMAL REPRODUCTION

Background:

- Reproduction (or procreation) is the biological process by which new "offspring" individual organisms are produced from their "parents".
- Reproduction is a fundamental feature of all living organisms.
- Each individual organism exists as the result of reproduction.
- It helps in continuity of the race and group.

Types: It is of two types. 1. Asexual Reproduction and 2.Sexual Reproduction.

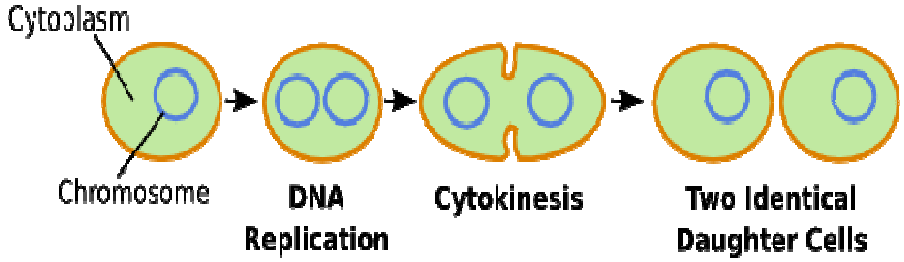
1. Asexual Reproduction:

- Do not involve the formation and fusion of gamets.
- Only a single parent is involved.
- Involve only mitotic divisions. Hence it is also called as somatogenic reproduction. Do not bring variations.
- New individuals produced are genetically similar to the parent.
- Reproduction is rapid and primitive type.
- It has no role in the evolution.

Types of Asexual Reproduction:

1. **Binary Fission:**

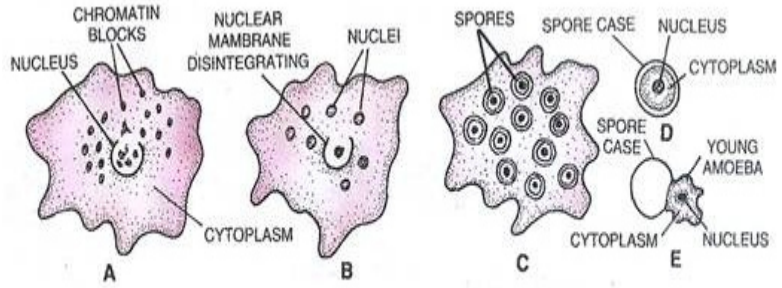
- In this type adult parental body divide into two equal daughter cells. In general it occurs in favourable conditions. It is type of mitosis in which nucleus divides first (karyokinesis) and followed by cytokinesis. Examples. Protozoans.amoeba.



- It is irregular: Ameoba.
- It is longitudinal: Euglena.
- It is Transverse: Paramecium.

2. Multiple fission:

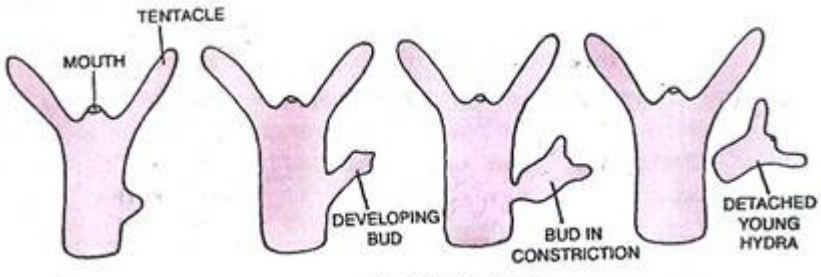
- It occurs generally in unfavorable conditions.
- Parental body divides into many daughter cells.
- Here, the nucleus of parent divides into many nuclei. Then after, each nuclei takes a small amount of cytoplasm and forms a daughter cell. Example: Ameoba, Merozoites of plasmodium.



Multiple Fission in uncysted *Amoeba*.

3. Budding:

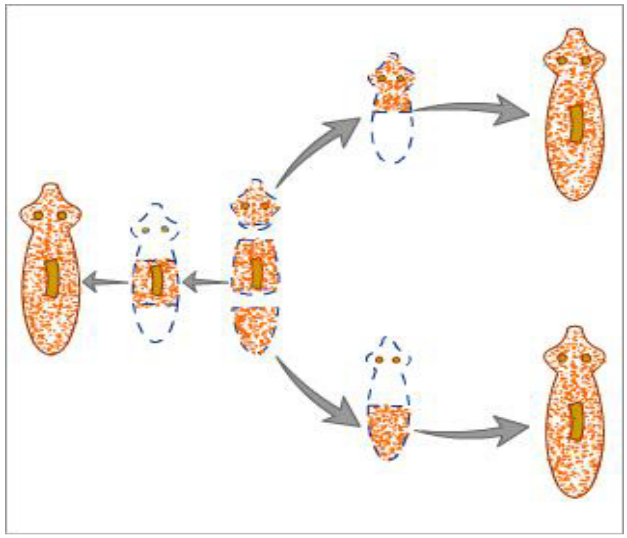
- In this type, one or more unicellular or multicellular outgrowths are formed from the parental body. They are called buds. On separation they may develop into new individual. Examples. Sponges, Hydra.



Budding in *Hydra*.

4. **Fragmentation:**

- In this type, parental body breaks into one or more fragments. Each fragment develops into an organism. Example: Flat worms, Star fish.



2. Sexual Reproduction:

- It involves the formation and fusion of gamets. Sperm and ovum are known as gamets. Sperm is the male gamete while ovum is the female gamete. They are formed in testes and ovary respectively.
- Two parents are involved.
- Involve both mitotic and meiosis divisions. It brings variations.
- New individuals produced are genetically dissimilar to the parent.
- Reproduction is slow and advanced type.
- It play important role in the evolution.

Sexual Reproduction is again following types.

- Endogamy: (Self Fertilization). In this type, the fusing gamets are derived from the same parent. Example. Taenia solium.
- Exogamy: (Cross fertilization): In this type fusing gamets are derived from different parents. Human, frog.
- Isogamy: The fusing gamets are identical in morphology and in physiology. Example. Monocystis (protozoan).
- Ansogamy: The fusing gamets are morphologically and physiologically non identical. It is advanced type and found in all higher animals including man.
- Conjugation: It involves temporary pairing of two parents. Exchange of nuclei (genetic material) takes place between the two. Example. Paramacium.

Human Reproductive System:

The essential features of human reproduction are

- Liberation of an ovum, or egg, at a specific time in the reproductive cycle,
- (2)Internal fertilization of the ovum by spermatozoa, or sperm cells,
- (3) Transport of the fertilized ovum to the uterus, or womb,
- (4) Implantation of the blastocyst, the early embryo developed from the fertilized ovum, in the wall of the uterus,
- (5) Formation of a placenta and maintenance of the unborn child during the entire period of gestation,
- (6) Birth of the child and expulsion of the placenta, and
- (7) Suckling and care of the child, with an eventual return of the maternal organs to virtually their original state.

For this biological process to be carried out, certain organs and structures are required in both the male and the female. The source of the ova (the female germ cells) is the female ovary and that of spermatozoa (the male germ cells) is the testis.

The male reproductive system:

It is formed of following parts.

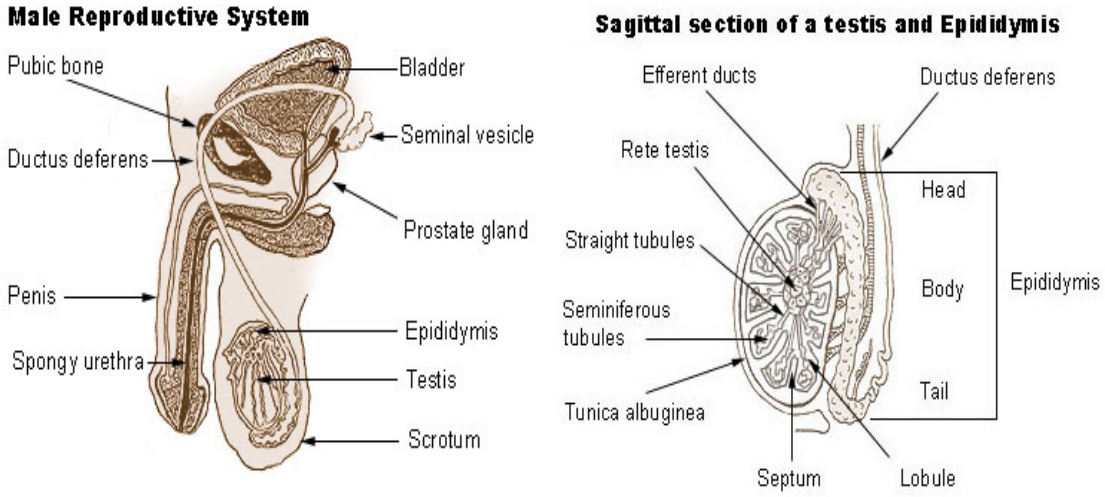
1. Testes. 2. Epididymis. 3. Vasa differentia. 4. Urethra. 5. Penis.
6. Accessoray glands.

1. Testes:

- They are paired, oval, pinkish and primary sex organs of the male. Each testis is an oval structure about 5 cm long and 3 cm in diameter.
- They are extra abdominal and present in thin walled skin pouches called scrotum.
- Scrotal sacs are filled with tissue fluid called hydrocoel.
- Testes are held in position in scrotum by a small, thick, white fibrous ligament, called gubernaculums.
- Scrotal sac connected to the abdominal cavity through inguinal canal.
- Scrotal sacs act as thermoregulators and keep the testicular temperature 2°C lower than the body temperature for normal spermatogenesis.

Histology:

- Histologically each testes is covered by a white fibrous capsule called tunica albugenea. Inside it forms many septa.
- The septa divide the testes into a number of lobules (200-300).
- Each lobule has 1-3 convoluted seminiferous tubules. They open into a network of tubules called retetis.Each testes contain about 900 seminiferous tubules.
- Each seminiferous tubule is lined by germinal epithelium. It is formed of germ cells and sertoli cells or nurse cells.
- Germinal cells undergo spermatogenesis and form haploid, motile male gamets called sperms.
- Sertoli cells provide nutrition to developing sperms.
- Inbetween the seminiferous tubules, there are groups of endocrine cells, called interestial or Leydig's cells. They secrete male sex hormone or testosterone. It controls the development of secondary sexual characters in male.
- So, the main function of the testes is spermatogenesis and secretion of testosterone.



Sperm cells pass through a series of ducts to reach the outside of the body. After they leave the testes, the sperm passes through the epididymis, vasa deferens, ejaculatory duct, and urethra.

Epididymis:

- It is a long (about 6 meters) tube that is tightly coiled to form a comma-shaped organ located along the superior and posterior margins of the testes.
- When the sperm leave the testes, they are immature and incapable of fertilizing ova. They complete their maturation process and become fertile as they move through the epididymis. It is differentiated into three parts.

1. **Head or caput epididymus**: It is swellen upper part and receives the sperms from fine and ciliated ducts of rete testis called vasa efferentia.
2. **Body or Corpus:** It is the middle part and stores the sperms temporarily.
3. **Tail or Cauda Epididymus**: It is the terminal part of epididymus. Mature sperm are stored in the lower portion, or tail, of the epididymis.

Vasa Deferens:

- The vasa deferens is also called sperm duct.
- It is a fibro muscular tube that is continuous with the epididymis.
- It begins at the bottom (tail) of the epididymis then turns sharply upward along the posterior margin of the testes and enters the abdomino pelvic cavity through the inguinal canal.

- It crosses over the ureter and posterior portion of the urinary bladder, and then descends along the posterior wall of the bladder toward the prostate gland.
- Just before it reaches the prostate gland, each ductus deferens enlarges to form an ampulla called seminal vesicle. It helps in conduction of sperms through peristalsis.

Ejaculatory Duct:

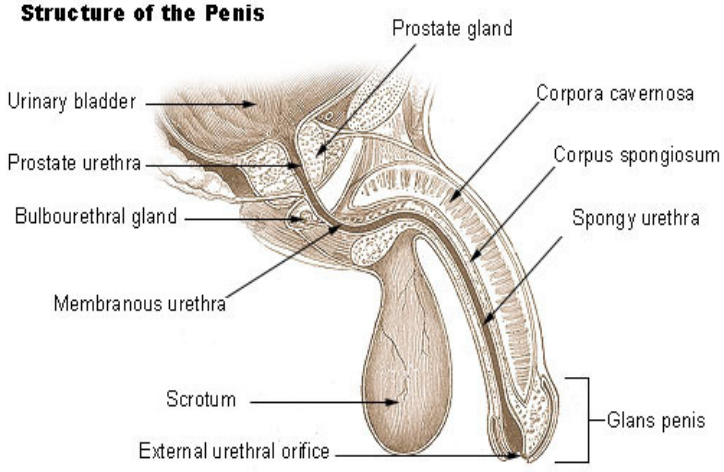
- Each vas deferens, at the ampulla, joins the duct from the adjacent seminal vesicle (one of the accessory glands) to form a short ejaculatory duct. Each ejaculatory duct passes through the prostate gland and empties into the urethra.

Urethra

- The urethra extends from the urinary bladder to the external urethral orifice at the tip of the penis. It is a common passageway for both sperm and urine. It receives the ejaculatory duct, which contains sperm and secretions from the seminal vesicles, and numerous ducts from the prostate glands. The ducts from the bulbo urethral glands open into the penile urethra.

Penis

- The penis, the male copulatory organ, is a cylindrical hanging organ located anterior to the scrotum and functions to transfer sperm to the vagina.
- The penis consists of three columns of erectile tissue that are wrapped in connective tissue and covered with skin.
- The two dorsal columns are the corpora cavernosa. The single, midline ventral column surrounds the urethra and is called the corpus spongiosum.



- The penis has a root, body (shaft), and glans penis (tip).
- The corpus spongiosum expands at the distal end to form the glans penis.
- The urethra, which extends throughout the length of the corpus spongiosum, opens through the external urethral orifice at the tip of the glans penis.
- A loose fold of skin, called the prepuce, or foreskin, covers the glans penis.

ACCESSORY GLANDS

The accessory glands of the male reproductive system are:

1. Seminal vesicles 2. Prostate gland 3.Bulbourethral glands. These glands secrete fluids that enter the urethra.

Seminal Vesicles

- The paired seminal vesicles are saccular glands posterior to the urinary bladder. Each gland has a short duct that joins with the vasa deferens at the ampulla. The fluid from the seminal vesicles is viscous and contains fructose, which provides an energy source for the sperm. It forms about 60% of semen and mainly formed of prostaglandans.

Prostate

- The prostate gland is a firm, dense structure that is located just inferior to the urinary bladder. It is about the size of a walnut and encircles the urethra as it leaves the urinary bladder.
- Numerous short ducts from the substance of the prostate gland empty into the prostatic urethra. The secretions of the prostate are thin, milky colored, and alkaline. They function to enhance the motility of the sperm. It also neutralizes the acidity of urine which may kill the sperms.

Bulbourethral Glands or Cowper's glands

- They are paired, small, size of pea and located near the base of the penis.
- A short duct from each gland enters the proximal end of the urethra. In response to sexual stimulation, the bulbourethral glands secrete an alkaline mucus-like fluid. This fluid neutralizes the acidity of the urine residue in the urethra, helps to neutralize the acidity of the vagina, and provides some lubrication for the tip of the penis during intercourse.

Seminal Fluid

- Seminal fluid, or semen, is a slightly alkaline mixture of sperm cells and secretions from the accessory glands.
- The volume of semen in a single ejaculation may vary from 1.5 to 6.0 ml. There are usually 50 to 150 million sperm per milliliter of semen. Sperm

counts below 10 to 20 million per milliliter usually present fertility problems.

MALE SEXUAL RESPONSE AND HORMONAL CONTROL

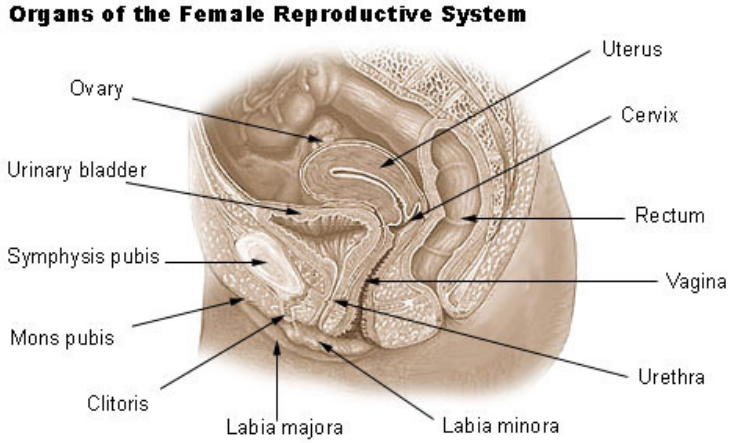
The male sexual response includes erection and orgasm accompanied by ejaculation of semen. Orgasm is followed by a variable time period during which it is not possible to achieve another erection.

Three hormones are the principle regulators of the male reproductive system: follicle-stimulating hormone (FSH) stimulates spermatogenesis; luteinizing hormone (LH) stimulates the production of testosterone; and testosterone stimulates the development of male secondary sex characteristics and spermatogenesis.

FEMALE REPRODUCTIVE SYSTEM

The organs of the female reproductive system produce and sustain the female sex cells (egg cells or ova), transport these cells to a site where they may be fertilized by sperm, provide a favorable environment for the developing fetus, move the fetus to the outside at the end of the development period, and produce the female sex hormones. The female reproductive system includes the ovaries, Fallopian tubes, uterus, vagina, accessory glands, and external genital organs.

- Ovaries
- Genital Tract
- External Genitalia
- Female Sexual Response and Hormonal Control
- Mammary Glands

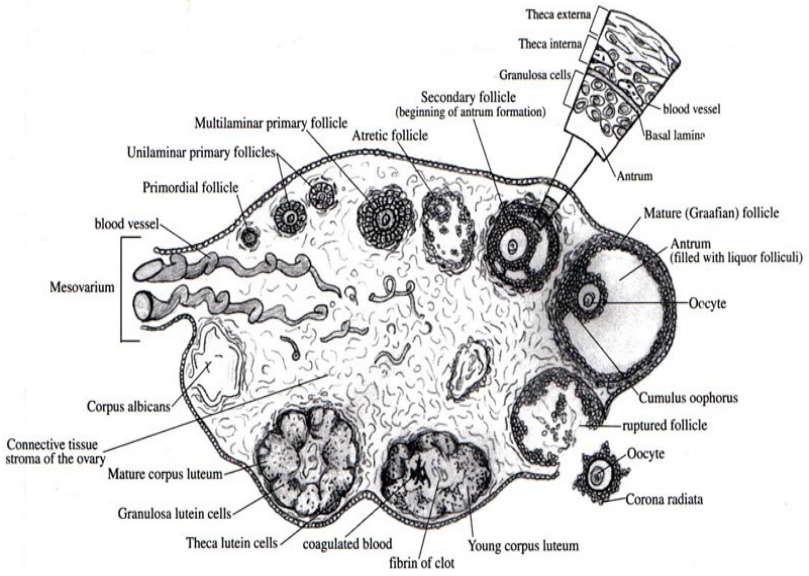


OVARIES

- They are primary female reproductive organs.
- Each ovary is a solid, ovoid structure about the size and shape of an almond, about 3.5 cm in length, 2 cm wide, and 1 cm thick.
- The ovaries are located in shallow depressions, called ovarian fossae, one on each side of the uterus, in the lateral walls of the pelvic cavity. They are held loosely in place by peritoneal ligaments.

Structure

- The ovaries are covered on the outside by a layer of simple cuboidal epithelium called germinal (ovarian) epithelium.
- Below this layer is a dense connective tissue called the tunica albuginea is present.
- The substance of the ovaries is distinctly divided into an outer cortex and an inner medulla.
- The cortex appears more dense and granular due to the presence of numerous ovarian follicles in various stages of development. Each of the follicles contains an oocyte, a female germ cell.
- The medulla is a loose connective tissue with abundant blood vessels, lymphatic vessels, and nerve fibers.



Follicular Maturation

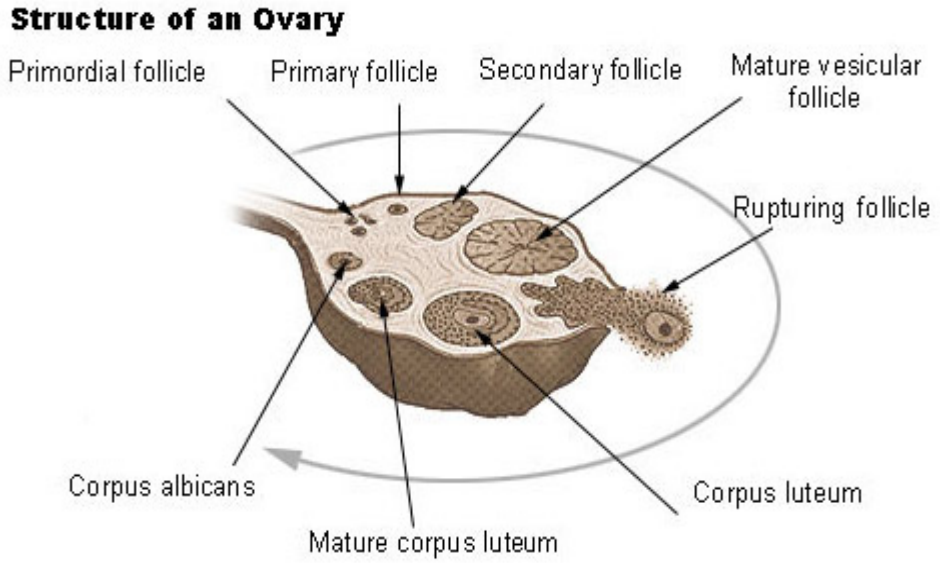
Oogenesis

- Female sex cells, or gametes, develop in the ovaries by a form of meiosis called oogenesis.
- The sequence of events in oogenesis is similar to the sequence in spermatogenesis, but the timing and final results are different.
- Early in fetal development, primitive germ cells in the ovaries differentiate into oogonia. These divide rapidly to form thousands of cells, still called oogonia, which have a full complement of 46 (23 pairs) chromosomes.
- Oogonia then enter a growth phase, enlarge, and become primary oocytes. The diploid (46 chromosomes) primary oocytes replicate their DNA and begin the first meiotic division, but the process stops in prophase and the cells remain in this suspended state until puberty. Many of the primary oocytes degenerate before birth, but even with this decline, the two ovaries together contain approximately 700,000 oocytes at birth. This is the lifetime supply, and no more will develop. This is quite different than the male in which spermatogonia and primary spermatocytes continue to be produced throughout the reproductive lifetime. By puberty the number of primary oocytes has further declined to about 400,000.
- Beginning at puberty, under the influence of follicle-stimulating hormone, several primary oocytes start to grow again each month. One of the primary oocytes seems to outgrow the others and it resumes meiosis I. The other cells degenerate.
- The large cell undergoes an unequal division so that nearly all the cytoplasm, organelles, and half the chromosomes go to one cell, which becomes a secondary oocyte.
- The remaining half of the chromosomes go to a smaller cell called the first polar body. The secondary oocyte begins the second meiotic division, but the process stops in metaphase. At this point ovulation occurs.
- If fertilization occurs, meiosis II continues. Again this is an unequal division with all of the cytoplasm going to the ovum, which has 23 single-stranded chromosome.
- The smaller cell from this division is a second polar body. The first polar body also usually divides in meiosis I to produce two even smaller polar bodies.
- If fertilization does not occur, the second meiotic division is never completed and the secondary oocyte degenerates. Here again there are obvious differences between the male and female. In spermatogenesis, four

functional sperm develop from each primary spermatocyte. In oogenesis, only one functional fertilizable cell develops from a primary oocyte. The other three cells are polar bodies and they degenerate.

Ovarian Follicle Development

- An ovarian follicle consists of a developing oocyte surrounded by one or more layers of cells called follicular cells. Primordial follicles, which consist of a primary oocyte surrounded by a single layer of flattened cells, develop in the fetus and are the stage that is present in the ovaries at birth and throughout childhood.



- Beginning at puberty, follicle-stimulating hormone stimulates changes in the primordial follicles.
- The follicular cells become cuboidal, the primary oocyte enlarges, and it is now a primary follicle. The follicles continue to grow under the influence of follicle-stimulating hormone.
- Most of these primary follicles degenerate along with the primary oocytes within them, but usually one continues to develop each month.
- The granulosa cells start secreting estrogen and a cavity, or antrum, forms within the follicle. When the antrum starts to develop, the follicle becomes a secondary follicle. The granulose cells also secrete a glycoprotein substance that forms a clear membrane, the zona pellucida, around the oocyte.

- After about 10 days of growth the follicle is a mature. It is called vesicular or Graafian follicle. It forms a "blister" on the surface of the ovary and contains a secondary oocyte ready for ovulation.

Ovulation

- Ovulation, prompted by luteinizing hormone from the anterior pituitary, occurs when the mature follicle at the surface of the ovary ruptures and releases the secondary oocyte into the peritoneal cavity.
- The ovulated secondary oocyte, ready for fertilization is still surrounded by the zona pellucida and a few layers of cells called the corona radiata.
- If it is not fertilized, the secondary oocyte degenerates in a couple of days. If a sperm passes through the corona radiata and zona pellucida and enters the cytoplasm of the secondary oocyte, the second meiotic division resumes to form a polar body and a mature ovum.
- After ovulation and in response to luteinizing hormone, the portion of the follicle enlarges and is transformed into a corpus luteum.
- The corpus luteum is a glandular structure that secretes progesterone and estrogens. Its fate depends on whether fertilization occurs.
- The corpus luteum remains functional for about 10 days. If fertilization does not take place, then it begins to degenerate into a corpus albicans, and its hormone output ceases.
- If fertilization occurs, the corpus luteum persists and continues its hormone functions until the placenta develops sufficiently to secrete the necessary hormones. Again, the corpus luteum ultimately degenerates into corpus albicans, but it remains functional for a longer period of time.

GENITAL TRACT

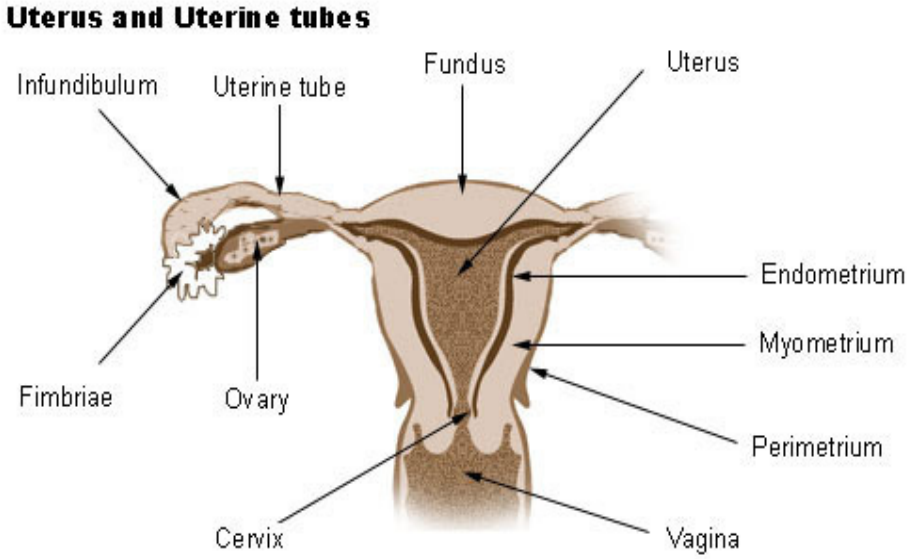
Fallopian Tubes

- They are paired, long, ciliated, muscular and tubular structures.
- Each fallopian tube is associated with each ovary.
- The end of the tube near the ovary expands to form a funnel-shaped infundibulum, which is surrounded by fingerlike extensions called fimbriae.
- Because there is no direct connection between the infundibulum and the ovary, the oocyte enters the peritoneal cavity before it enters the Fallopian tube.
- At the time of ovulation, the fimbriae increase their activity and create currents in the peritoneal fluid that help propel the oocyte into the

Fallopian tube. The journey through the Fallopian tube takes about 7 days. Because the oocyte is fertile for only 24 to 48 hours, fertilization usually occurs in the Fallopian tube.

Uterus

- It is hollow, muscular and highly vascular and present in pelvis between the bladder and rectum. It is lined with the endometrium and myometrium.
- The upper dome shaped part is called fundus.fallopian tubes open in it. The lower narrow part is called cervix and it opens into vagina.
- It receives the fertilized oocyte and provides an appropriate environment for the developing fetus.
- Before the first pregnancy, the uterus is about the size and shape of a pear, with the narrow portion directed inferiorly. After childbirth, the uterus is usually larger, and then regresses after menopause.

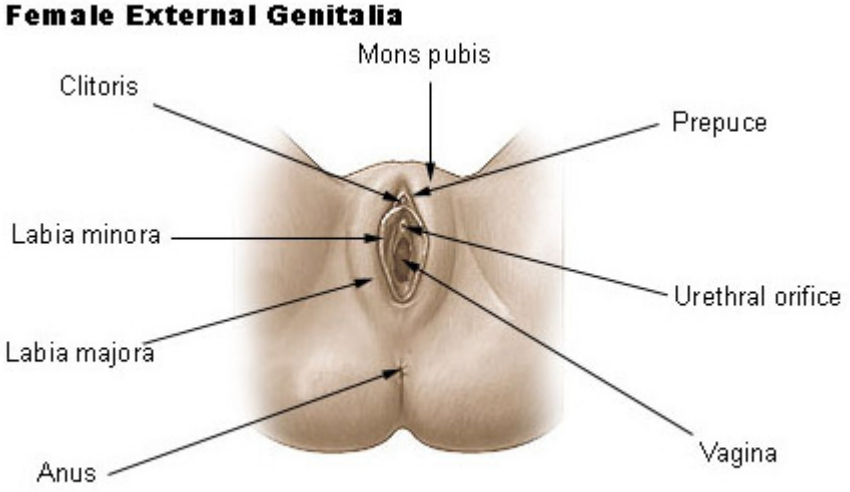


Vagina

- The vagina is a fibro muscular tube, about 10 cm long, which extends from the cervix of the uterus to the outside.
- It is located between the rectum and the urinary bladder. It serves as a passageway for menstrual flow, receives the erect penis during intercourse, and is the birth canal during childbirth. Internally it is lined by folding of mucous membrane. The foldings are known as vaginal rugae.

EXTERNAL GENITALIA (VULVA)

- The external genitalia are the accessory structures of the female reproductive system that are external to the vagina. They are also referred to as the vulva or pudendum.
- The external genitalia include the labia majora, mons pubis, labia minora, clitoris, and glands within the vestibule.
- The clitoris is an erectile organ. It is homologus to the male penis. It responds to sexual stimulation. Posterior to the clitoris, the urethra, vagina, paraurethral glands and greater vestibular glands open into the vestibule.



FEMALE SEXUAL RESPONSE & HORMONE CONTROL

- The female sexual response includes stimulation and orgasm but there is no ejaculation. A woman may become pregnant without having an orgasm.
- Follicle-stimulating hormone, luteinizing hormone, estrogen, and progesterone have major roles in regulating the functions of the female reproductive system.
- At puberty the hormonal stimulation, cause the hypothalamus to start secreting gonadotropin-releasing hormone. This hormone enters the blood and goes to the anterior pituitary gland where it stimulates the secretion of follicle-stimulating hormone and luteinizing hormone.
- These hormones, in turn, affect the ovaries and uterus and the monthly cycles begin. A woman's reproductive cycles last from menarche to menopause.

- The monthly ovarian cycle begins with the follicle development during the follicular phase, continues with ovulation during the ovulatory phase, and concludes with the development and regression of the corpus luteum during the luteal phase.
- The uterine cycle takes place simultaneously with the ovarian cycle. The uterine cycle begins with menstruation during the menstrual phase, continues with repair of the endometrium during the proliferative phase, and ends with the growth of glands and blood vessels during the secretory phase.
- Menopause occurs when a woman's reproductive cycles stop. This period is marked by decreased levels of ovarian hormones and increased levels of pituitary follicle-stimulating hormone and luteinizing hormone. The changing hormone levels are responsible for the symptoms associated with menopause.