PUBLIC HEALTH POLICY & MANAGEMENT

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Name of the Study Material: PUBLIC HEALTH POLICY & MANAGEMENT

ISBN : ************

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Year of Print: 2020

No. of Copies: ******

Printed and Published by:

For:

Directorate of Distance & Continuing Education
Utkal University, Bhubaneswar - 751007
www.ddceutkal.ac.in

DIRECTORATE OF DISTANCE & CONTINUING EDUCATION UTKAL UNIVERSITY : VANI VIHAR BHUBANESWAR:-751007.

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We wish you happy reading.

DIRECTOR

CONTENT

UNIT 1 Introduction to the Human Body, Cell and Blood

Structure

1.0 OBJECTIVES

In this unit we will learn about:

- The human body – from a single cell to a large body
- The cell and its structure
- Functions of the organelles of a cell
- Cell cycle and reproduction i.e. mitosis and meiosis
- Types of cell and their functions in the human body.
- explain the composition of blood and its role in our body,
- discuss about various blood groups,

1.1 INTRODUCTION

The body consists of various systems that interact with each other. Making up these systems are organs and tissues that work together to carry out a specific function, such as digestion. The different types of tissues that make up organs and other body parts are highly specialized. For example, the stomach has muscular walls for churning food and a mucosa lining that secretes gastric juices and protective mucus. The interconnected cells that make up these tissues each contain genes that program cell activities. These genes are tiny regions of DNA that dictate cell activity and inherited traits. Studying about the human body from the cell level gives us an insight into the amazing animal that we are- humans.
Study of the human body leads to a better understanding of health and disease apart from appreciating the human machinery.

1.2 THE HUMAN BODY

Human beings (*Homo sapiens*) are biological organisms. The basic physical requirements of humans, as with all organisms, are: *water*, for a variety of metabolic processes; *food*, to supply energy, raw materials for building new living matter, and chemicals necessary for vital reactions; *oxygen*, to release energy from food materials; *heat*, to promote chemical reactions; and *pressure*, to allow breathing.

The levels of organization of the human body are, from the simplest to the most complex: chemical, cellular, tissue, organ, system, and organism. Each level of body organization represents an association of units from the preceding level.

Figure 1.2: From cell to body

Chemical and **cellular** levels are the basic structural and functional levels.

A **tissue** is an aggregation of similar cells that performs a specific function. There are four types of tissues found in humans.

An **organ** is composed of several tissue types that are integrated to perform a particular function.

A **system** is an organization of two or more organs and associated tissues working as a unit to perform a common function or set of functions. The body systems are:

1. The **muscular and skeletal systems** function in body support and locomotion.
2. The **endocrine and nervous systems** function in integration and coordination by maintaining consistency of body functioning.
3. The **digestive, respiratory, circulatory, lymphatic, and urinary systems** are involved with processing and transporting body substances.

    - The **digestive system** mechanically and chemically breaks down foods for cellular use and eliminates undigested wastes.
    - The **respiratory system** supplies oxygen to the blood eliminates carbon dioxide, and helps regulate acid-base balance.
    - The **circulatory system** transports respiratory gases, nutrients, wastes, and hormones; helps regulate body temperature and acid-base balance; and protects against disease and fluid loss.
    - The **lymphatic system** transports lymph from tissues to the blood stream, defends the body against infections, and aids in the absorption of fats.
    - The **urinary system** functions to remove wastes from the blood; regulate the chemical composition, volume, and electrolyte balance of the blood; and helps to maintain the acid-base balance of the body.

4. The **integumentary system** functions to protect the body, regulate body temperature, eliminate wastes, and receive sensory stimuli.
5. The **reproductive system** functions to produce gametes for sexual reproduction and to produce sex hormones.

Systems of the Human Body:

Human body is made of ten different systems. All the systems require support and coordination of other systems to form a living and healthy human body. If any one of these systems is damaged, human body will become unstable and this lack of stability will ultimately lead to death. The instability caused by damage of one system cannot be stabilized by other systems because functions of one system cannot be performed by other systems. Knowledge of human body systems is very important for a professional. Although, generally, the structural aspects of human body systems are studied in anatomy and the functional aspects are studied in physiology but it is very important to have a coordination between the two subjects because knowledge of structure is incomplete without the knowledge of function and the knowledge of function is incomplete without the knowledge of structure.

Name:	Components	Role
Skeletal System	Bones, Associated cartilages, Joints	Strength, Support, Shape, Protection, Leverage, Cell Production
Muscular System	Muscles (Skeletal Muscles, Smooth mucles, Cardiac Muscles)	Motor power for movements of body parts.
Nervous System	Brain, Spinal Cord, Nerves, Nerve Endings	Control and Coordination of all body functions (Nervous coordination)
Respiratory System	Lungs, Nose, Trachea, Bronchi, Bronchioles, Alveolar sacs, Alveoli	Gaseou exchange
Cardiovascular System	Heart, Blood vessels (Arteries, Veins and Capillaries), Blood	Flow of blood (and nutrients) throughout body
Lymphatic System	Lymph vessels, Central lymphoid tissue, Peripheral Lymphoid Organs, Lymphocytes	Drainage and Protection
Endocrine System	Endocrine glands (Pituitary gland, Thyroid gland, Parathyroid glands, Adrenal glands, Pancreas (endocrine part), Testes (endocrine part), Ovary (endocrine part), Liver (endocrine part))	Regulation of body functions (Chemical coordination)
Digestive System	Alimentary Canal (Oral Cavity, Esophagus, Stomach, Small Intestine, Large Intestine, Anus), Liver, Pancreas, Salivary glands, Teeth, Tongue	Digestion and absorption of food
Urinary System	Kidneys, Ureters, Urinary bladder, Urethra	Regulation of body's internal environment, and production and excretion of urine
Male Reproductive System	Penis, Testes	Formation of sperms and semen, and fertilizing the female
Female Reproductive System	Uterus, Ovaries, Vulva, Labia, Clitoris	Formation of eggs and bearing the fetus during development

Figure 1.2a: Organs in the human body

Anatomical Position and Terminology

All terms of direction that describe the relationship of one body part to another are made in reference to a standard anatomical position.

In **anatomical position**, the body is erect, feet are parallel and flat on the floor, eyes are directed forward, and arms are at the sides of the body with the palms of the hands turned forward and the fingers pointing downward.

Descriptive and directional terms are used to communicate the position of structures, surfaces, and regions of the body with respect to anatomical position. Commonly used terms are listed and defined below.

In addition to the terms listed in the table below, three planes of reference are used to locate and describe structures within the body.

- The **midsagittal plane** is the plane of symmetry, dividing the body into right and left halves.
- A **coronal plane** divides the body into front and back portions, and
- The **transverse (horizontal or cross-sectional) plane** divides the body into superior and inferior portions.

Term	***Definition***
Superior (cranial)	Toward the head
Inferior (caudal)	Toward the bottom (tail)
Anterior (ventral)	Toward the front
Posterior (dorsal)	Toward the back
Medial	Toward the midline of the body
Lateral	Toward the side of the body
Internal (deep)	Away from the surface of the body
External (superficial)	Toward the surface of the body
Proximal	Toward the main mass of the body
Distal	Away from the main mass of the body
Visceral	Related to internal organs
Parietal	Related to the body walls

Body Regions and Body Cavities

The principal **body regions** are the *head, neck, trunk* (divided into the thorax and the abdomen), *upper extremity* (two), and *lower extremity* (two).

The **body cavities** are confined spaces in which organs are protected, separated, and supported by associated membranes.

- The **posterior (dorsal) cavity** includes the **cranial** and **vertebral cavities** and contains the brain and spinal cord.
- The **anterior (ventral) cavity** includes the **thoracic, abdominal**, and **pelvic cavities** and contains the visceral organs.
- The abdominal cavity and the pelvic cavity are frequently referred to collectively as the **abdominopelvic cavity** because there is no physical division between these two regions. The visceral organs located in the thoracic cavity are the heart and lungs.
- The thoracic cavity is partitioned into two **pleural cavities**, one surrounding each lung and the **pericardial cavity** surrounding the heart. The area between the two lungs is known as the **mediastinum**. The viscera of the abdominal cavity include the stomach, small intestine, large intestine, spleen, liver, and gallbladder.

The body cavities serve to segregate organs and systems by function:

- the major portion of the nervous system occupies the posterior cavity;
- the principal organs of the respiratory and circulatory systems are in the thoracic cavity;
- the primary organs of digestion are in the abdominal cavity; and
- the reproductive organs are in the pelvic cavity.

Body membranes, composed of thin layers of connective and epithelial tissue, serve to cover, protect, lubricate, separate, or support visceral organs or to line body cavities. The two principal types are **mucous membranes** and **serous membranes**.

- Mucous membranes secrete a thick, viscous substance called mucous that lubricates and protects the body organs where it is secreted. Examples of mucous membranes are the epithelial membranes lining the nasal cavity, the trachea, and the oral cavity. Mucous membranes are found lining the inside walls of many other body organs.
- Serous membranes line the thoracic and abdominopelvic cavities and cover the visceral organs. They are composed of thin sheets of epithelial tissue that lubricate, support, and compartmentalize visceral organs. **Serous fluid** is the watery lubricant they secrete. The serous membranes of the thoracic cavity are the **parietal** and **visceral pleura**, lining the thoracic walls and diaphragm and the outer surface of the lungs respectively, and the **parietal** and **visceral pericardium** surrounding the heart. The serous membranes of the abdominopelvic cavity are the **parietal** and **visceral peritoneum**, lining the abdominal wall and covering the abdominal viscera respectively; and the **mesentery**, a double fold of which supports the viscera and loosely anchors it to the abdominal body wall.

1.3 CELL

A cell is the "*smallest self-functioning unit found in all the living organisms".* Cells may exist as independent units of life (as in monads) or may form colonies or tissues as in the higher plants and animals. Cells are not only the building blocks of the body, but are the functional unit of life too. Every cell arises from preexisting cells. All cells have the same genetic material. Hence, it is capable of giving rise to a new individual.

All the activities of an organism are present in miniature form in each cell. Therefore, the cell is the ***basic unit of life*** and ***the structural unit of an organism.***

The cell theory is based on the two statements - 'All organisms are composed of cells' and 'All cells come from preexisting cells'.

1.3.1 Types of organisms

Before we can discuss the various components of a cell, it is important to know what organism the cell comes from. There are two general categories of cells: **prokaryotes** and **eukaryotes**.

- It appears that life arose on earth about 4 billion years ago. The simplest of cells, and the first types of cells to evolve, were **prokaryotic cells (**organisms that lack a nuclear membrane). **Bacteria** are the best known and most studied form of prokaryotic organisms.

  Prokaryotes are unicellular organisms that do not develop or differentiate into multi cellular forms. Some bacteria grow in filaments, or masses of cells, but each cell in the colony is identical and capable of independent existence. The cells may be adjacent to one another because they did not separate after cell division or because they remained enclosed in a common sheath or slime secreted by the cells. Typically, there is no continuity or communication between the cells. Prokaryotes are capable of inhabiting almost every place on the earth, from the deep ocean, to the edges of hot springs, to just about every surface of our bodies.

  Prokaryotes are distinguished from eukaryotes on the basis of nuclear organization, specifically their lack of a nuclear membrane. Prokaryotes also lack any of the intracellular organelles and structures that are characteristic of eukaryotic cells. Most of the functions of organelles, such as mitochondria, chloroplasts, and the Golgi apparatus, are taken over by the prokaryotic plasma membrane. Prokaryotic cells have three architectural regions: appendages called **flagella** and **pili**—proteins attached to the cell surface; a **cell envelope** consisting of a capsule, a **cell wall**, and a **plasma membrane**; and a **cytoplasmic region** that contains the **cell genome** (DNA) and ribosomes and various sorts of inclusions.

- **Eukaryotes** include fungi, animals, and plants as well as some unicellular organisms. Eukaryotic cells are about 10 times the size of a prokaryote and can be as much as 1000 times greater in volume. The major and extremely significant difference between prokaryotes and eukaryotes is that eukaryotic cells contain membrane-bound compartments in which specific metabolic activities take place. Most important among these is the presence of a **nucleus**, a membrane-delineated compartment that houses the eukaryotic cell's DNA. It is this nucleus that gives the eukaryote—literally, true nucleus—its name.

  Eukaryotic organisms also have other specialized structures, called **organelles**, which are small structures within cells that perform dedicated functions. As the name implies, you can think of organelles as small organs. There are a dozen different types of organelles commonly found in eukaryotic cells.

  The origin of the eukaryotic cell was a milestone in the evolution of life. Although eukaryotes use the same genetic code and metabolic processes as prokaryotes, their **higher level of organizational complexity** has permitted the development of truly multicellular organisms. Without eukaryotes, the world would lack mammals, birds, fish, invertebrates, mushrooms, plants, and complex single-celled organisms.

  Figure 1.3.1: Eukaryotes and prokaryotes.

1.3.2 Structure of human cell or cell organization

The word *cell* comes from the Latin word *cella*, meaning "small room". Cells consist of a protoplasm enclosed within a membrane. This membrane separates its interior from its environment, regulates what moves in and out (selectively permeable), and maintains the electric potential of the cell. All cells possess DNA, the hereditary material of genes, and RNA, containing the information necessary to build various proteins such as enzymes, the cell's primary machinery. There are also other kinds of bio molecules in cells such as proteins and nucleic acids. Only red blood cells differ and they lack a cell nucleus and most organelles in order to accommodate maximum space for hemoglobin.

Figure 1.3.2a: A typical animal cell

Figure 1.3.2b: Cell differentiation

1.3.3 Functions of cell and cell organelles

Within cells, there is an intricate network of organelles, which have unique functions. These organelles allow the cell to function properly. We start from the outside of the cell i.e., its surface and move to the inside i.e., the nucleus.

Figure 1.3.3: Cell and cell organelles (Structure of the cell)

Cell surface

Plasma membrane

- Is the outer membrane of cell that controls cellular traffic.
- It contains proteins that span through the membrane and allow passage of materials.
- It is made of proteins that are surrounded by a phospholipid bi-layer.

Cytoplasm

It is the collective term for cytosol and organelles contained within. It is a colloidal suspension and it is mainly composed of water with free-floating molecules. Its viscosity constantly changes according to the cell cycle stages.

1. Centrioles
   - They are paired cylindrical organelles near nucleus
   - They are composed of nine tubes, each with three tubules
   - They are involved in cellular division
   - They lie at right angles to each other
2. Cytoskeleton
   - Composed of microtubules
   - Supports cell and provides shape
   - Aids movement of materials in and out of cells
3. Endoplasmic reticulum
   - Tubular network fused to nuclear membrane

- Goes through cytoplasm onto cell membrane
- Stores, separates, and serves as cell's transport system
- Smooth type: lacks ribosomes
- Rough type (pictured): ribosomes embedded in surface

4. Golgi apparatus
    - Protein 'packaging plant'
    - A membrane structure found near nucleus
    - Composed of numerous layers forming a sac
5. Lysosome
    - Digestive 'plant' for proteins, lipids, and carbohydrates
    - Transports undigested material to cell membrane for removal
    - Vary in shape depending on process being carried out
    - Cell breaks down if lysosome explodes
6. Mitochondria
    - Second largest organelle with unique genetic structure
    - Double-layered outer membrane with inner folds called *cristae*
    - Energy-producing chemical reactions take place on cristae
    - Controls level of water and other materials in cell
    - Recycles and decomposes proteins, fats, and carbohydrates, and forms urea
7. Ribosomes
    - Each cell contains thousands
    - Miniature 'protein factories'
    - Composes 25% of cell's mass
    - Stationary type: embedded in rough endoplasmic reticulum
    - Mobile type: injects proteins directly into cytoplasm
8. Vacuoles
    - Membrane-bound sacs for storage, digestion, and waste removal
    - Contains water solution
    - Contractile vacuoles for water removal (in unicellular organisms)

Nucleus:

There can be one or more nucleus per cell. It is spherical in shape and is denser than the surrounding cytoplasm. It contains the following:

1. Chromosomes
    - Usually in the form of chromatin
    - Contains genetic information
    - Composed of DNA
    - Thicken for cellular division
    - Set number per species (i.e. 23 pairs for human)
2. Nuclear membrane
    - Surrounds nucleus
    - Composed of two layers
    - Numerous openings for nuclear traffic
3. Nucleolus
    - Spherical shape
    - Visible when cell is not dividing
    - Contains RNA for protein manufacture

1.3.4 Properties of Cells

1. **Cells are complex and highly organized**
    - They contain numerous internal structures
    - Some are membrane bound (organelles) while others do not
2. **Cells contain a genetic blueprint and machinery to use it**
    - Genes are instructions for cells to create specific proteins

- All cells use the same types of information
    - The genetic code is universal
    - The machinery used for synthesis is interchangeable
- However, for this to function properly, information transfer must be error free
    - Errors are called *mutations*

3. **Cells arise from the division of other cells**
    - Daughter cells inherit the genes from the mother cells
    - Mitosis - the genetic complement of each daughter cell is identical to the other and to the mother cell. This is asexual reproduction
    - Meiosis - the genetic complement of each daughter cell is reduced by half and each daughter cell is genetically unique. This is used in sexual reproduction
    - Daughter cells inherit cytoplasm and organelles from the mother cells
4. **Cells acquire and utilize energy**
    - Plant cells undergo photosynthesis
        - convert light energy and CO_2 to chemical energy (ATP and glucose)
    - Most cells respire
        - release energy found in organic compounds
        - convert organic compounds to CO_2 and O_2
        - make ATP
5. **Cells can perform a variety of chemical reactions**
    - Transform simple organic molecules into complex molecules (anabolism)
    - Breakdown complex molecules to release energy (catabolism)
    - Metabolism = all reactions performed by cells
6. **Cells can engage in mechanical activities**
    - Cells can move
    - Organelles can move
    - Cells can respond to stimuli
        - chemotaxis - movement towards chemicals
        - phototaxis - movement towards light
        - hormone responses
        - touch responses
7. **Cells can regulate activities**
    - Cells control DNA synthesis and cell division
    - Gene regulation - cells make specific proteins only when needed
    - Turn on and off metabolic pathways
8. **Cells all contain the following structures:**
    - Plasma membrane - separates the cell from the external environment
    - Cytoplasm - fluid-filled cell interior
    - Nuclear material - genetic information stored as DNA

1.4 CELL DIVISION (REPRODUCTION)

Cell division involves the distribution of identical genetic material, DNA, to two daughters cells. What is most remarkable is the fidelity with which the DNA is passed along, without dilution or error, from one generation to the next.

Significance of Cell division:

- All Organisms Consist of Cells and Arise from Preexisting Cells
    - Mitosis is the process by which new cells are generated.

    - Meiosis is the process by which gametes are generated for reproduction.
- The Cell Cycle Represents All Phases in the Life of a Cell
    - DNA replication (S phase) must precede mitosis, so that all daughter cells receive the same complement of chromosomes as the parent cell.
    - The gap phases separate mitosis from S phase. This is the time when molecular signals mediate the switch in cellular activity.
    - Mitosis involves the separation of copied chromosomes into separate cells
- Unregulated Cell Division Can Lead to Cancer
    - Cell-cycle checkpoints normally ensure that DNA replication and mitosis occur only when conditions are favorable and the process is working correctly.
    - Mutations in genes that encode cell-cycle proteins can lead to unregulated growth, resulting in tumor formation and ultimately invasion of cancerous cells to other organs.

Before learning about cell division , we must know about chromosomes and DNA (the genetic material).

DNA: DNA, or deoxyribonucleic acid, is the hereditary material in humans and almost all other organisms. Nearly every cell in a person's body has the same DNA. Most DNA is located in the cell nucleus (where it is called nuclear DNA), but a small amount of DNA can also be found in the mitochondria (where it is calledmitochondrial DNA or mtDNA).

The information in DNA is stored as a code made up of four chemical bases: adenine (A), guanine (G), cytosine (C), and thymine (T). Human DNA consists of about 3 billion bases, and more than 99 percent of those bases are the same in all people. The order, or sequence, of these bases determines the information available for building and maintaining an organism, similar to the way in which letters of the alphabet appear in a certain order to form words and sentences.

DNA bases pair up with each other, A with T and C with G, to form units called base pairs. Each base is also attached to a sugar molecule and a phosphate molecule. Together, a base, sugar, and phosphate are called a nucleotide. Nucleotides are arranged in two long strands that form a spiral called a double helix. The structure of the double helix is somewhat like a ladder, with the base pairs forming the ladder's rungs and the sugar and phosphate molecules forming the vertical sidepieces of the ladder.

An important property of DNA is that it can replicate, or make copies of itself. Each strand of DNA in the double helix can serve as a pattern for duplicating the sequence of bases. This is critical when cells divide because each new cell needs to have an exact copy of the DNA present in the old cell.

Figure 4a: The double helix

In the nucleus of each cell, the DNA molecule is packaged into thread-like structures called chromosomes. Each chromosome is made up of DNA tightly coiled many times around proteins called histones that support its structure.

Chromosomes are not visible in the cell's nucleus—not even under a microscope—when the cell is not dividing.

Each chromosome has a constriction point called the centromere, which divides the chromosome into two sections, or "arms." The short arm of the chromosome is labeled the "p arm." The long arm of the chromosome is labeled the "q arm." The location of the centromere on each chromosome gives the chromosome its characteristic shape, and can be used to help describe the location of specific genes.

Figure 4b: From DNA to chromosome

In humans, each cell normally contains 23 pairs of chromosomes, for a total of 46. Twenty-two of these pairs, called autosomes, look the same in both males and females. The 23rd pair, the sex chromosomes, differ between males and females. Females have two copies of the X chromosome, while males have one X and oneY chromosome. The 22 autosomes are numbered by size. The other two chromosomes, X and Y, are the sex chromosomes. This picture of the human chromosomes lined up in pairs is called a karyotype.

Figure 4c: Chromosomes in human cell

Figure 4d: The cell cycle

1.4.1 Mitosis

Mitosis is important for the maintenance of the chromosomal set; each cell formed receives chromosomes that are alike in composition and equal in number to the chromosomes of the parent cell.

Mitosis occurs in the following circumstances:

1. **Development and growth**

The number of cells within an organism increases by mitosis. This is the basis of the development of a multi cellular body from a single cell i.e., zygote and the basis of the growth of a multi cellular body.

2. **Cell replacement**

In some parts of body, like the skin and digestive tract, cells are constantly sloughed off and replaced by new ones. New cells are formed by mitosis and that is why they are exact copies of the cells being replaced. Similarly, RBCs (red blood cells) have short life span (only about 4 months) and new RBCs are formed by mitosis.

- The stages of the cell cycle can be broken down into six stages:
    - Interphase, Prophase, Metaphase, Anaphase, Telophase

Interphase

- is the "resting" or non-mitotic portion of the cell cycle.
- It is comprised of G1, S, and G2 stages of the cell cycle.
- DNA is replicated during the S phase of Interphase

Prophase - the first stage of mitosis.

- The chromosomes condense and become visible
- The centrioles form and move toward opposite ends of the cell ("the poles")
- The nuclear membrane dissolves
- The mitotic spindle forms (from the centrioles in animal cells)
- Spindle fibers from each centriole attach to each sister chromatid

Metaphase

- The Centrioles complete their migration to the poles
- The chromosomes line up in the middle of the cell ("the equator")

Anaphase

- Spindles attached to kinetochores begin to shorten.
- This exerts a force on the sister chromatids that pulls them apart.
- Spindle fibers continue to shorten, pulling chromatids to opposite poles.
- This ensures that each daughter cell gets identical sets of chromosomes

Telophase

- The chromosomes decondense
- The nuclear envelope forms
- Cytokinesis reaches completion, creating two daughter cells

Figure 1.4.1: Mitosis

1.4.2 Meiosis

Meiosis is a special type of cell division that occurs in sexually reproducing organisms.

Meiosis reduces the chromosome number by half, enabling sexual recombination to occur.

- Meiosis of diploid cells produces haploid daughter cells, which may function as gametes.

- Gametes undergo fertilization, restoring the diploid number of chromosomes in the zygote

Meiosis and fertilization introduce genetic variation in three ways:

- Crossing over between homologous chromosomes at prophase I.
- Independent assortment of homologous pairs at metaphase I:
  - Each homologous pair can orient in either of two ways at the plane of cell division.
  - The total number of possible outcomes = 2n (n = number of haploid chromosomes).
- Random chance fertilization between any one female gamete with any other male gamete.

Importance of Meiosis:

The Role of Sexual Reproduction in Evolution:

a) Sexual reproduction in a population should decline in frequency relative to asexual reproduction.
   - Asexual reproduction: No males are needed, all individuals can produce offspring.
   - Sexual reproduction: Only females can produce offspring, therefore fewer are produced.

b) Sexual reproduction may exist because it provides genetic variability that reduces susceptibility of a population to pathogen attack.

The stages of meiosis can be broken down into two main stages **Meiosis I** and **Meiosis II**

- **Meiosis I** can be broken down into four sub stages: Prophase I, Metaphase I, Anaphase I and Telophase I
- **Meiosis II** can be broken down into four sub stages: Prophase II, Metaphase II, Anaphase II and Telophase II

Meiosis I

Prophase I - most of the significant processes of Meiosis occur during Prophase I

- The chromosomes condense and become visible
- The centrioles form and move toward the poles
- The nuclear membrane begins to dissolve
- The homologs pair up, forming a tetrad
  - Each tetrad is comprised of four chromotids - the two homologs, each with their sister chromatid
- Homologous chromosomes will swap genetic material in a process known as **crossing over** (abbreviated as XO)
  - Crossing over serves to **increase genetic diversity** by creating four unique chromatids
- Genetic material from the **homologous chromosomes** is randomly swapped
- This creates four unique chromatids
- Since each chromatid is unique, the overall genetic diversity of the gametes is greatly increased.

Figure 1.4.2: Meiosis (in comparison with meiosis)

1.5 TISSUE

Tissues are groups of cells with a common structure (form) and function (job).There are four main tissues in the body – epithelium, muscle, connective tissue and nervous tissue.

Figure 1.5: Main tissues in human body

1.5.1 Types and functions of tissues

1. **EPITHELIUM TISSUE**: They are closely attached to each other forming a protective barrier. They always have one (apical) surface open to outside the body or inside (cavity) an internal organ. They always have one fixed (basal) section attached to an underlying connective tissue. They have no blood vessels but can soak up nutrients from blood vessels in connective tissue underneath. They are innervated i.e. have lots of nerves in them and are very good at regenerating (fixing itself) like in sunburn, skinned knee in minor falls etc.

Classifications (types):

1) By shape

- squamous - flat and scale-like
- cuboidal - as tall as they are wide
- columnar - tall, column-shaped

2) By cell arrangement

- Simple epithelium - single layer of cells ((usually for absorption and filtration)
- Stratified epithelium - stacked up call layers (protection from abrasion (rubbing) - mouth, skin.)

Functions :

- It protects us from the outside world – skin.
- Absorbs – stomach and intestinal lining (gut)
- Filters – the kidney
- Secretes – forms glands

2. **CONNECTIVE TISSUE:** It wraps around and cushions and protects organs. As tendon and ligaments, it protects joints and attached muscles to bone and each other. It runs through organ capsules and in deep layers of skin giving strength. It also stores nutrients.

Connective Tissue is found in three forms:

- Ground substance, which is like a gel around cells and fibre
- Fibers that provide strength, elasticity and support, and
- Cells

Types of connective tissue:

1) Loose Connective Tissue:

a) Areolar Connective Tissue – cushion around organs, loose arrangement of cells and fibers.

b) Adipose Tissue – storehouse for nutrients, packed with cells and blood vessels

c) Reticular Connective Tissue – internal supporting framework of some organs, delicate network of fibers and cells

2) Dense Connective Tissue:

a) Dense Regular Connective Tissue – tendons and ligaments, regularly arranged bundles packed with fibers

- running same way for strength in one direction.

b) Dense Irregular Connective Tissue – skin, organ capsules, irregularly arranged bundles packed with fibers

- for strength in all directions.

3) Special connective tissues

a) Cartilage

- provides strength with flexibility while resisting wear, i.e. epiglottis, external ear, larynx.

- cushions and shock absorbs where bones meet, i.e. intervertebral discs, joint capsules

b) Bone

- provides framework and strength for body
- allows movement
- stores calcium
- contains blood-forming cells

c) Blood

- transports oxygen, carbon dioxide, and nutrients around the body
- immune response.

3) NERVOUS TISSUE: It conducts impulses to and from body organs via neurons.

The 3 Elements of Nervous Tissue are:

- Brain
- Spinal cord
- Nerves

4) MUSCLE TISSUE: It is responsible for body movement**.** It helps move blood, food, and waste through body's organs. It is also responsible for mechanical digestion.

The 3 Types of Muscle Tissue are:

- Smooth Muscle – organ walls and blood vessel walls, involuntary, spindle-shaped cells for pushing things through organs
- Skeletal Muscle – large body muscles, voluntary, striated muscle packed in bundles and attached to bones for movement
- Cardiac Muscle – heart wall, involuntary, striated muscle with intercalated discs connecting cells for synchronized contractions during heart beat.

Figure 1.5.1: Sub categories of tissues

1.6 BLOOD

Blood, as we know, has several important roles to play. It carries oxygen and nutrients to the tissues and carries waste products away. It helps maintain body temperature and normal pH levels in body tissues. The protective functions of blood include *clot formation* and the *prevention of infection.*

1.6.1 ITS COMPOSITION

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

Figure 1.6.1 : BLOOD and its components

1.6.2 Blood and its components

Among all the body's systems, the blood is unique: it is the only tissue in the body that flows. This flowing tissue, endlessly making its course from the heart to the remotest parts of the body and returning, is a sea in which the body is bathed. Blood has two distinct parts.

- **Plasma**, the liquid part of the blood, makes up about 55% of the blood volume. Since there is a total of 5 liters of blood in the body of an average adult, the **plasma volume (PV)** in the body is about 2.75 liters.
  - Plasma is a yellowish solution consisting of about 91% water, and the other 9% is a host of substances indispensable to life. Among them are:

    nutrients such as glucose, fats, and amino acids;

    chemicals important to the body, such as sodium, potassium, and calcium;

    special proteins, such as fibrinogen, albumin, and various globulins that produce antibodies, which fight off viruses and other unwelcome intruders in the body; and

hormones, which are regulatory substances such as insulin, and epinephrine, more familiarly known as adrenaline, which speeds up the heart rate whenever some emergency requires a greater blood flow to the muscles.

Role of plasma:

Role of plasma in the body is to help transport food and oxygen to the cells of the body and to carry wastes away from the cells.

In addition, with its potent arsenal to draw upon, plasma plays a crucial role in maintaining the body's chemical balance, water content, and temperature at a safe level. That is, the plasma serves the body by helping to maintain **homeostasis**, or a stable internal environment in the body.

By analyzing plasma, medical doctors can find out what types of nutrients are circulating throughout the body, and they can measure the levels of hormones and other constituents that plasma helps to transport.

The cellular portion of blood normally makes up about 45% of the blood volume and it consists primarily of three cellular components namely:

- white blood cells (**WBCs**, also known as **leukocytes**),
- platelets, and
- red blood cells (**RBCs**, also known as **erythrocytes**).

The (White blood cells) WBCs constitute the blood's mobile security system. Some WBCs are endowed with the curious ability to wiggle out of the bloodstream and back in again. The WBCs can move like an amoeba, slipping through thin walls of capillaries and wandering among cells and tissues. They converge together in great numbers wherever invading bacteria, viruses, fungi, or parasites gain entry into the body, destroying them by swallowing them or by synthesizing **antibodies**, which are complex proteins that react with and destroy these foreign substances. Whenever white cells mobilize for action, the body compensates by manufacturing more. Double the usual number may appear in the blood within hours. Often this rising white cell count, as physicians describe it, serves as an early tip-off that a dangerous infection has entered the body.

The white blood cells or Leukocytes are the first line of defense of the immune system. Leukocytes are derived from bone marrow stem cells and have three main categories: Lymphocytes, Phagocytes, and Auxiliary Cells. Neutrophils, basophils, and eosinophils are called *granulocytes* because they have granules in their cytoplasm.

- **Lymphocytes**
  There are two types of lymphocytes: T-Cells and B-cells. T-cells develop in the thymus, a lymphatic organ in the chest behind the breastbone, whereas B-cells develop in the adult bone marrow. T-cells produce cytokine proteins which are interpreted by phagocytes as commands to destroy the material that they have taken up. The T-lymphocytes act against tumor cells and cells infected with viruses. B-cells produce antibodies that help phagocytes to recognize foreign material. Lymphocytes have agranular clear cytoplasm and are smaller than the three granulocytes. Lymphocytes account for 25-35% of the white blood cells. A relative increase in the proportion of lymphocytes is typical of infectious mononucleosis or a chronic infection.

- **Phagocytes**
  Named from the Greek word "phagein" (to eat), phagocytes are cells that engulf foreign particles, including infectious agents, such as bacteria. Monocytes, neutrophils, and eosinophils are the main phagocytic cells. They search and embrace foreign particles, and then destroy them. **Neutrophils** account for 50-70% of all leukocytes. Elevated numbers of neutrophils are usually due to an acute infection such as appendicitis. **Eosinophils** account for less than 5% of the white blood cells. Eosinophil levels may increase due to parasitic diseases, bronchial asthma or hay fever. **Monocytes** are agranular and bigger than other leukocytes. These phagocytic cells defend the body against viruses and bacteria and account for 3-9% of all leukocytes.

- **Auxiliarycells**
  Basophils, along with mast cells and platelets, secrete inflammatory mediators which attract leukocytes to the point of infection. **Basophils** represent less than 1% of all leukocytes. The large basophilic granules contain histamines that cause vasodilation and heparin that acts like an anticoagulant.

Platelets: The smallest of blood's three cellular components are the platelets, named for their resemblance to tiny plates. Platelets are vital to blood clotting. When they touch the roughened surface of a torn blood vessel, they burst apart, releasing chemicals that set off a reaction in the blood leaking out. The result is that they convert one of the plasma's proteins, fibrinogen, into a network of fibers that trap RBCs - thereby forming a clot which seals the wound.

The red blood cells, or RBCs : RBCs outnumber the WBCs about 700 to 1. Their exclusive and all-important job is to pick up oxygen in the lungs, carry it to the rest of the body, and carry waste carbon dioxide back the other way. Their life is hectic and short. Every three or four months they grow old, or are eaten, and then replaced by new recruits sent into the bloodstream from the bone marrow.The study of the activity of the RBCs is called **erythrokinetics**. Erythrokinetics involves looking at the entire lifetime of a RBC from its "birth" (it is born in the bone marrow), through its passage around the body (each RBC travels around the body in about a minute), all the way through its destruction. A normal lifetime for each RBC is 90 to 120 days.

The RBC's effectiveness as an oxygen-carrier is due to its content of **hemoglobin**, a compound of protein and iron which gives blood its red color. Each RBC contains nearly 300 million hemoglobin molecules. Hemoglobin has a chemical way of latching onto oxygen as the blood passes through the lungs and holding it in its grip until the destination is reached. As the blood passes through the tissue capillaries, the hemoglobin will not release oxygen into the tissues if too much oxygen is already there, but if the oxygen concentration is too low, sufficient oxygen will be released by the hemoglobin to re-establish an adequate tissue oxygen concentration. (This is a part of the **homeostatic control mechanism**.)

When, for any reason, the hemoglobin content in the bloodstream dips below the minimum for body needs, the result is **anemia**. Anemia is a reduction in the number or volume of RBCs. This reduction in RBCs results, obviously, in a reduction in the amount of hemoglobin and, therefore, in a reduction in the body's oxygen-carrying capacity. Another cause of anemia could be a diet deficient in iron-rich foods.

Normal RBCs are biconcave disks that are capable of changing their shape as they- pass through capillaries. Actually, the RBC is a "bag" that can be deformed into almost any shape without rupturing the cell. They are remarkably flexible and remarkably small. In normal men the average number of RBCs ***per cubic millimeter*** is 5,200,000 and in normal women 4,700,000. The number of RBCs varies in the two sexes and at different ages.

Also, if a person moves to a higher altitude, for instance, to the mountains, the number of RBCs present in that person may not be enough to supply the body with oxygen. This is because as you go into higher altitudes, the atmospheric pressure becomes lower. For each liter of air you breathe at lower atmospheric pressures, there are fewer molecules of air, including fewer molecules of oxygen. With fewer molecules of oxygen available, your lungs are not able to supply each RBC with the amount of oxygen to which it is accustomed. In this condition, the RBCs cannot deliver enough oxygen to the body (including the brain) and we become dizzy. Therefore, the body responds by increasing the production of RBCs so that the oxygen needs of the body can be met.

1.6.2 Blood clotting

The Blood Clotting Mechanism: When a wound starts bleeding on our bodies, an enzyme called thromboplastin is released from damaged tissue cells which combines with the calcium and prothrombin in the blood. As a result of the chemical reaction, a mesh of threads form which act as a protective layer, which eventually solidifies. The top layer of cells die with time and become cornified, forming a scab. Underneath the scab, or protective layer, new cells form. When damaged cells are completely replaced, the scab drops off.

Figure 1.6.2: BLOOD CLOTTING

Blood has to coagulate in the right time and place and when normal conditions are restored, the clot should vanish. The system functions flawlessly down to the minutest detail.If there is bleeding, the clot should form immediately in order to prevent the creature from dying. Furthermore, the clot should cover the entire wound and, more importantly, should only form over, and remain right on top of, the wound. Otherwise all the blood of the creature could coagulate and cause its death, which is why the clot should form at the right time at the right place.

The smallest elements of the bone marrow, the blood platelets or thrombocytes, are crucial. These cells are the main elements behind the coagulation of blood. A protein, called the Von Willebrand factor, ensures that, in their continuous patrol of the blood stream, these platelets do not miss the place of the injury. The platelets that become entangled in the location of the injury release a substance that collects countless others to the same place. These cells eventually shore up the open wound. The platelets die after performing their duty in locating the wound. Their sacrifice is only a part of the coagulation system in the blood.

Thrombin is another protein that facilitates coagulation of blood. This substance is produced only at the location of the wound. This production must be neither more nor less than necessary, and has also to start and stop exactly at the required times. There are more than twenty body chemicals called enzymes that have roles in the production of thrombin. These enzymes can trigger its reproduction or halt it. The process is under so much scrutiny that thrombin only forms when there is a real wound to the tissues. As soon as the enzymes of coagulation reach a satisfactory level in the body, fibrinogens that are composed of proteins are formed. In a very short while, a mesh of fibres forms a web, which is formed at the location of the escaping blood. In the meantime, patrolling platelets continue to become entangled and accumulate at the same location. What is called a clot is the plug that is formed due to this accumulation. When the wound totally heals, the clot dissolves.

1.6.3 Blood groups

Although all blood is made of the same basic elements, not all blood is alike. In fact, there are eight different common blood types, which are determined by the presence or absence of certain antigens – substances that can trigger an immune response if they are foreign to the body. Since some antigens can trigger a patient's immune system to attack the transfused blood, safe blood transfusions depend on careful blood typing and cross-matching.

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

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

There are very specific ways in which blood types must be matched for a safe transfusion:

Figure 1.6.3: Blood groups

Rh factor: Other than the A and B antigen, some other factor is also present on the surface of the RBCs called Rh antigen. Those who have it are called Rh (+) positive and those who do not have it are Rh (-) negative. This is the basis of the Rh blood group system.

In Caucasian (white) races, about 85% of human are Rh+ve, but among African blacks almost everyone is Rh -ve.

Rh stands for Rhesus monkey. RBC of Rhesus monkey when injected into rabbit developed antibodies to Rhesus RBC. Later, it was discovered that rabbit serum containing anti rhesus antibodies could agglutinate not only rhesus RBC, but also human RBC in about 85% cases, which was suggestive that these 85 % of human beings have an antigen identical to Rhesus RBC. This antigen was named as 'Rh antigen'. Human beings having this antigen were labeled 'Rh positive'. Thus, in a Rh system, blood may be either positive or negative.

A person with Rh -ve blood does not have Rh antibodies naturally in the blood plasma (as one can have A or B antibodies, for instance). However, a person with Rh -ve blood can develop Rh antibodies in the blood plasma if he or she receives blood from a person with Rh+ve blood, whose Rh antigens can trigger the production of Rh antibodies. A person with Rh+ve blood can receive blood from a person with Rh -ve blood without any problems. However, if an Rh -ve individual is given Rh +ve blood, he develops anti Rh-ve antibodies.

Rh Incompatibility

Rh compatibility sometimes leads to complications which are generally not seen with other types of mismatched transfusions.

One of the critical manifestations of Rh-incompatibility is ***'Erythroblastosis Foetalis*** '. It happens when a girl is Rh –ve and later in life (during pregnancy)if she has a Rh-positive fetus in her uterus then there can be major complications.. The chances of any abnormalities resulting from Rh incompatibility are negligible during first pregnancy, 3% during second and 10% during third. If the fetus and mother happen to be of same group, i.e., A,B or AB but mother is Rh -ve and foetus Rh +ve, during 2nd and subsequent pregnancies, mother gets sensitize with Rh antigens of fetal blood, resulting in production of anti-Rh antibodies, which will destroy fetal RBC, causing 'erythoblastosis foetalis'.

Transfusion of blood:

In ancient times, patients were bled to get rid of their foul fluid. Later, as blood was transfused after the discovery of circulation, patients died after receiving transfusion. The blood being transfused from one patient was not compatible with the recipient's. Later considerable advances in transfusion medicine took place. During the first world war, the collection and storage of blood was perfected. During the second world war, individual components of b!ood were separated. In early 1980s, doctors started training in the specialty of blood transfusion and actively participating in patient care.

Blood transfusion refers to the infusion of blood or blood components into an individual for the treatment of a medical condition (e.g., anemia, loss of blood due to injury etc.).Transfused blood may be homologous (from a donor) or autologous (previously stored blood from the recipient).

It is important to note that blood transfusion is only to be given when there is no alternative. Though blood transfusion is safe, the main risk of transfusion is being given blood of the wrong group or a smaller risk of catching an infection. To ensure one receives the right blood, the clinical staff makes careful identification checks before any transfusion.

Blood is usually split up into four separate components and then transfused according to requirement. :

- ***Whole blood:*** This is rarely used these days, only in instances of severe blood loss. Instead, it is usually separated into its individual components.
- ***Red cells:*** These are used in the treatment of all kinds of anemia, which cannot be medically corrected, such as when rheumatoid arthritis or cancer is involved, when red cells break down in the newborn, and for sickle cell disease. They're also essential to replace lost red cells after such things as accidents, surgery and after childbirth, not to mention pre-op 'top-ups' for existing anemic patients and for bum victims.
- ***Platelets:*** Bone marrow failure and post transplant and chemotherapy treatments and leukemia are instances when platelets are a benefit to the patient.
- ***Plasma:*** Fresh frozen plasma is used after obstetric loss of blood usually childbirth, during cardiac surgery and to reverse any anti-coagulant treatment.

1.7 IMMUNE SYSTEM

The immune system is a network of cells, tissues, and organs that work together to defend the body against attacks by “foreign” invaders. These are primarily microbes—tiny organisms such as bacteria, parasites, and fungi that can cause infections. Viruses also cause infections, but are too primitive to be classified as living organisms. The human body provides an ideal environment for many microbes. It is the immune system’s job to keep them out or, failing that, to seek out and destroy them.

The immune system protects the body from possibly harmful substances by recognizing and responding to antigens. Antigens are substances (usually proteins) on the surface of cells, viruses, fungi, or bacteria. Nonliving substances such as toxins, chemicals, drugs, and foreign particles (such as a splinter) can also be antigens. The immune system recognizes and destroys substances that contain antigens.

Our own body's cells have proteins that are antigens. These include a group of antigens called HLA antigens.The immune system learns to see these antigens as normal and usually does not react against them.

Figure 1.7: The Immune system

The major components of the immune system include:

Lymph nodes: Small, bean-shaped structures that produce and store cells that fight infection and disease and are part of the lymphatic system — which consists of bone marrow, spleen, thymus, and lymph nodes. Lymph nodes also contain lymph, the clear fluid that carries those cells to different parts of the body. When the body is fighting infection, lymph nodes can become enlarged and feel sore.

Spleen: The largest lymphatic organ in the body contains white blood cells that fight infection or disease. The spleen also helps control the amount of blood in the body and disposes of old or damaged blood cells.

Bone Marrow: The yellow tissue in the center the bones produces white blood cells.

Lymphocytes: These small white blood cells play a large role in defending the body against disease. The two types of lymphocytes are B-cells, which make antibodies that attack bacteria and toxins, and T-cells, which help destroy infected or cancerous cells. Killer T-cells are a sub-group of T-cells that kill cells that are infected with viruses and other pathogens or are otherwise damaged. Helper T-cells help determine which immune responses the body makes to a particular pathogen.

Thymus: This small organ is where T-cells mature.

Leukocytes: These white blood cells that identify and eliminate pathogens are the second arm of the innate immune system. The innate leukocytes include the phagocytes (macrophages, neutrophils, and dendritic cells), mast cells, eosinophils, basophils, and natural killer cells.

Figure 1.7.1: Major components of the immune system

Diseases of the immune system

Disorders of the immune system can result in autoimmune diseases, inflammatory diseases and cancer.

Immunodeficiency occurs when the immune system is not as strong as normal, resulting in recurring and life-threatening infections. In humans, immunodeficiency can either be the result of a genetic disease such as severe combined immunodeficiency, acquired conditions such as HIV/AIDS, or through the use of immunosuppressive medication.

On the opposite end of the spectrum, autoimmunity results from a hyperactive immune system attacking normal tissues as if they were foreign bodies.

Common autoimmune diseases include Hashimoto's thyroiditis, rheumatoid arthritis, diabetes mellitus type 1 and systemic lupus erythematosus.

Asthma and allergies also involve the immune system. A normally harmless material such as grass pollen, food particles, mold or pet dander is mistaken for a severe threat and attacked.

While symptoms of immune diseases vary, fever and fatigue are common signs that the immune system is not functioning properly.

Blood components in immune system:

The immune system includes certain types of white blood cells. It also includes chemicals and proteins in the blood, such as antibodies, complement proteins, and interferon. Some of these directly attack foreign substances in the body, and others work together to help the immune system cells.

Lymphocytes are a type of white blood cell. There are B and T type lymphocytes.

- B lymphocytes become cells that produce antibodies. Antibodies attach to a specific antigen and make it easier for the immune cells to destroy the antigen.
- T lymphocytes attack antigens directly and help control the immune response. They also release chemicals, known as cytokines, which control the entire immune response.

As lymphocytes develop, they normally learn to tell the difference between our own body tissues and substances that are not normally found in our body. Once B cells and T cells are formed, a few of those cells will multiply and provide "memory" for the immune system. This allows the immune system to respond faster and more efficiently the next time we are exposed to the same antigen. In many cases it will prevent from getting sick. For example, a person who has had chickenpox or has been immunized against chickenpox is immune from getting chickenpox again.

INFLAMMATION

Inflammation occurs when tissues are injured by bacteria, trauma, toxins, heat, or any other cause. The damaged cells release chemicals including histamine, bradykinin, and prostaglandins. These chemicals cause blood vessels to leak fluid into the tissues, causing swelling. This helps isolate the foreign substance from further contact with body tissues.

The chemicals also attract white blood cells called phagocytes that "eat" germs and dead or damaged cells. This process is called phagocytosis. Phagocytes eventually die. Pus is formed from a collection of dead tissue, dead bacteria, and live and dead phagocytes.

TYPES OF IMMUNITY:

1. Innate immunity

Innate, or nonspecific, immunity is the defense system with which you were born. It protects you against all antigens. Innate immunity involves barriers that keep harmful materials from entering your body. These barriers form the first line of defense in the immune response. Examples of innate immunity include:

- Cough reflex

- Enzymes in tears and skin oils
- Mucus, which traps bacteria and small particles
- Skin
- Stomach acid

Innate immunity also comes in a protein chemical form, called innate humoral immunity. Examples include the body's complement system and substances called interferon and interleukin-1 (which causes fever).

If an antigen gets past these barriers, it is attacked and destroyed by other parts of the immune system.

2. Acquired immunity

Acquired immunity is immunity that develops with exposure to various antigens. Our immune system builds a defense against that specific antigen.

3. Passive immunity

Passive immunity is due to antibodies that are produced in a body other than our own. Infants have passive immunity because they are born with antibodies that are transferred through the placenta from their mother. These antibodies disappear between ages 6 and 12 months.

Passive immunization may also be due to injection of antiserum, which contains antibodies that are formed by another person or animal. It provides immediate protection against an antigen, but does not provide long-lasting protection. Immune serum globulin (given for hepatitis exposure) and tetanus antitoxin are examples of passive immunization.

IMMUNIZATION

Vaccination (immunization) is a way to trigger the immune response. Small doses of an antigen, such as dead or weakened live viruses, are given to activate immune system "memory" (activated B cells and sensitized T cells). Memory allows your body to react quickly and efficiently to future exposures.

1.8 SUMMARY

1.9 Check your progress:

- What are the levels of organization of the human body? List the different systems in the human body.
- What is the structure of a cell? Describe with a labeled diagram.
- Draw and label an animal cell and its organelles.
- Differentiate between eukaryotic and prokaryotic cells.
- What do you understand by cell cycle?
- What is cell reproduction? Explain.
- What do you understand by ‘mitosis’. Explain with diagram.
- What is‘meiosis? Draw diagram and explain.
- What is the difference between mitosis and meiosis. Explain with diagram.
- What is the composition of blood?
- What is plasma? Describe few of its functions.
- What are the three blood cells in the body? Describe them.
- What are the different blood group systems?
- What do you mean by Rh incompatibility?
- What do you understand by the term 'blood transfusion'? What is the main risk involved in it?
- What are the four components of blood? Which one of these is used to treat anemia?
- What are the components of the immune system?

1.10 GLOSSARY

- **Active Transport**: the movement of solutes against a gradient and requires the expenditure of energy.
- **Adenosine Triphosphate (ATP):** a cell's source of energy.
- **Bulk Flow:** the collective movement of substances in the same direction in response to a force
- **Cells:** the microscopic fundamental unit that makes up all living things
- **Cell Membrane:** boundary of the cell, sometimes called the plasma membrane
- **Cytoplasm:** a water-like substance that fills cells. The cytoplasm consists of cytosol and the cellular organelles, except the cell nucleus. The cytosol is made up of water, salts, organic molecules and many enzymes that catalyze reactions. The cytoplasm holds all of the cellular organelles outside of the nucleus, maintains the shape and consistency of the cell, and serves as a storage place for chemical substances.
- **Cytoskeleton:** made of threadlike proteins, helps cells maintain their shape and allows cells and their contents to move
- **Dialysis:** the diffusion of solutes across a selectively permeable membrane. Most commonly heard of when a patient has had renal failure. In medicine, dialysis is a type of renal replacement therapy which is used to provide an artificial replacement for lost kidney function due to renal failure. It is a life support treatment and does not treat any kidney diseases.
- **Endocrine cells:** similar to exocrine cells, but secrete their products directly into the bloodstream instead of through a duct
- **Endocytosis:** the capture of a substance outside the cell when the plasma membrane merges to engulf it
- **Endoplasmic Reticulum:** organelle that play an important role in making proteins and shuttling cellular products; also involved in metabolisms of fats, and the production of various materials
- **Epithelial Cells:** cells that aid in secretion, absorption, protection, trans-cellular transport, sensation detection, and selective permeability
- **Exocrine Cells:** cells that secrete products through ducts, such as mucus, sweat, or digestive enzymes
- **Exocytosis:** the process of vesicles fusing with the plasma membrane and releasing their contents to the outside of the cell
- **Facilitated Diffusion:** the diffusion of solutes through channel proteins in the plasma membrane
- **Golgi Apparatus:** "packages" cellular products in sacs called vesicles so that the products can cross the cell membrane and exit the cell
- **Glycolysis:** process in which sugars (glucose) are converted to acid
- **Lysosomes:** sac-like compartments that contain a number of powerful degradative enzymes
- **Microfilaments:** provide mechanical support for the cell, determine the cell shape, and in some cases enable cell movements

- **Microtubules:** function as the framework along which organelles and vesicles move within a cell
- **Mitochondria:** the organelles that function as the cell "powerhouse", generating ATP
- **Nucleus:** controls the cell; houses the genetic material
- **Organelles:** bodies embedded in the cytoplasm that serve to physically separate the various metabolic activities that occur within cells
- **Osmosis:** the diffusion of water molecules across a selectively permeable membrane from an area of high solute concentration to an area of low solute concentration.
- **Passive Transport:** the movement of substances down a concentration gradient and does not require energy use
- **Peroxisomes:** organelles in which oxygen is used to oxidize substances, breaking down lipids and detoxifying certain chemicals
- **Phagocytosis:** a form of endocytosis wherein large particles are enveloped by the cell membrane of a (usually larger) cell and internalized to form a phagosome, or "food vacuole." In animals, phagocytosis is performed by specialized cells called phagocytes, which serve to remove foreign bodies and thus fight infection. In vertebrates, these include larger macrophages and smaller granulocytes, types of blood cells. Bacteria, dead tissue cells, and small mineral particles are all examples of objects that may be phagocytosed.
- **Pinocytosis:** also called cellular drinking, is a form of endocytosis, a process in which small particles are taken in by a cell by splitting into smaller particles. The particles then form small vesicles which subsequently fuse with lysosomes to hydrolyze, or to break down, the particles. This process requires adenosine triphosphate (ATP).
- **Receptor-mediated Endocytosis:** occurs when specific molecules in the fluid surrounding the cell bind to specialized receptors in the plasma membrane
- **Red Blood Cells (erythrocytes):** cells that collect oxygen in the lungs and deliver it through the blood to the body tissues
- **Ribosomes:** play an active role in the complex process of protein synthesis, where they serve as the structures that facilitate the joining of amino acids
- **Simple Diffusion:** the net movement of substances from an area of higher concentration to an area of lower concentration
- **Vacuoles:** spaces in the cytoplasm that sometimes serve to carry materials to the cell membrane for discharge to the outside of the cell
- **White Blood Cells (leukocytes):** produced in the bone marrow and help the body to fight infectious disease and foreign objects in the immune system

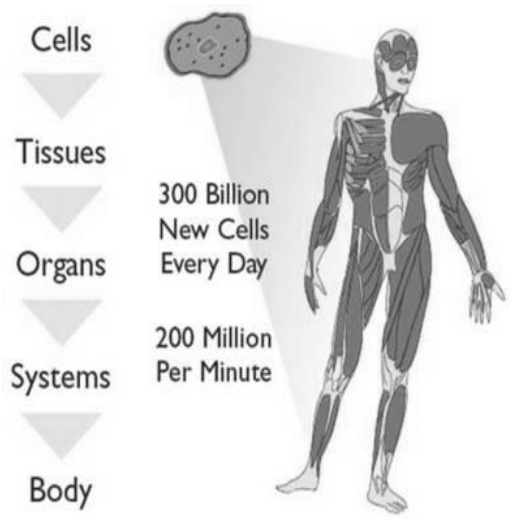


Figure 1: From cell to body

Figure 2: Organs in the human body

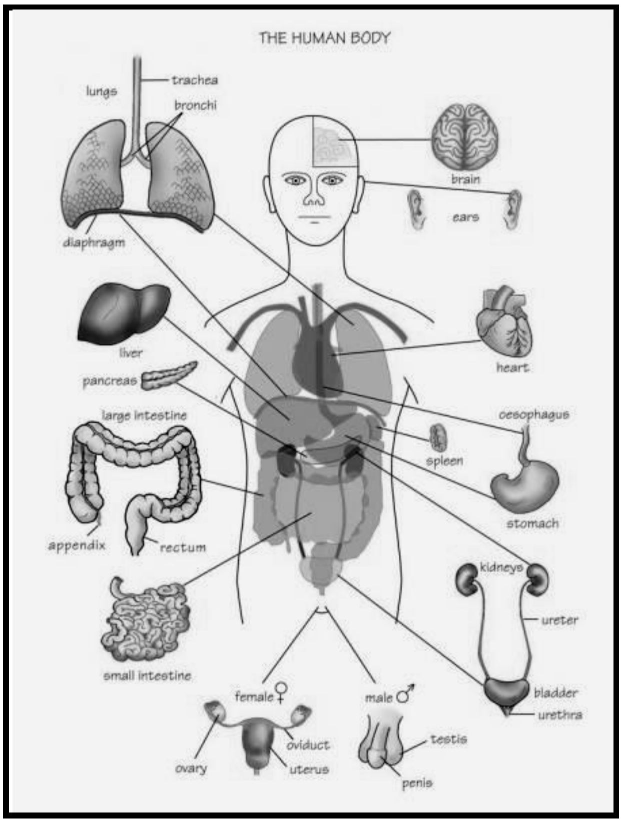


Figure 1.3: A typical animal cell

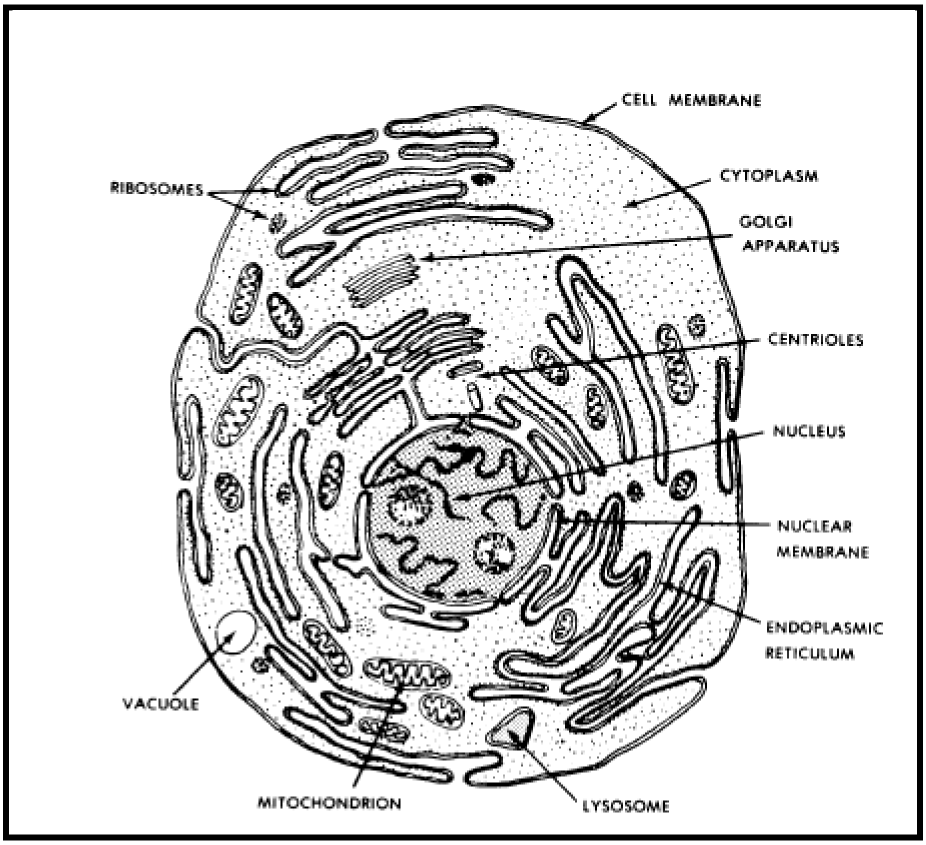


Figure 1.3.2a Cell differentiation

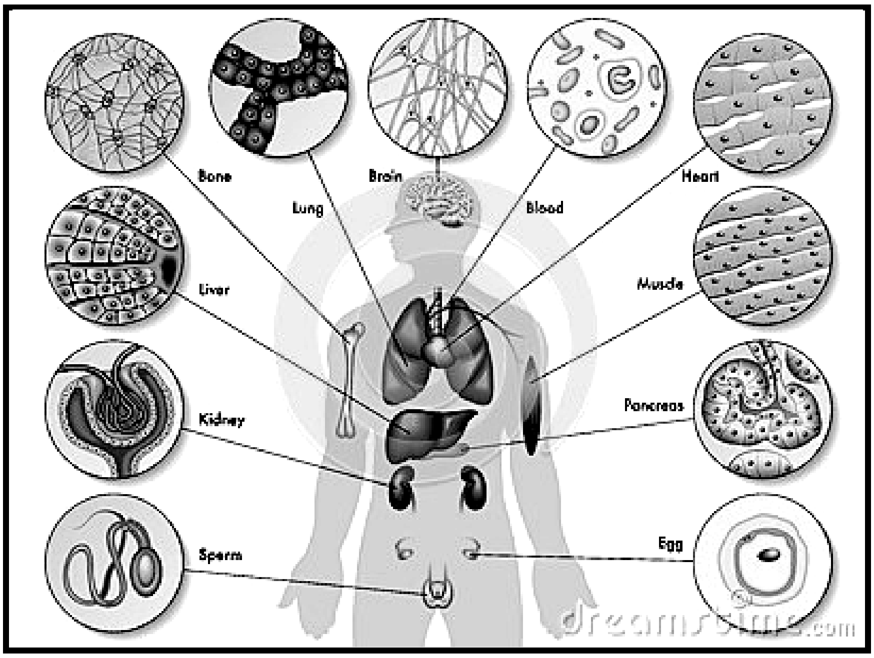


Figure 3. Eukaryotes and prokaryotes.

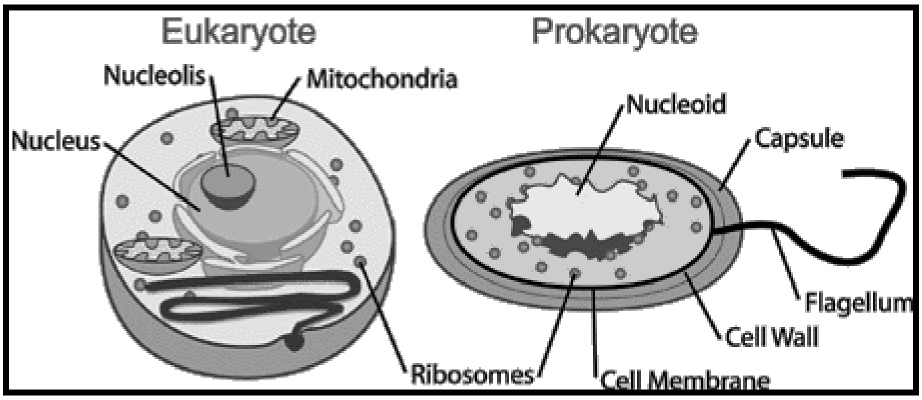
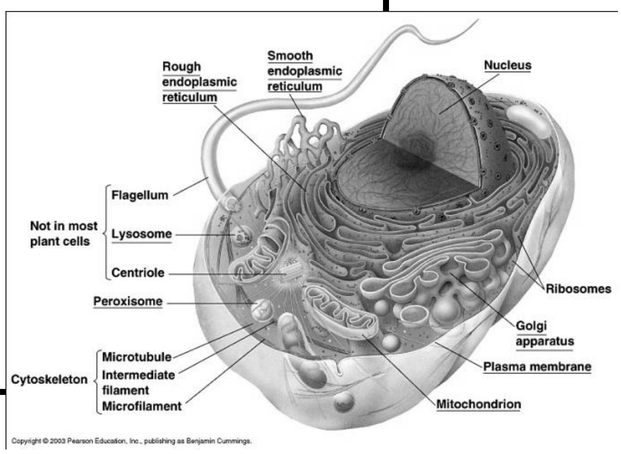


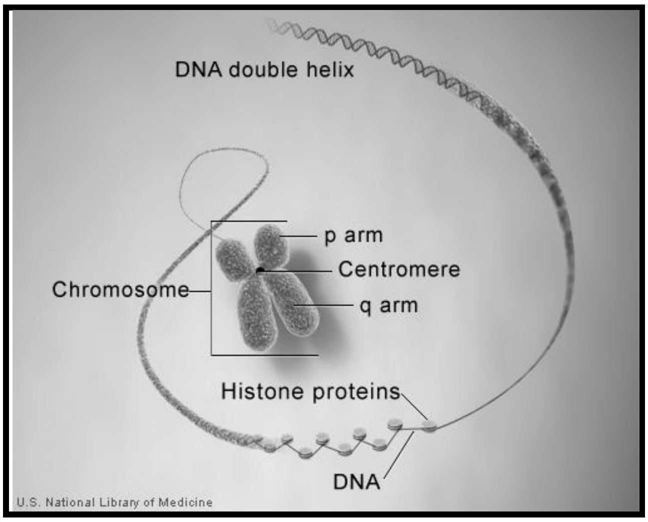
Figure 4: Structure of the cell

Figure 4a: The double helix



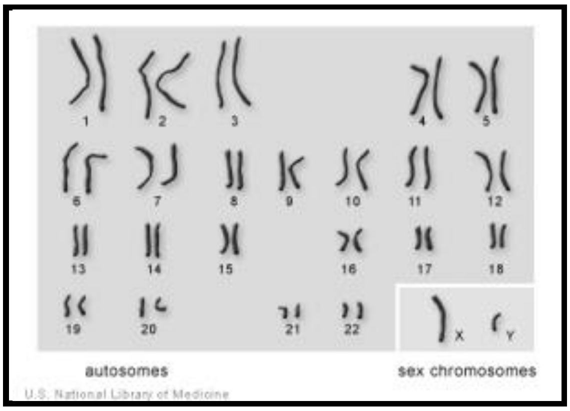
Source:
http://ghr.nlm.nih.gov/

Figure 4b: From DNA to chromosome



Source: http://ghr.nlm.nih.gov/

Figure 4c: Chromosomes in human cell



Source: http://ghr.nlm.nih.gov/

Figure 4d: The cell cycle

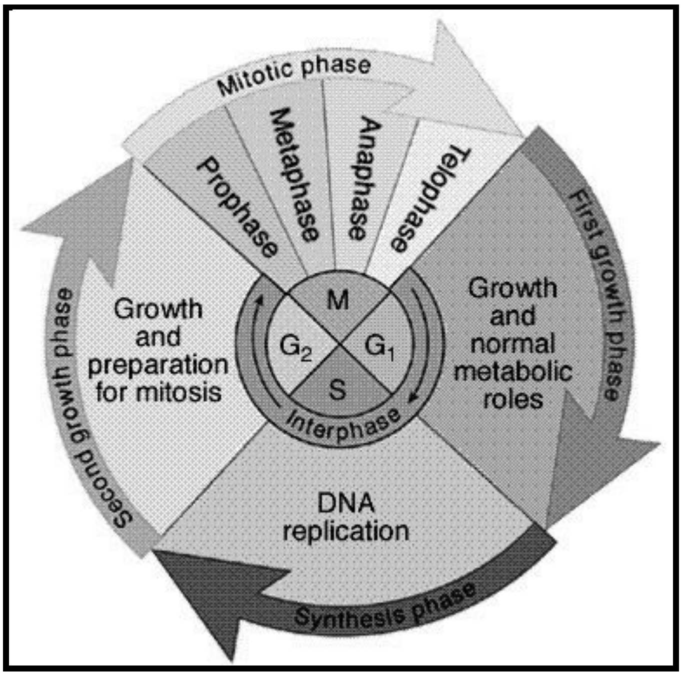


Figure 1.4.1: Mitosis

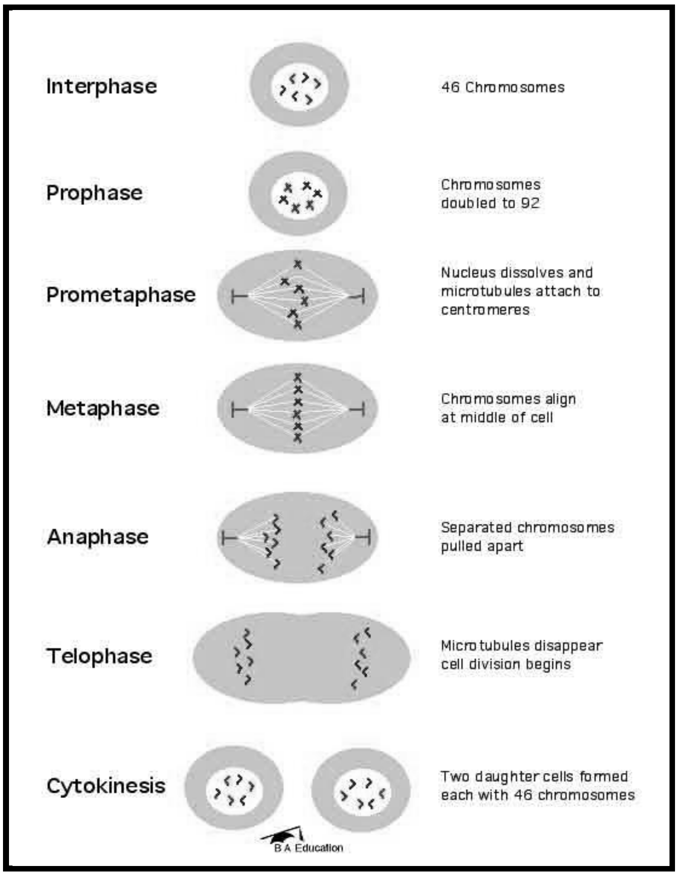


Figure 1.4.2: MEIOSIS (in comparison with mitosis)

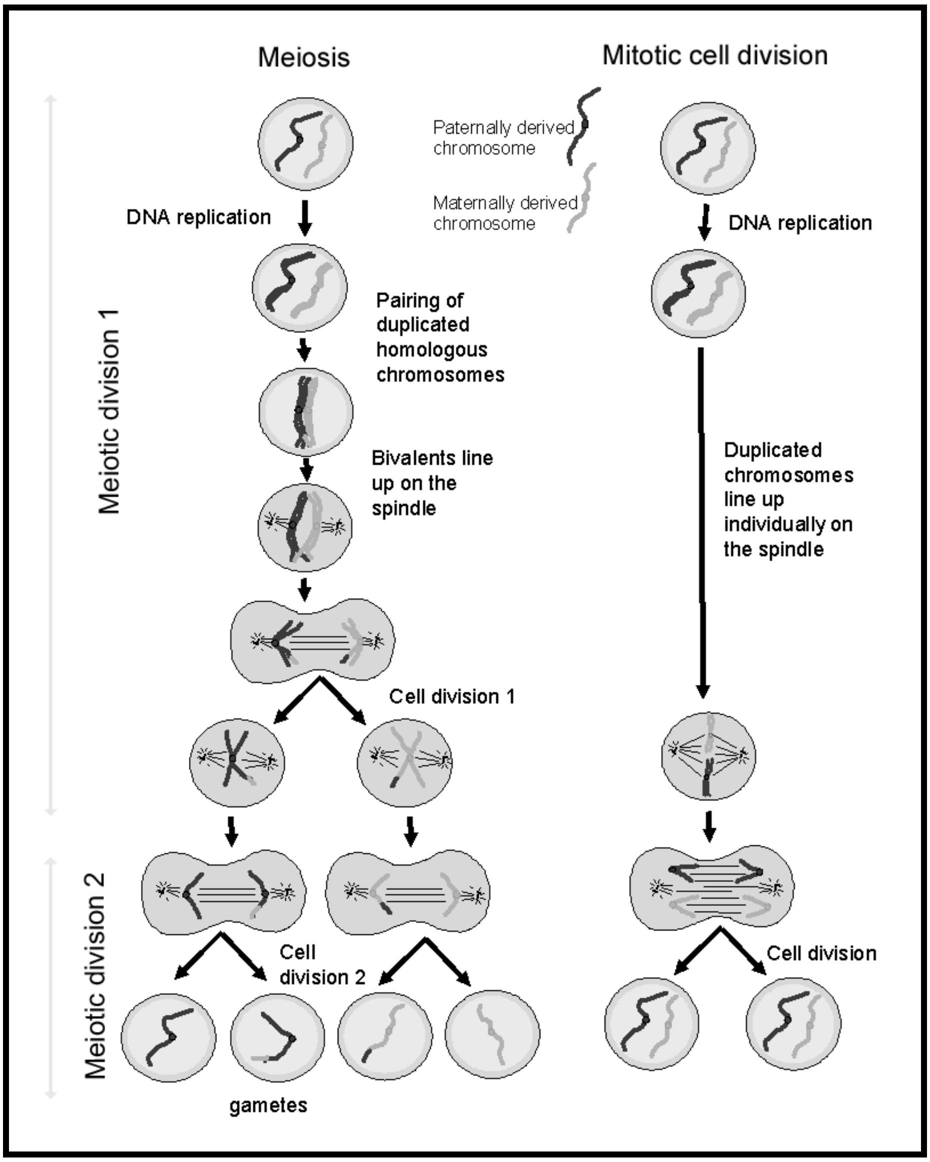


Figure 1.5: Main tissues in the human body

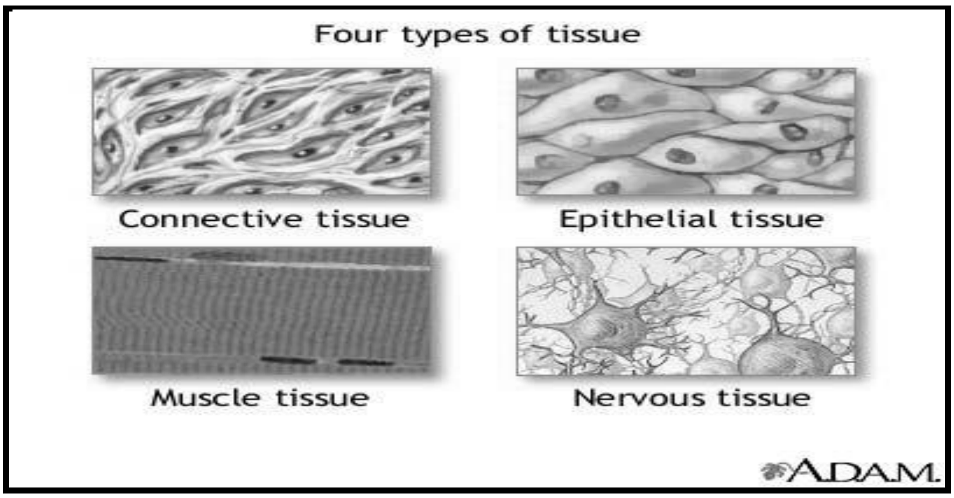
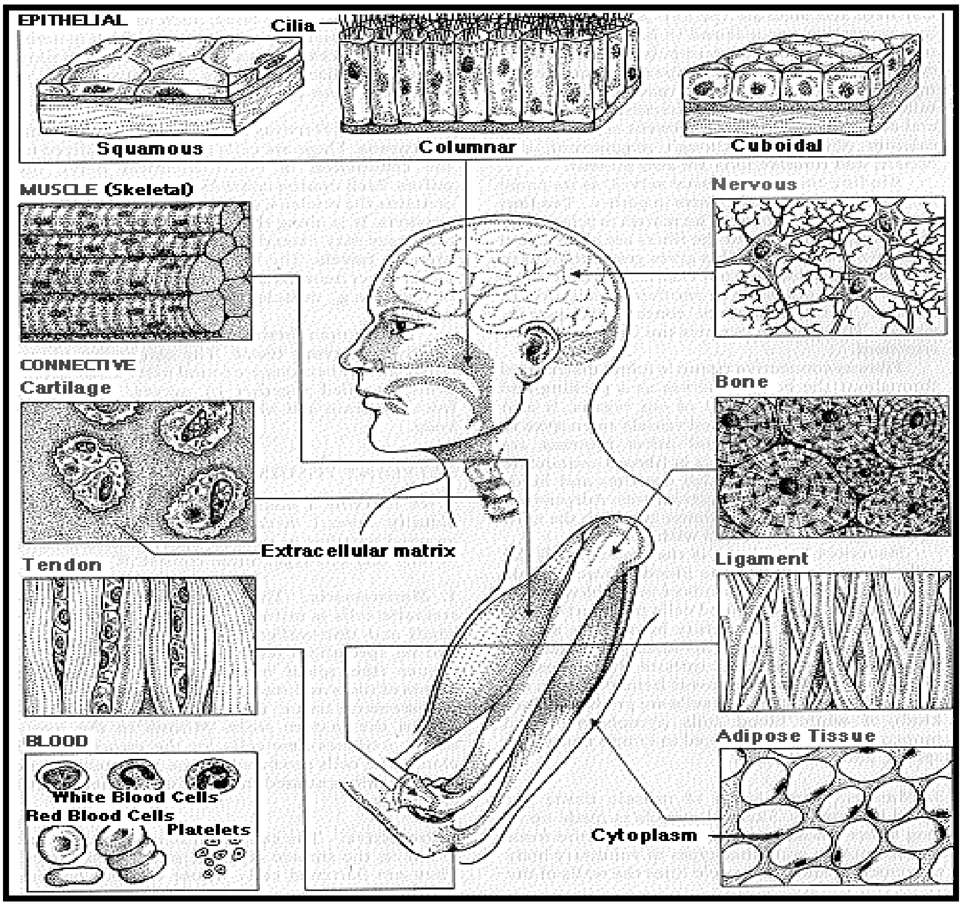


Figure 1.5.1: Sub categories of tissues



Source: *www.exploringnature.org/graphics/teaching.../Tissue_identification.pdf*

Figure 1.6.1: BLOOD and its components

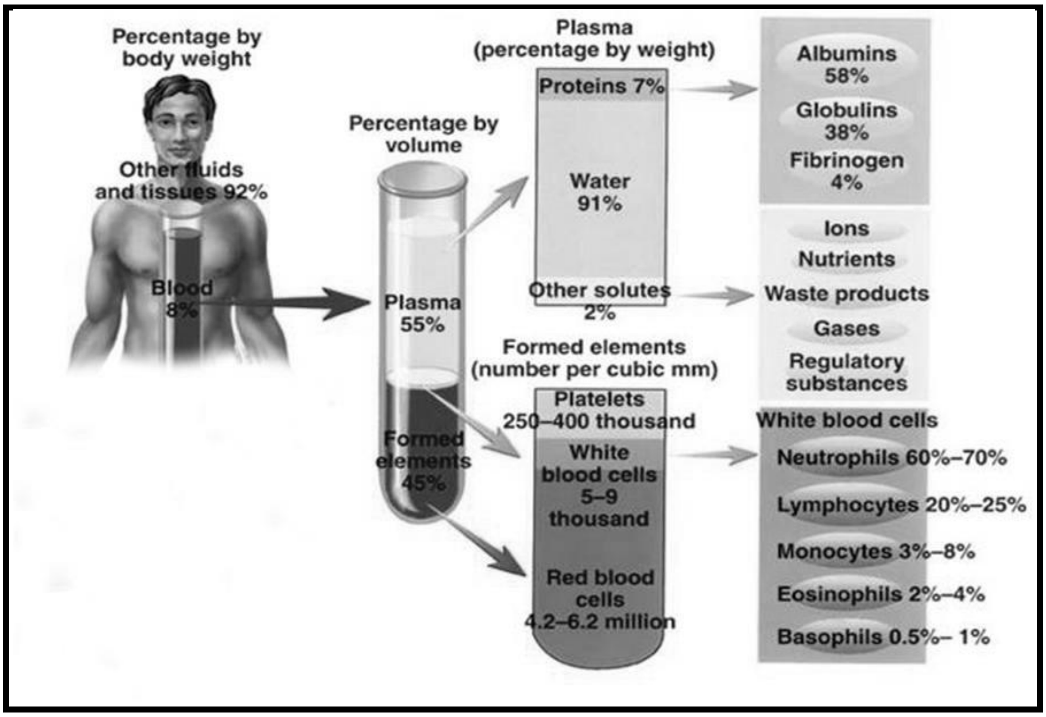


Figure 12: BLOOD CLOTTING

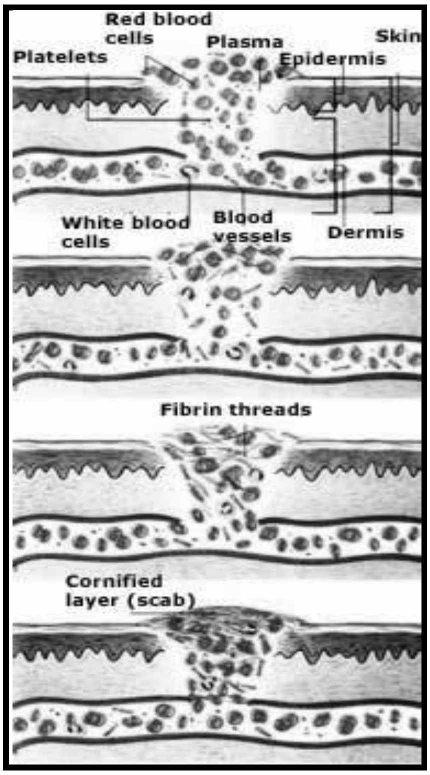
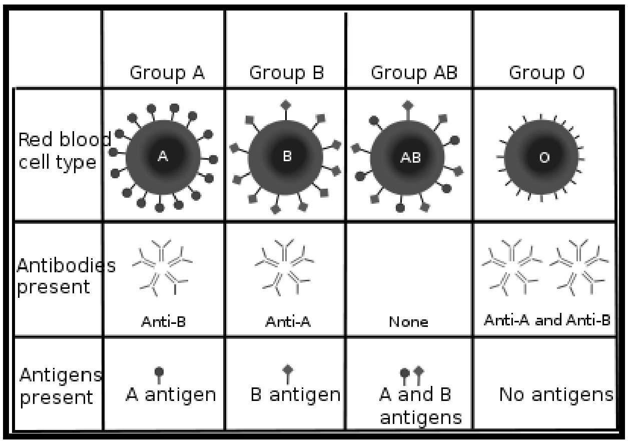


Figure 1.6.3 : Blood groups



	Group A	Group B	Group AB	Group O
Red blood cell type	A	B	AB	O
Antibodies present	Anti-B	Anti-A	None	Anti-A and Anti-B
Antigens present	A antigen	B antigen	A and B antigens	No antigens

Figure 1.7 : The immune system

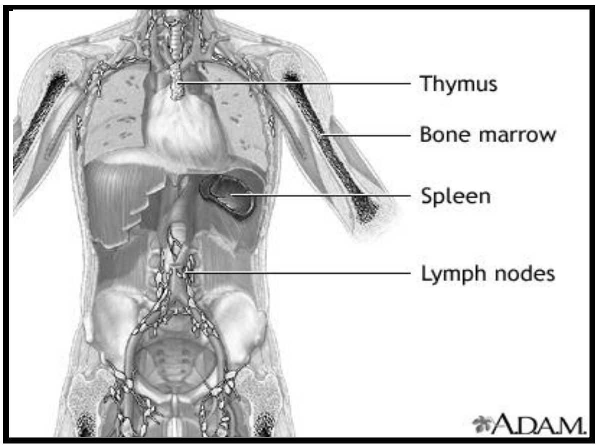
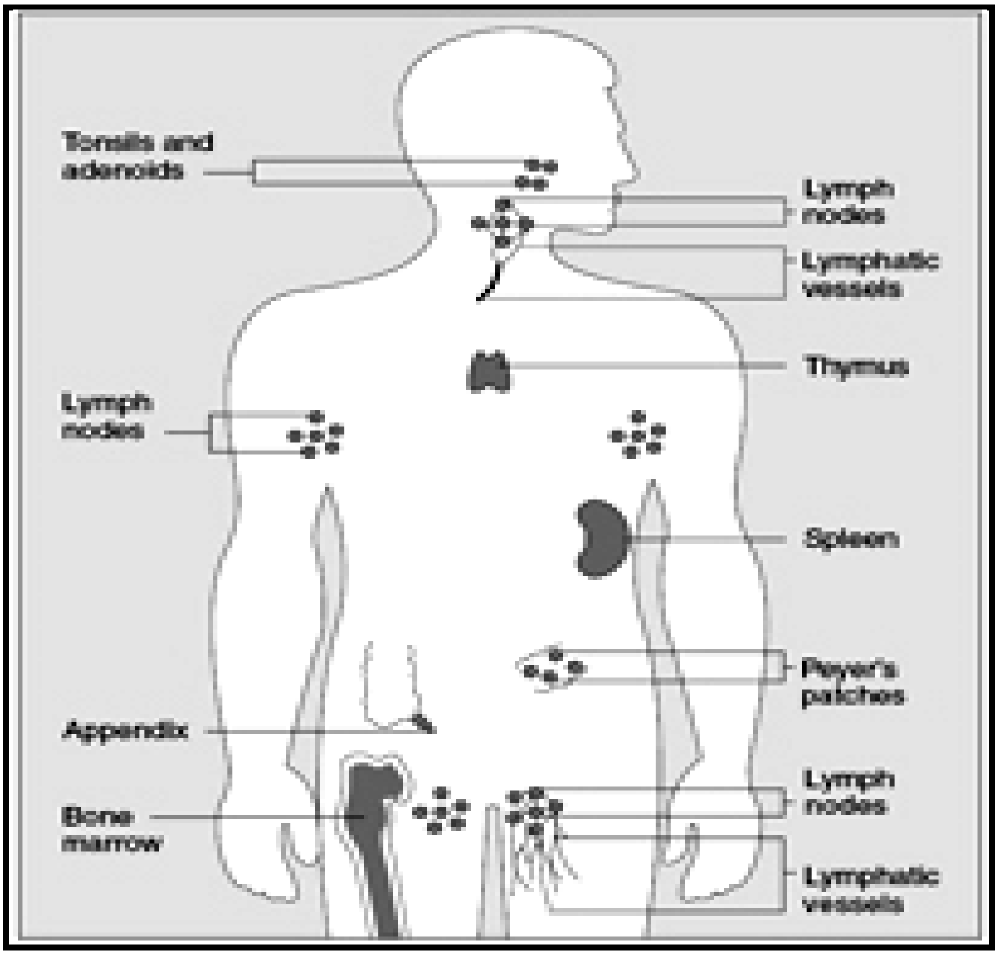


Figure 1.7.1: Major components of the immune system

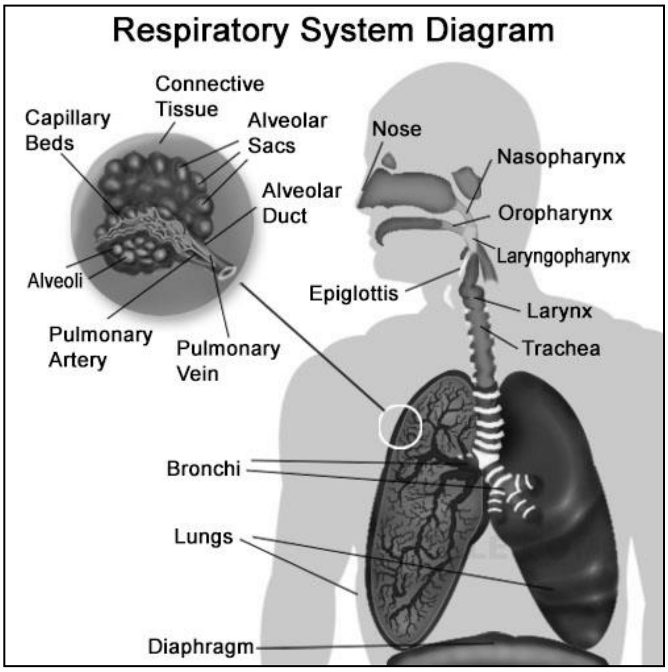


UNIT 2 THE RESPIRATORY SYSTEM

2.0 Objective

2.1 INTRODUCTION

The respiratory system is responsible for the exchange of life-giving gases for waste products in the human body. The human respiratory system can be divided into two major parts, the exchange of gases in the lungs and the exchange of gases in the body tissues. The lungs serve as a gas exchange organ where blood can be supplied with oxygen and carbon dioxide can be removed. The chest wall and diaphragm are muscles that act as a pump that expands and contracts the chest to allow the inflow and outflow of air. At rest, the average adult inhales about half a liter of air about 15 times per minute. This air moves into tiny air sacs in the lungs called alveoli where oxygen and carbon dioxide is exchanged with nearby blood vessels by simple diffusion.

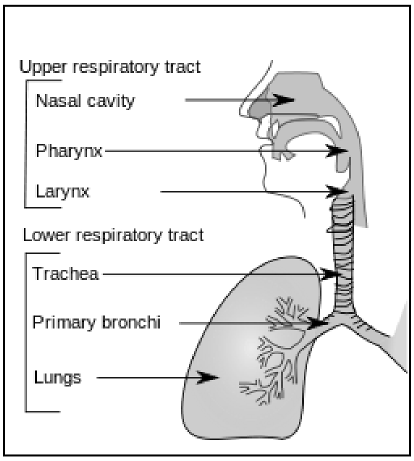


2.2 STRUCTURE AND FUNCTION OF THE HUMAN RESPIRATORY SYSTEM

The respiratory tract is divided anatomically into 2 main parts:

1. upper respiratory tract - consisting of the nose, nasal cavity and the pharynx.
2. lower respiratory tract - consisting of the larynx, trachea, bronchi and the lungs.

Between them, the upper and lower respiratory tracts make up the whole respiratory system.

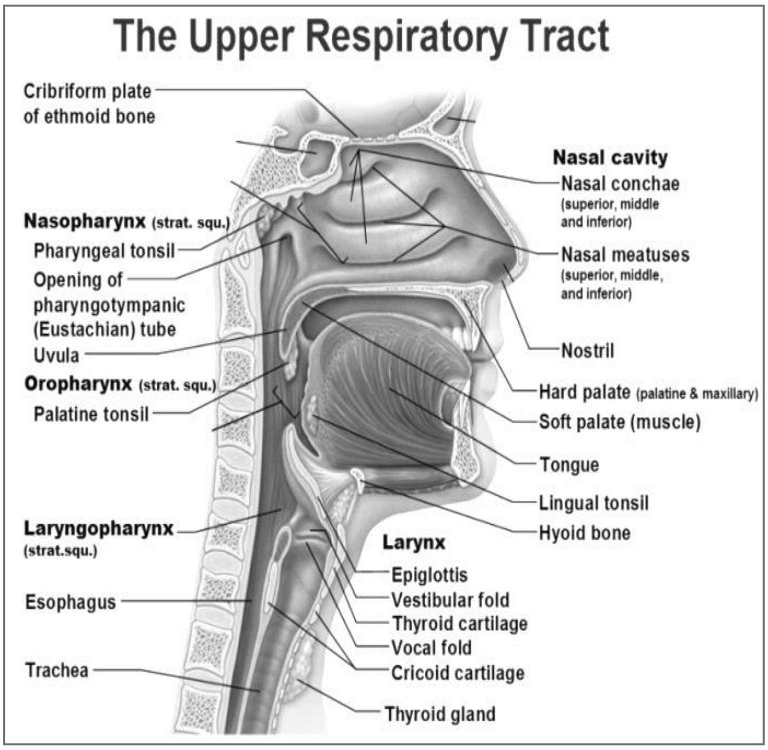


2.2.1 The upper respiratory tract

The upper airway is a collapsible, compliant tube. This is because it has to be able to withstand suction pressures generated by the rhythmic contraction of the diaphragm that sucks air into the lungs.

Components of the UTI are:

- Nose, nasal cavity, and paranasal sinuses
- Pharynx
- Larynx (The larynx can be considered part of the upper respiratory tract, the lower respiratory tract, or both, depending on the source.). The larynx is also called the voice box and has the associated cartilage that produce sound.



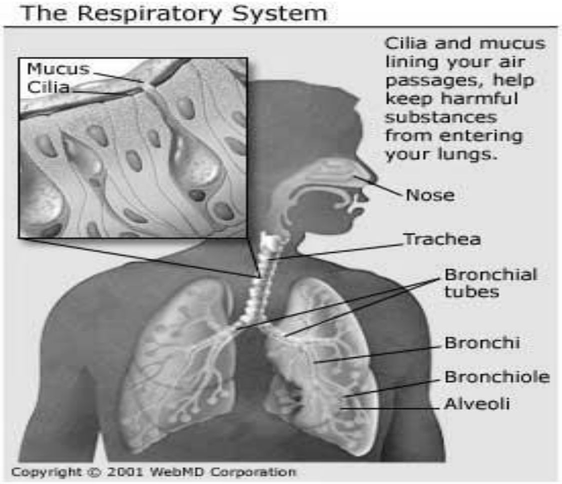
2.2.2 The nose and the nasal cavity

The nose has two holes called **nostrils**. A wall called the septum deep inside our nose, close to the skull, separates the nostrils and the nasal passages. The septum is made of **cartilage, which** is flexible material that is firmer than skin or muscle. It is not as hard as bone, and if we push on the tip of the nose, we can feel how wiggly it is.

Our nose is also a two-way street. When we inhale outside air enters the lungs through the nose and when we exhale the old air from our lungs leaves the body through the nose. However, our nose is more than a passageway for air. The nose also warms, moistens, and filters the air before it goes to the lungs.

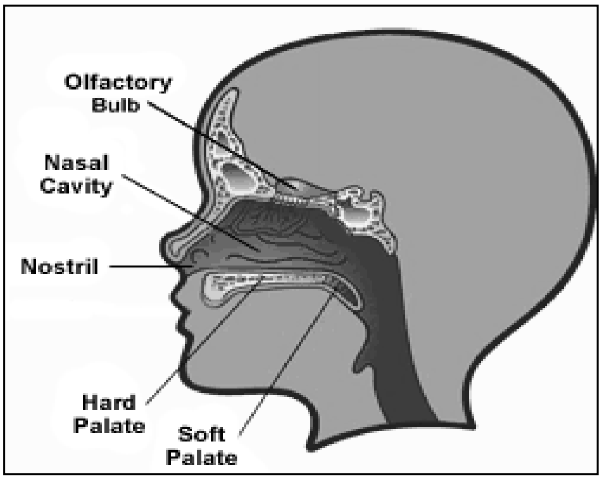
The inside of our nose is lined with a moist, thin layer of tissue called a **mucous membrane**. This membrane warms up the air and moistens it. Mucus captures dust, germs, and other small particles that could irritate our lungs. In case something gets trapped we sneeze. Sneezes can send those unwelcome particles speeding out of our nose at 100 mph!

Further back in the nose are even smaller hairs called **cilia** that can be seen only with a microscope. The cilia move back and forth to move the mucus out of the sinuses and back of the nose. Cilia can also be found lining the air passages, where they help move mucus out of the lungs.



NASAL CAVITY. Behind the nose, in the middle of our face, is a space called the nasal cavity which connects with the back of the throat. The nasal cavity is separated from the inside of the mouth by the palate (roof of mouth).

When we inhale air through our nostrils, the air enters the nasal passages and travels into the nasal cavity. The air then passes down the back of our throat into the **trachea** or windpipe, on its way to the lungs.



2.2.2 The pharynx

The Pharynx is a 5 inch long conical, fibromuscular cavity within the throat is situated posterior to the nasal and oral cavities and the larynx. This is why the pharynx can be divided into three regions depending on the position. The three regions are:

- Nasopharynx: It connects the upper portion of the throat with the nasal cavity.
- Oropharynx: It is located between the soft palate and upper part of epiglottis.
- Laryngopharynx: This part of the pharynx is located below the epiglottis. It opens into the esophagus and larynx.

Only air passes from the nose through the nasopharynx, while both food and air pass from the mouth into the oropharynx. The third section, that is the laryngopharynx, once again only permits passage of air going to the lungs.

Thick connective tissues and muscle fibers attach the pharynx to the base of the skull. Moreover, in the walls of the pharynx exist both longitudinal as well as circular muscles. The alternating contractions of these muscles causes the bolus to move from the pharynx into the food pipe or esophagus. The pharynx also houses the tonsils and adenoids. The pharynx plays an important role both the respiratory as well as the digestive system.

Function of the Pharynx

The pharynx is a common passageway for air and food, which is why pharynx has dual role. The pharynx opens into two pathways, one that leads to the esophagus or food passage and the other trachea or air passage.

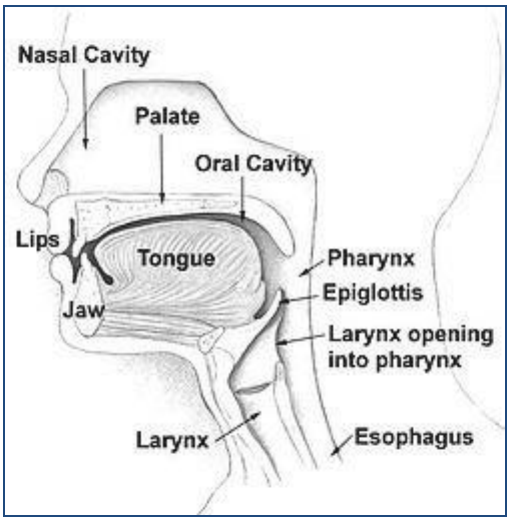
In Respiratory System

The air inhaled from the nose and mouth is taken to the pharynx, from which it is sent to the trachea or wind pipe. The air is then sent to the lungs. The mucus lining in the walls of the oropharynx can change slightly to adapt both food as well as air, thus, the pharynx is also a part of the respiratory system. Any injury or damage caused to the pharynx is seen to impede breathing.

Vocalization:

The process by which humans are able to make vocal sounds and speak is called vocalization. When air passes through the pharynx and then into larynx, it causes the vocal cords in the larynx to vibrate, thereby helping in production of sound, which is used for speech in humans.

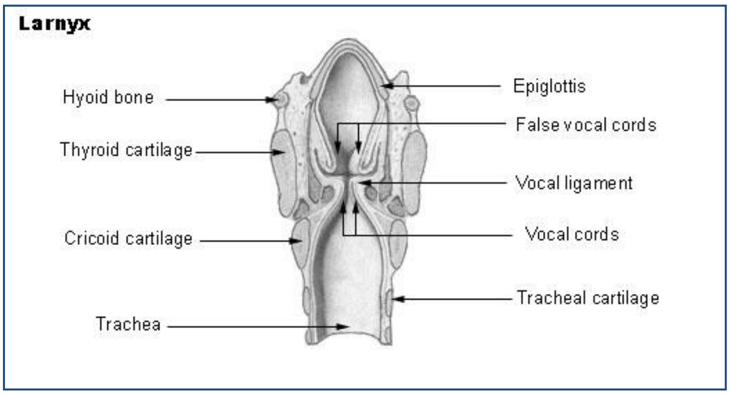
The pharynx, with all the major functions it performs, is a crucial part of the body. It coordinates both inspiration and swallowing while eating, with the help of a flap called epiglottis. If this coordination is missing, choking and aspiration can occur, which are fatal conditions. When this pharynx gets infected, we suffer from sore throat conditions like pharyngitis, which is inflammation of the pharynx. That is why we find it so difficult to swallow food with a sore throat.

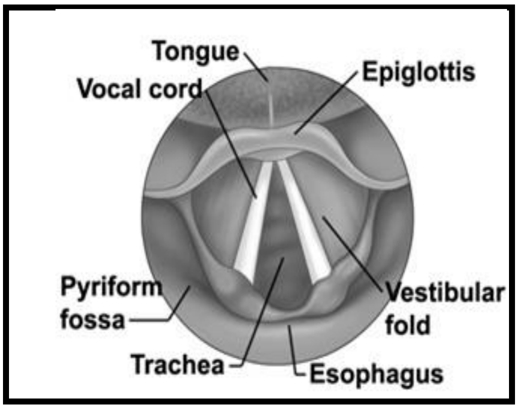


2.2.3 The larynx

Larynx, also called voice box, is a hollow, tubular structure connected to the top of the windpipe (trachea) through which air passes on its way to the lungs. The larynx also produces vocal sounds and prevents the passage of food and other foreign particles into the lower respiratory tracts.

The larynx is composed of an external skeleton of cartilage plates that prevents collapse of the structure. The plates are fastened together by membranes and muscle fibres. The front set of plates, called thyroid cartilage, has a central ridge and elevation commonly known as the Adam's apple.





2.2.4 The trachea

We know that air passes down the back of our throat into the **trachea** or windpipe, on its way to the lungs.

The trachea is about 10 to 16 centimetres (4 to 6 in) in length and has an inner diameter of about 25 millimetres (1.0 in). It commences at the lower border of the larynx, level with the sixth cervical vertebra, and bifurcates into the primary bronchi at the vertebral level of thoracic vertebra T5, or up to two vertebrae lower or higher, depending on breathing.

There are about fifteen to twenty incomplete C-shaped cartilaginous rings that reinforce the anterior and lateral sides of the trachea to protect and maintain the airway, leaving a membranous wall dorsally without cartilage.

The trachealis muscle connects the ends of the incomplete rings and contracts during coughing, reducing the size of the lumen of the trachea to increase the airflow rate. The esophagus lies posterior to the trachea. The cartilaginous rings are incomplete to allow the trachea to collapse slightly so that food can pass down the esophagus. A flap-like epiglottis closes the opening to the larynx during swallowing to prevent swallowed matter from entering the trachea.

2.2.5 The bronchi

Bronchus (singular of bronchi) is a passage which allows the flow of air into lungs. The bronchi extend from trachea to the lungs.

The tracheal tube, when divided into two at the caudal end, gives rise to the left and right bronchus.

The left bronchus is shorter than the right one; the left one is sub-divided into 2 lobar bronchi; right bronchus, on the other hand, is sub-divided into 3 lobar bronchi.

2.2.6 The bronchioles and alveoli

BRONCHIOLES:

The bronchi extend into the lungs spreading in a tree-like manner as bronchial tubes. The bronchial tubes subdivide and with each subdivision, their walls get thinner. This dividing of the bronchi into thin-walled tubes results in the formation of bronchioles. The bronchioles terminate in small air chambers, each of which contains cavities known as alveoli.

ALVEOLI:

The alveoli are sac-shaped bodies present inside the lungs, at the tip of alveolar ducts. The alveoli function like an interface for the exchange of oxygen and carbon dioxide between lungs and capillaries.These capillaries connect the alveoli with the rest of the body.

Gas Exchange Process

The process of gas exchange in alveoli is characterized by inhalation of oxygen and exhalation of carbon dioxide.

- Oxygen enters the blood cells by means of alveoli and a network of capillaries.
- Oxygen is carried to the tissues of different parts of the body by means of blood.
- Carbon dioxide is collected by the blood and carried to lungs.
- Carbon dioxide diffuses from capillaries that surround the alveoli and is finally exhaled by lungs.

Finally, there are cells in the alveolar walls which secrete a fluid that keeps the inner surface of the alveoli moist, allowing gases to dissolve. This fluid also contains a natural detergent that prevents the sides of the alveoli from sticking together. Between the alveoli is a thin layer of cells called the interstitium, which contains blood vessels and cells that help support the alveoli.

2.2.7 The lungs and the pleura

THE LUNGS

The lungs are a pair of spongy, air-filled organs located on either side of the chest (thorax). The lungs are divided first into right and left, the left being smaller to accommodate the heart, then into lobes (three on the right, two on the left) supplied by lobar bronchi.

Bronchi, pulmonary arteries and veins (which supply deoxygenated blood and remove oxygenated blood), bronchial arteries and veins (which supply oxygenated blood to the substance of the lung itself) and lymphatics all enter and leave the lung by its root (or hilum).

Each lobe of the lung is further divided into pyramidal **bronchopulmonary segments**. Bronchopulmonary segments have the apex of the pyramid in the hilum where they receive a tertiary bronchus, and appropriate blood vessels.

The 10 segments of the right lung and eight of the left are virtually self contained units not in communication with other parts of the lung. This is of obvious use in surgery when appropriate knowledge will allow a practically bloodless excision of a diseased segment.

The trachea (windpipe) conducts inhaled air into the lungs through its tubular branches, called bronchi. The bronchi then divide into smaller and smaller branches (bronchioles), finally becoming microscopic.

The bronchioles eventually end in clusters of microscopic air sacs called alveoli. In the alveoli, oxygen from the air is absorbed into the blood. Carbon dioxide, a waste product of metabolism, travels from the blood to the alveoli, where it can be exhaled.

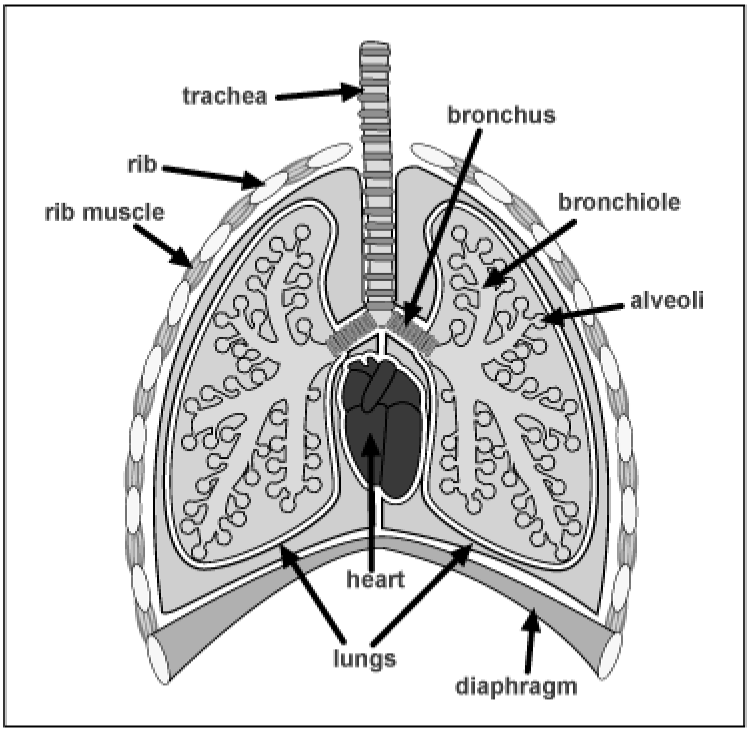
THE PLEURA

The lungs are covered by a thin tissue layer called the **pleura**. The same kind of thin tissue lines the inside of the chest cavity -- also called pleura. A thin layer of fluid acts as a lubricant allowing the lungs to slip smoothly as they expand and contract with each breath.

Each lung is enclosed in a cage bounded below by the diaphragm and at the sides by the chest wall and the mediastinum (technical term for the bit around the heart).

Breathing works by making the cage bigger: the pleural layers slide over each other and the pressure in the lung is decreased, so air is sucked in. Breathing out does the reverse, the cage collapses and air is expelled. The main component acting here is the **diaphragm.** This is a layer of muscle which is convex above, domed, and squashed in the centre by the heart. When it contracts it flattens and increases the space above it. When it relaxes the abdominal contents push it up again. The proportion of breathing which is diaphragmatic varies from person to person. For instance breathing in children and pregnant women is largely diaphragmatic, and more in women than in men.

THE VENTILATION SYSTEM:



Gaseous exchange relies on simple diffusion. In order to provide sufficient oxygen and to get rid of sufficient carbon dioxide there must be

- a large surface area for gaseous exchange
- a very short diffusion path between alveolar air and blood
- concentration gradients for oxygen and carbon dioxide between alveolar air and blood.

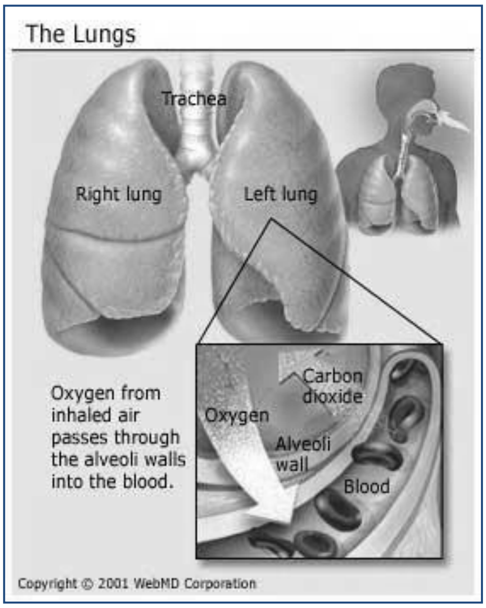
The surface available in an adult is around 140m2 in an adult, around the area of a singles tennis court. The blood in the alveolar capillaries is separated from alveolar air by 0.6* in many places (1* = one thousandth of a mm) .

A ventilation system is needed to maintain the concentration gradients of gases in the alveoli. Diffusion of gases occurs due to the concentration gradient of oxygen and carbon dioxide between the alveoli and the blood. The body needs to get rid of carbon dioxide, which is a product of cell respiration and needs to take in oxygen, as it is needed for cell respiration to make ATP. There must be a low concentration of carbon dioxide in the alveoli so that carbon dioxide can diffuse out of the blood in the capillaries and into the alveoli. Also there must be a high concentration of oxygen in the in the alveoli so that oxygen can diffuse into the blood in the capillaries from the alveoli. The ventilation system makes this possible by getting rid of the carbon dioxide in the alveoli and bringing in more oxygen.

2.3 THE MECHANICS AND PROCESS OF RESPIRATION

Air passages

Air first passes through the nose where it is moisturized and warmed before passing to the trachea. The single trachea branches to become bronchi, bronchioles, alveolar ducts and then the terminal air sacs called alveoli. The airway branches about 23 times before ending in the terminal alveoli. Gas is exchanged in the respiratory bronchioles, alveolar ducts and alveoli. The branching of the airways leads to a great increase in the surface area for gas exchange (about 70 square meters - the size of a tennis court). The alveoli are surrounded by pulmonary capillaries. The gas exchange occurs over a membrane two cells thick (one capillary wall cell and one alveolar wall cell).



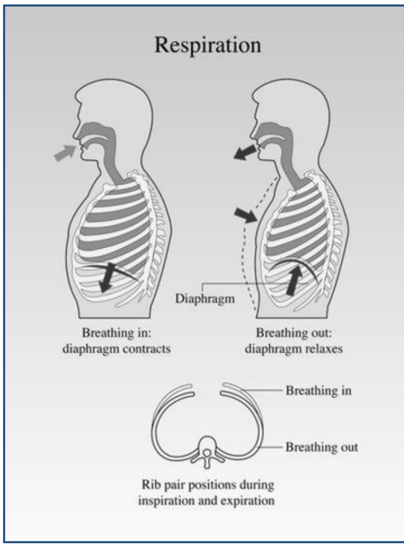
Blood circulation

All of the body's blood passes through the lungs by way of the **pulmonary artery**. This blood receives oxygen and releases carbon dioxide and other waste gases. The oxygen-rich blood returns to the heart by way of the **pulmonary veins**.

The lung tissue itself is nourished by the smaller **bronchial arteries** that come from the systemic circulation. This blood drains into the **bronchial veins**.

Inspiration & expiration

Air enters the lungs due to the effects of muscle contractions. The diaphragm is a sheet-like muscle at the bottom of the chest cavity that pulls down on the lungs causing them to expand. The diaphragm typically accounts for about 75% of lung expansion. The chest wall also expands as the muscles between the ribs contract. This is due to a "bucket-handle" effect. Imagine a bucket on its side with the handle hanging loosely. If the handle is pulled upward, it actually has to swing outward. Therefore the ribs swing outward when the rib muscles contract and this increases the volume of the chest cavity.

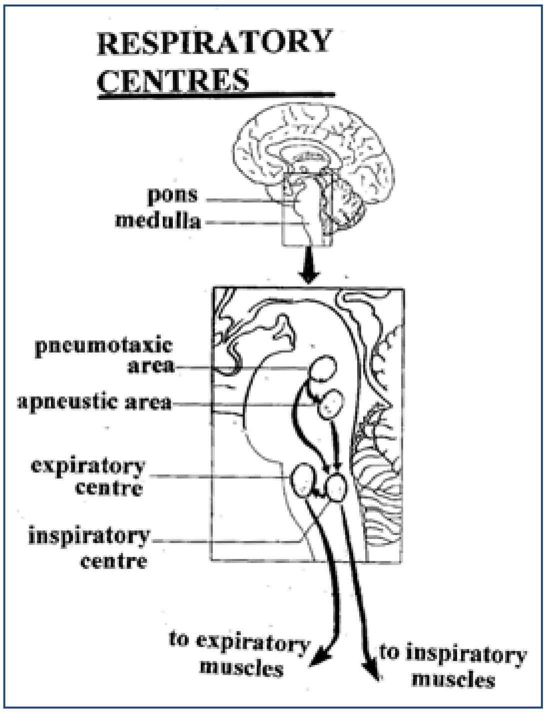


Gas exchange

Gas exchange or "respiration" occurs in two major places in the body. First, in the lungs, oxygen is delivered to the blood while carbon dioxide is removed.

In the body tissues, the opposite occurs. Oxygen is removed from the blood by body tissue cells and carbon dioxide is released into the blood.

2.4 REGULATION OF RESPIRATION



Our respiratory rate changes at different times. When active, for example, your respiratory rate goes up; when less active, or sleeping, the rate goes down. Also, even though the respiratory muscles are voluntary, you can't consciously control them when you're sleeping. So, how is respiratory rate altered & how is respiration controlled when you're not consciously thinking about respiration?

The rhythmicity center of the medulla:

- controls automatic breathing
- consists of interacting neurons that fire either during inspiration (I neurons) or expiration (E neurons)
- I neurons - stimulate neurons that innervate respiratory muscles (to bring about inspiration)
- E neurons - inhibit I neurons (to 'shut down' the I neurons & bring about expiration)

Apneustic center (located in the pons) - stimulate I neurons (to promote inspiration)

Pneumotaxic center (also located in the pons) - inhibits apneustic center & inhibits inspiration

General Control of Breathing: Breathing is controlled by the medulla of the brainstem. It repeatedly triggers contraction of the diaphragm initiating inspiration. The rate of breathing changes with activity level in response to carbon dioxide levels, and to a lesser extent, oxygen levels, in the blood. Carbon dioxide lowers the pH of the blood.

There are control centers for respiration in both the **medulla** and the **pons** of the hindbrain.

There are **chemosensors** in the carotid artery and the arch of the aorta . The sensors of the aortal are sensitive to the level of oxygen in the blood. Sensors near the medulla are sensitive to the level of carbon dioxide in the blood. If oxygen level falls or carbon dioxide levels vary too greatly from the set point, a **negative feedback mechanism** increases respiratory rate. This brings in more oxygen and expels more carbon dioxide. Mammals are most sensitive to carbon dioxide levels because the amount of carbon dioxide varies most in respiration in response to different metabolic and environmental conditions.

2.5 TYPES OF RESPIRATION

The word respiration describes two processes.

- Internal or cellular respiration is the process by which glucose or other small molecules are oxidised to produce energy: this requires oxygen and generates carbon dioxide. The exchange of gases between the body spaces or fluids and the cells is called internal respiration or tissue respiration. The area over which this exchange takes place is called the respiratory surface.
- External respiration (breathing) The exchange of gases between the environment and the body is called external respiration or gaseous exchange.It involves simply the stage of taking oxygen from the air and returning carbon dioxide to it.
- Cellular respiration It takes places within the cells of an organism. biochemical processes involved in respiration break down the substate to release energy in the tissues within the cells of the organism. Thus it is called **cellular respiration.**

Respiration is the process of releasing energy from the breakdown of glucose. Respiration takes place in every living cell, all of the time and all cells need to respire in order to produce the energy that they require.

What is the energy is used for?

The energy produced during respiration is used in many different ways, some examples of what it is used for are:

- Working your muscles
- Growth and repair of cells
- Building larger molecules from smaller ones i.e. proteins from amino acids
- Allowing chemical reactions to take place
- Absorbing molecules in active transport
- Keeping your body temperature constant
- Sending messages along nerves

Types of Respiration

There are two main types of respiration, **aerobic** and **anaerobic** we will look at each one of these in detail now.

1. Aerobic Respiration

Aerobic means “with air”. This type of respiration needs oxygen for it to occur so it is called aerobic respiration. The word equation for aerobic respiration is:

Glucose + Oxygen ⟶ Carbon dioxide + Water + Energy

In the above equations we see that glucose is broken down by oxygen to release energy with carbon dioxide and water being produced as by-products of the reaction. Approximately 2900 kj of energy is released when only one glucose molecule is broken down by six oxygen molecules. The released energy is used to make a special energy molecule called **Adenosine triphosphate** (ATP). ATP is where the energy is stored for use later on by the body.

2. Anaerobic Respiration

Anaerobic means without air (“an” means without). Sometimes there is not enough oxygen around for animals and plants to respire, but they still need energy to survive. Instead they carry out respiration in the absence of oxygen to produce the energy they require this is called anaerobic respiration.

a) In animals

Our muscles need oxygen and glucose to respire aerobically and produce the energy they require, these are carried to the muscle via the blood. However if we were to carry out vigorous exercise our heart and lungs would not be able to get sufficient oxygen to our muscles in order for them to respire. In this case muscles carry out anaerobic respiration. The word and chemical equation for anaerobic respiration in is:

Glucose → Lactic acid + Energy

$C_6H_{12}O_6 \rightarrow 2C_3H_6O_3 + 120$ kj

As you can see anaerobic respiration is not as efficient as aerobic and only a small amount of energy is released. This is because glucose can only be partially broken down. As well as this inefficiency a poisonous chemical, lactic acid is also produced, if this builds up in the body it stops the muscles from working and causes a cramp. To rid the body of lactic acid oxygen is needed, the amount of oxygen required to break down the lactic acid is referred to as the **oxygen debt.**

2.6 ARTIFICIAL RESPIRATION

Artificial Respiration means forcing of air into and out of the lungs of one person by another person or by mechanical means. It is usually employed during suspension of natural respiration caused by disease, such as poliomyelitis or cardiac failure; by electric shock; by an overdose of depressive drugs such as morphine, barbiturates, or alcohol; or by suffocation resulting from drowning, breathing noxious gases, or blockage of the respiratory tract.

If the brain is deprived of oxygen for five minutes, it may be permanently damaged; slightly longer periods without oxygen usually result in death. The exception is drowning in very cold water, in which the body`s oxygen demand is greatly reduced; people have been revived after being submerged for one-half hour in cold water.

Because of the danger to the brain of even short periods without oxygen, artificial respiration is always be started immediately. The mouth-to-mouth method is recommended by the American Red Cross. In this method the unconscious person is laid face up on a firm surface. The neck is lifted and the head tilted as far back as possible to prevent the tongue from blocking the air passages. The victim`s nose is then pinched shut, and with the reviver`s mouth tightly covering the victim`s, the reviver gives four quick, deep breaths. If breathing does not resume, the reviver proceeds to give one breath each five seconds, allowing the air to come out of the victim`s lungs between breaths. This is continued until the victim resumes breathing or until trained help arrives. If the unconscious person is a baby or small child, both the mouth and nose are covered with the reviver`s mouth, and small puffs of air are breathed out to the victim at the rate of one every three seconds.

To restore breathing to a person who is choking, a rescuer gives four quick blows between the victim`s shoulder blades with the heel of the hand. If this does not dislodge the obstruction, the rescuer uses the stomach thrust, popularly called the Heimlich maneuver after its developer, the American physician Henry Jay Heimlich. The rescuer places the side of the fist against the victim`s stomach, below the ribs and above the navel. Then, using the other hand, the rescuer thrusts the fist up into the victim`s stomach forcefully four times. With children, a rescuer first turns the child head-down and slaps the child`s back. In applying the Heimlich maneuver to children, the rescuer uses only the first hand, and not the second.

A type of respiratory first aid that requires special training is called cardiopulmonary resuscitation (CPR). In this procedure, which is used for a person who has had a heart attack, the reviver alternately breathes for the victim and performs external massage on the person`s chest to keep blood moving through the body.

Mechanical devices for the administration of artificial respiration include a **portable resuscitator** used by police and fire departments and the **heart-lung machine** used to maintain oxygen saturation in the blood during open-heart surgery. Severe breathing difficulties may require help from a mechanical ventilator, which forces air into the lungs by way of a tube inserted into the upper airway through the nose, mouth, or a slit in the trachea. Comatose patients dependent on such a ventilator for a prolonged period may not resume spontaneous breathing. However a precedent was established for the removal of life-support ventilators in the absence of electrical activity in the brain cortex.

2.7 LET US SUM UP

Respiration refers to the mechanisms for obtaining oxygen from the air and delivering it to the tissues, while eliminating carbon dioxide from the body. Respiration in the former sense involves four processes:

(1) breathing, or ventilation of the lungs;

(2) gas exchange between air and blood in the lungs;

(3) gas transport in the blood; and

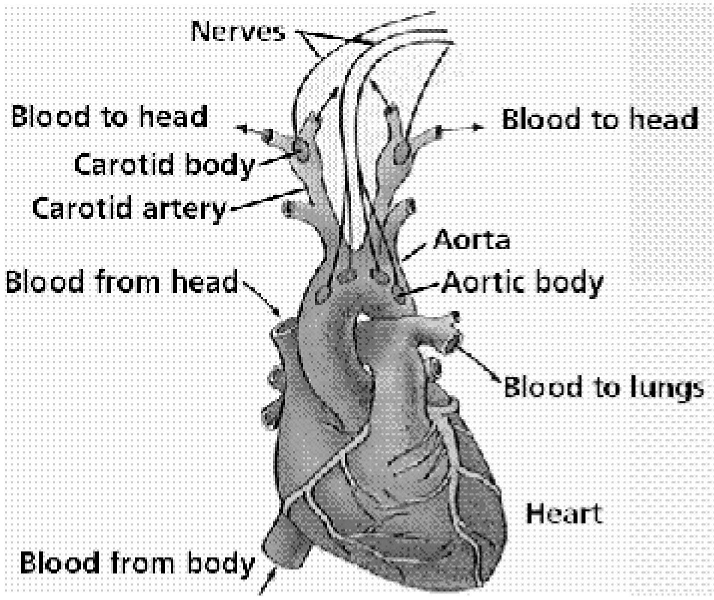
(4) gas exchange between the blood and target tissues.

The respiratory system consists of:

- the nasal cavity, which warms, cleans, and humidifies inhaled air;
- the **pharynx** , where the respiratory and digestive systems meet and then diverge again;
- the **larynx** , or voice box, which contains the vocal cords;
- **the trachea**, or windpipe, a tube about 12 centimeters (4.7 inches) long and 2.5 centimeters (just less than an inch) wide that passes behind the heart and branches like a Y at its lower end;
- **bronchi and bronchioles**, air tubes that begin at the fork of the trachea and divide into smaller and smaller divisions within each lung; and
- **alveoli,** millions of tiny air sacs in the lung.

2.8 GLOSSARY

2.9 CHECK YOUR PROGRESS



UNIT 3 THE DIGESTIVE SYSTEM

3.0 OBJECTIVE

In this unit we shall focus on the gastrointestinal or digestive system. We shall learn

- How food is the body's fuel source
- The components of the digestive system and
- How digestion happens.

3.1 INTRODUCTION

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

The digestive system is a group of organs working together to convert food into energy and basic nutrients to feed the entire body. Food passes through a long tube inside the body known as the alimentary canal or the gastrointestinal tract (GI tract). The alimentary canal is made up of the oral cavity, pharynx, esophagus, stomach, small intestines, and large intestines. In addition to the alimentary canal, there are several important accessory organs that help our body to digest food but do not have food pass through them. Accessory organs of the digestive system include the teeth, tongue, salivary glands, liver, gallbladder, and pancreas.

THE DIGESTIVE SYSTEM's function (in a nutshell): To achieve the goal of providing energy and nutrients to the body, six primary processes take place in the digestive system:

1. Ingestion of food
2. Secretion of fluids and digestive enzymes
3. Mixing and movement of food and wastes through the body
4. Digestion of food into smaller pieces
5. Absorption of nutrients
6. Excretion of wastes

Ingestion

The first function of the digestive system is ingestion, or the intake of food. The mouth is responsible for this function, as it is the orifice through which all food enters the body. The mouth and stomach are also responsible for the storage of food as it is waiting to be digested. This storage capacity allows the body to eat only a few times each day and to ingest more food than it can process at one time.

Secretion

In the course of a day, the digestive system secretes around 7 liters of fluids. These fluids include saliva, mucus, hydrochloric acid, enzymes, and bile. Saliva moistens dry food and contains salivary amylase, a digestive enzyme that begins the digestion of carbohydrates. Mucus serves as a protective barrier and lubricant inside of the GI tract. Hydrochloric acid helps to digest food chemically and protects the body by killing bacteria present in our food. Enzymes are like tiny biochemical machines that disassemble large macromolecules like proteins, carbohydrates, and lipids into their smaller components. Finally, bile is used to emulsify large masses of lipids into tiny globules for easy digestion.

Mixing and Movement

The digestive system uses 3 main processes to move and mix food:

- *Swallowing*. Swallowing is the process of using smooth and skeletal muscles in the mouth, tongue, and pharynx to push food out of the mouth, through the pharynx, and into the esophagus.
- *Peristalsis*. Peristalsis is a muscular wave that travels the length of the GI tract, moving partially digested food a short distance down the tract. It takes many waves of peristalsis for food to travel from the esophagus, through the stomach and intestines**,** and reach the end of the GI tract.
- *Segmentation*. Segmentation occurs only in the small intestine as short segments of intestine contract like hands squeezing a toothpaste tube. Segmentation helps to increase the absorption of nutrients by mixing food and increasing its contact with the walls of the intestine.

Digestion

Digestion is the process of turning large pieces of food into its component chemicals. Mechanical digestion is the physical breakdown of large pieces of food into smaller pieces. This mode of digestion begins with the chewing of food by the teeth and is continued through the muscular mixing of food by the stomach and intestines. Bile produced by the liver is also used to mechanically break fats into smaller globules. While food is being mechanically digested it is also being chemically digested as larger and more complex molecules are being broken down into smaller molecules that are easier to absorb. Chemical digestion begins in the mouth with salivary amylase in saliva splitting complex carbohydrates into simple carbohydrates. The enzymes and acid in the stomach continue chemical digestion, but the bulk of chemical digestion takes place in the small intestine thanks to the action of the pancreas. The pancreas secretes an incredibly strong digestive cocktail known as pancreatic juice, which is capable of digesting lipids, carbohydrates, proteins and nucleic acids. By the time food has left the duodenum, it has been reduced to its chemical building blocks—fatty acids, amino acids, monosaccharides, and nucleotides.

Absorption

Once food has been reduced to its building blocks, it is ready for the body to absorb. Absorption begins in the stomach with simple molecules like water and alcohol being absorbed directly into the bloodstream. Most absorption takes place in the walls of the small intestine, which are densely folded to maximize the surface area in contact with digested food. Small blood and lymphatic vessels in the intestinal wall pick up the molecules and carry them to the rest of the body. The large intestine is also involved in the absorption of water and vitamins B and K before feces leave the body.

Excretion

The final function of the digestive system is the excretion of waste in a process known as defecation. Defecation removes indigestible substances from the body so that they do not accumulate inside the gut. The timing of defecation is controlled voluntarily by the conscious part of the brain, but must be accomplished on a regular basis to prevent a backup of indigestible materials.

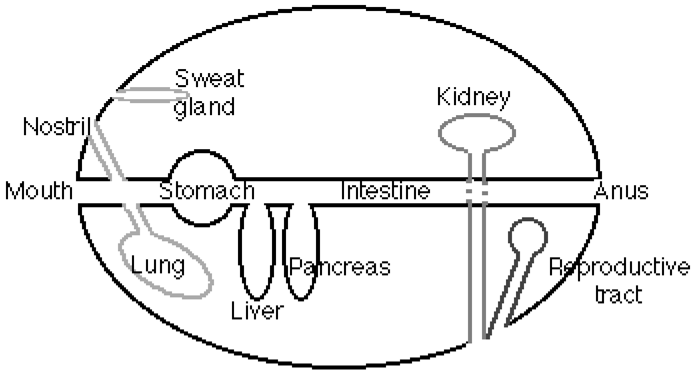
3.2 THE DIGESTIVE TRACT

In an adult male human, the gastrointestinal (GI) tract is 5 meters (20 ft) long or up to 9 meters (30 ft) without the effect of muscle tone, and consists of the upper and lower GI tracts. The upper GI tract includes the esophagus, stomach and duodenum and the lower GI tract includes the anus, rectum, colon, and cecum.

All food ingested is digested extracellularly; that is, outside of cells.

- Digestive enzymes are secreted from cells lining the inner surfaces of various exocrine glands.
- The enzymes hydrolyze the macromolecules in food into small, soluble molecules that can be
- absorbed into cells.

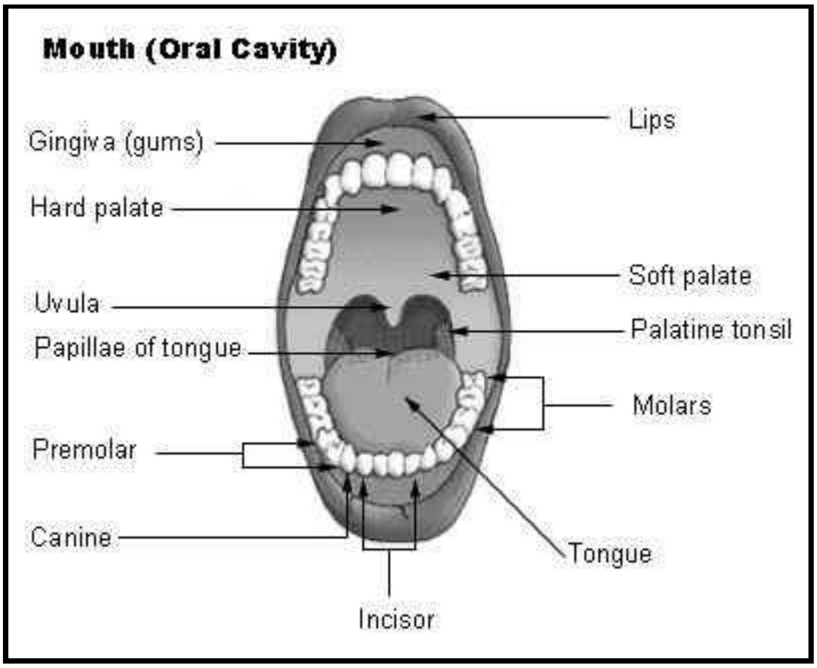
The Topology



The diagram shows the major topological relationships in the body. The linings of all

- exocrine glands, including digestive glands,
- nasal passages, trachea, and lungs,
- kidney tubules, collecting ducts, and bladder,
- reproductive structures like the vagina, uterus, and fallopian tubes are all continuous with the surface of the body. Anything placed within their lumen is, strictly speaking, outside the body. This includes
- the secretions of all exocrine glands (in contrast to the secretions of endocrine glands, which are deposited in the blood).
- Any indigestible material placed in the mouth which will appear, in due course, at the other end.

3.3 THE ORAL CAVITY



Food placed in the mouth is

- ground into finer particles by the teeth,
- moistened and lubricated by saliva (secreted by three pairs of **salivary glands**)
- small amounts of starch are digested by the amylase present in saliva
- the resulting bolus of food is swallowed into the **esophagus** and
- carried by **peristalsis** to the stomach.

The first section of the mouth is known as the oral cavity, or the mouth cavity. This space is bordered in the front and to the sides by the two alveolar arches, which contain the teeth. Toward the back it is bordered by the isthmus of the fauces. This entire structure is also called the mouth; the structures within the mouth allow us to taste and masticate (chew) food, to swallow food and drink, and to manipulate the air that comes up from the voice box so that we can form words.

Inside the mouth are many accessory organs that aid in the digestion of food—the tongue, teeth, and salivary glands. Teeth chop food into small pieces, which are moistened by saliva before the tongue and other muscles push the food into the pharynx.

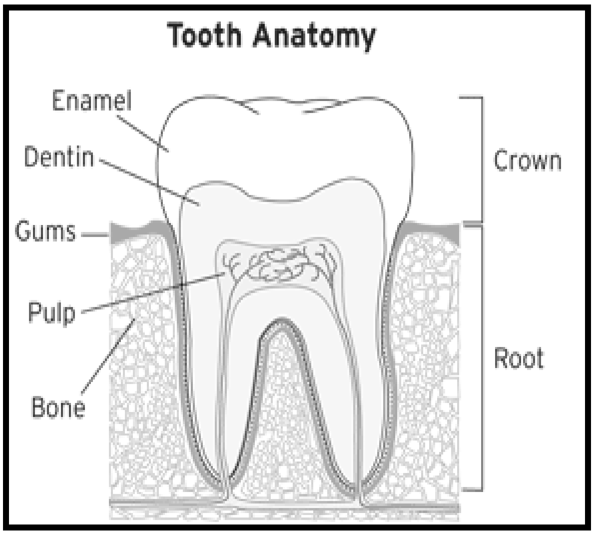
3.3.1 TEETH

Teeth begin developing in the fetus. Good nutrition from the mother during pregnancy is important in the development of the teeth. The mother's diet should have adequate amounts of calcium, phosphorus, vitamin C, and vitamin D.

Parts of the tooth

Each tooth has four main parts, including the following:

- **Enamel.** The outer layer of the tooth and the hardest material in the body.
- **Dentin.** The inner layer and the main part of the tooth, and the largest dental tissue.
- **Pulp.** Soft tissue on the inside of the tooth that contains the nerve and the ability to produce dentin.
- **Root.** The part of the tooth that secures it into the jaw.



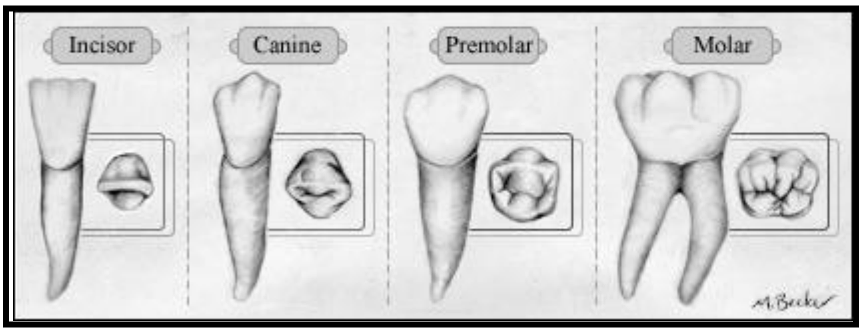
While every child is different, the primary teeth begin to come in between the ages of six and 12 months. Most of the primary teeth (baby teeth) will have erupted by 33 months. Girls tend to have their teeth come in before boys. There are a total of 20 primary teeth. Usually, about one tooth erupts per month once the teeth have started coming in. There is normally a space between all the baby teeth. This leaves room for the larger permanent teeth to erupt. Your child will begin losing his/her primary teeth (baby teeth) around the age of 6. The first teeth to be lost are usually the central incisors. This is then followed by the eruption of the first permanent molars. The last baby tooth is usually lost around the age of 12, and is the cuspid or second molar. There will be a total of 32 permanent, or adult, teeth.

Different Parts of a Tooth

- **Crown**— the top part of the tooth, and the only part you can normally see. The shape of the crown determines the tooth's function. For example, front teeth are sharp and chisel-shaped for cutting, while molars have flat surfaces for grinding.
- **Gum line**— where the tooth and the gums meet. Without proper brushing and flossing, plaque and tartar can build up at the gum line, leading to gingivitis and gum disease.
- **Root**— the part of the tooth that is embedded in bone. The root makes up about two-thirds of the tooth and holds the tooth in place.
- **Enamel**— the outermost layer of the tooth. Enamel is the hardest, most mineralized tissue in the body — yet it can be damaged by decay if teeth are not cared for properly.
- **Dentin**— the layer of the tooth under the enamel. If decay is able to progress its way through the enamel, it next attacks the dentin — where millions of tiny tubes lead directly to the dental pulp.
- **Pulp**— the soft tissue found in the center of all teeth, where the nerve tissue and blood vessels are. If tooth decay reaches the pulp, you usually feel pain.

What Are the Different Types of Teeth?

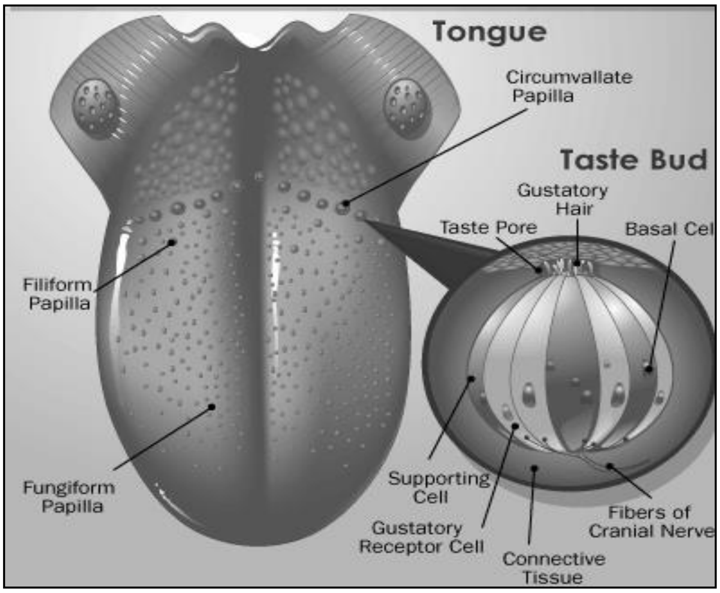
Every tooth has a specific job or function (use the dental arch in this section to locate and identify each type of tooth):



- **Incisors**— the sharp, chisel-shaped front teeth (four upper, four lower) used for cutting food.
- **Canines**— sometimes called cuspids, these teeth are shaped like points (cusps) and are used for tearing food.

- **Premolars**— these teeth have two pointed cusps on their biting surface and are sometimes referred to as bicuspids. The premolars are for crushing and tearing.
- **Molars**— used for grinding, these teeth have several cusps on the biting surface

3.3.2 TONGUE



While the tongue's muscles guide food between the teeth and shape it so that it is digestible, the peripheral sense organ is perhaps better known for its role in the perception of taste. The tongue not only detects **gustatory** (taste) sensations, but also helps sense the tactile, thermal and even painful stimuli that give food its flavor.

The tongue is a muscular organ. Mucous membrane covers the tongue's mass of muscles and fat. The double-layered membrane helps block microbes and pathogens from entering the digestive system and other body cavities that come into contact with the outside. The epithelial layer of the mucous membrane secretes mucus that helps moisten the mouth and food.

The tongue is attached by its base to the hyoid bone and by a fold of its mucous membrane covering called the ***frenulum.*** The superior surface of the tongue is covered by stratified squamous epithelium with little projections ***called papillae.***

Most people mistake the bumpy structures that cover the tongue's surface for **taste buds**. These are actually **papillae**: goblet-shaped elevations that sometimes contain taste buds and help create friction between the tongue and food. There are three types of papillae. These are:

a) ***Circumvallate papillae:*** These are the largest of the papillae, about 8 to 12 in number. These are arranged in a V-shape.

b) ***Fungiform papillae:*** These are. situated mainly at the tip and the edges of the tongue. They have a flat, rounded head like fungus. The fungiform papillae are rich in blood vessels and have a marked red color.

c) ***Filiform papillae:*** These are long and slender and are the smallest of the three types of papillae. They are found to be most numerous on the edges and anterior two thirds of the tongue.

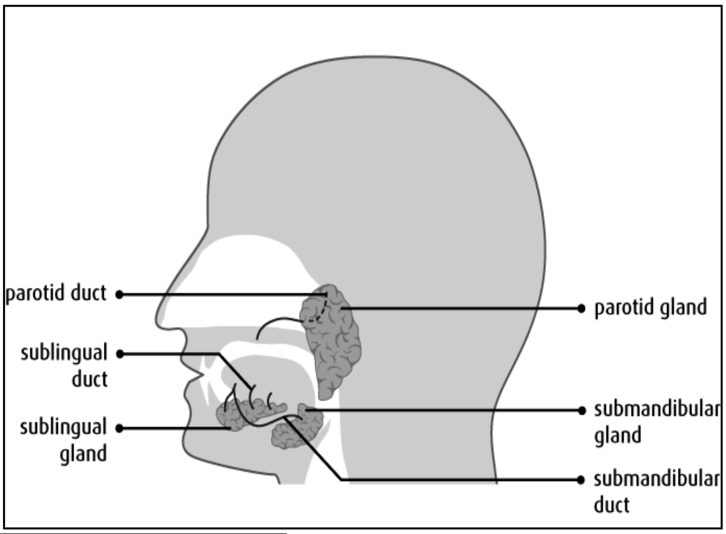
Taste buds are smaller structures, tucked away in the folds between papillae. Every taste bud is made up of basal and supporting cells that help maintain about 50 **gustatory receptor cells**. These specialized receptors are stimulated by the chemical makeup of solutions. They respond to several primary tastes: sweet, salty, bitter, sour, **umami** (savory) and fat, which some scientists claim might be a sixth taste. When a stimulus activates a gustatory cell, the receptor will synapse with neurons and send an electrical impulse to the gustatory region of the cerebral cortex. The brain interprets the sensation as taste.

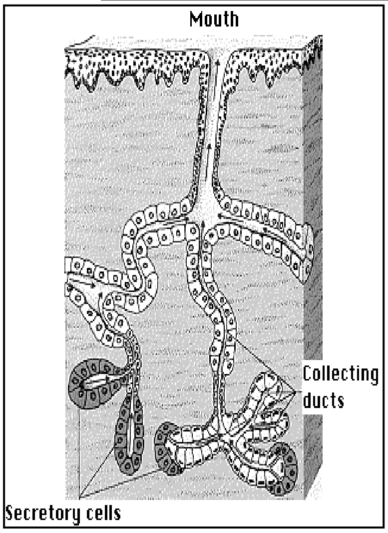
Each gustatory receptor cell has a long, spindle like protrusion called a **gustatory hair** that comes into contact with the outside environment. The hair extends from a small opening, or **taste pore**, and mingles with molecules of food introduced by saliva. The saliva solution contains digestive enzymes that help break down foods chemically.

Aside from the tongue's ability to detect gustatory stimuli, it also perceives temperature and the complex tactile sensations that food scientists call **mouth feel**. The tongue, along with the rest of the mouth, helps determine a food's texture, oiliness, chewiness, viscosity and density.

The tongue is an important organ. It accurately reflects the state of our digestive system. As a whole, the tongue has a high value as a diagnostic tool.

3.3.3 SALIVARY GLANDS





These produce the clear liquid that is released into the mouth (saliva, or spit). There are three pairs of major salivary glands and many minor glands. Saliva lubricates the mouth and starts the breakdown of chewed food. It is made up of water, enzymes, mucin and protein.

The parotid is the largest salivary gland and is situated below the ear. The saliva is released through an opening called the parotid duct which enters the mouth on the inside of the cheek next to the upper molar teeth. There is one on each side. It secretes saliva to facilitate mastication and swallowing and to begin the digestion of starches.

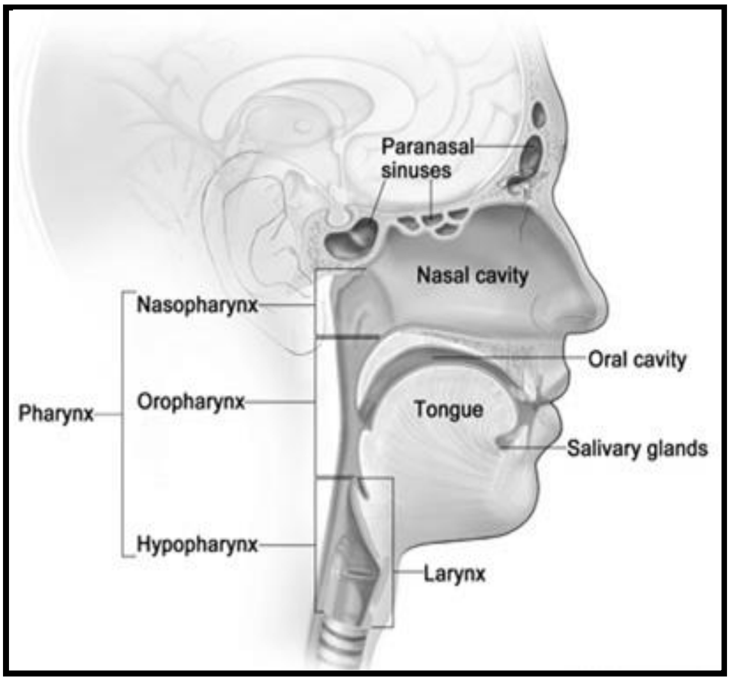
The submandibular salivary gland is situated under the mandible (lower jawbone) and releases saliva just underneath the front of the tongue, behind the front teeth. There is one on each side. The secretion produced is a mixture of both serous fluid and mucus, and enters the oral cavity via the submandibular duct .Approximately 70% of saliva in the oral cavity is produced by the submandibular glands, even though they are much smaller than the parotid glands.

The sublingual salivary glands are situated under the tongue and release saliva from many small openings (ducts) under the tongue. This pair of salivary glands sits next to each other under the tongue. Approximately 5% of saliva entering the oral cavity come from these glands. The secretion produced is mainly mucus in nature.

Minor salivary glands: There are 800-1000 minor salivary glands located throughout the oral cavity within the submucosa of the oral mucosa in the tissue of the buccal, labial, and lingual mucosa, the soft palate, the lateral parts of the hard palate, and the floor of the mouth or between muscle fibers of the tongue. They are 1-2mm in diameter. Their secretion is mainly mucous in nature (except for Von Ebner glands) and have many functions such as coating the oral cavity with saliva.

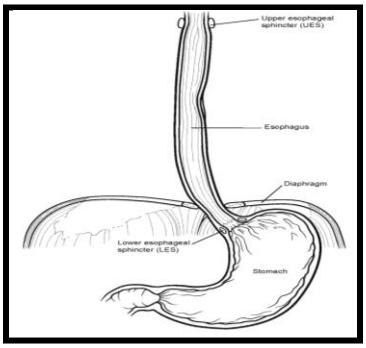
Von Ebner glands: Von Ebner glands are glands found in a trough circling the circumvallate papillae on the dorsal surface of the tongue near the sulcus terminalis. They secrete a purely serous fluid that begins lipid hydrolysis. They also facilitate the perception of taste through secretion of digestive enzymes and proteins.

3.4 The pharynx



The pharynx, or throat, is a funnel-shaped tube connected to the posterior end of the mouth. The pharynx is responsible for the passing of masses of chewed food from the mouth to the esophagus. The pharynx also plays an important role in the respiratory system, as air from the nasal cavity passes through the pharynx on its way to the larynx and eventually the lungs. Because the pharynx serves two different functions, it contains a flap of tissue known as the epiglottis that acts as a switch to route food to the esophagus and air to the larynx.

3.5 The esophagus



The esophagus (gullet) is one of the few organs traversing 3 regions of the body--namely, the neck, thorax, and abdomen. Accordingly, it is divided into 3 parts: cervical, thoracic, and abdominal. The esophagus is a 25-cm-long vertical muscular tube that which normally remains collapsed and that runs from the laryngopharynx (throat or hypopharynx) in the neck through the thorax (chest) to the stomach in the abdomen. The thoracic esophagus enters the abdomen via the esophageal hiatus in the diaphragm at the level of T10 and has a small (2-3 cm) intra-abdominal length. The esophagogastric junction (cardia), therefore, lies in the abdomen below the diaphragm to the left of the midline at the level of T11.

3.6 The stomach

The stomach is a muscular sac that is located on the left side of the abdominal cavity, just inferior to the diaphragm. In an average person, the stomach is about the size of their two fists placed next to each other. This major organ acts as a storage tank for food so that the body has time to digest large meals properly. The stomach also contains hydrochloric acid and digestive enzymes that continue the digestion of food that began in the mouth.

The wall of the stomach is lined with millions of **gastric glands**, which together secrete 400–800 ml of gastric juice at each meal. Several kinds of cells are found in the gastric glands

- parietal cells
- chief cells
- mucus-secreting cells
- hormone-secreting (endocrine) cells

Parietal cells

Parietal cells secrete hydrochloric acid and intrinsic factor.

Hydrochloric acid (HCl)

Parietal cells contain a H^+/K^+ ATPase. This transmembrane protein secretes H^+ ions (protons) by active transport, using the energy of ATP. The concentration of H^+ in the gastric juice can be as high as 0.15 M, giving gastric juice a pH somewhat less than 1. With a concentration of H^+ **within** these cells of only about 4×10^{-8}M, this example of active transport produces more than a million-fold increase in concentration. No wonder that these cells are stuffed with mitochondria and are extravagant consumers of energy.

Intrinsic factor

Intrinsic factor is a protein that binds ingested vitamin B_{12} and enables it to be absorbed by the intestine. A deficiency of intrinsic factor — as a result of an autoimmune attack against parietal cells — causes **pernicious anemia**.

Chief cells

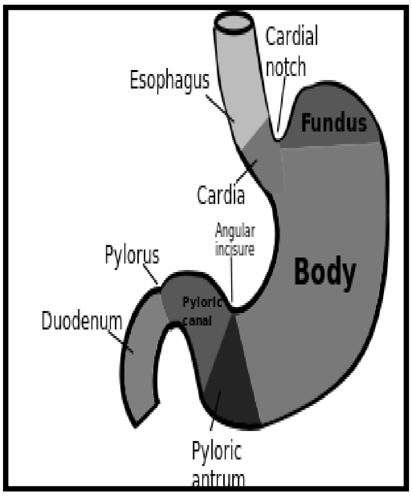
The chief cells synthesize and secrete **pepsinogen**, the precursor to the proteolytic enzyme **pepsin**.Pepsin breaks long polypeptide chains into shorter lengths.

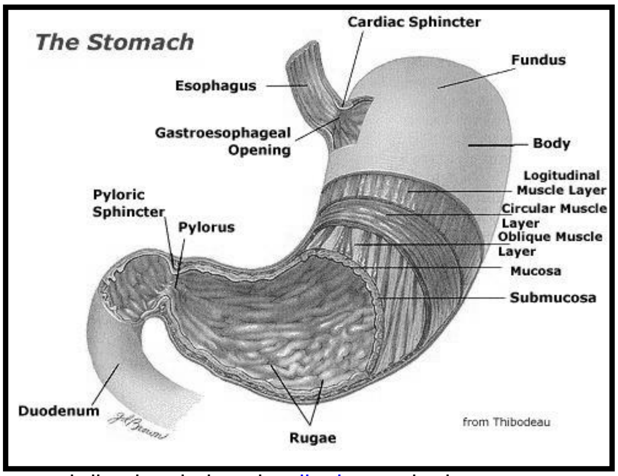
Secretion by the gastric glands is stimulated by the hormone gastrin. Gastrin is released by endocrine cells in the stomach in response to the arrival of food.

Absorption in the stomach

Very little occurs. However, some water, certain ions, and such drugs as aspirin and ethanol are absorbed from the stomach into the blood (accounting for the quick relief of a headache after swallowing aspirin and the rapid appearance of ethanol in the blood after drinking alcohol). Notably, these substances are also well-recognized causes of gastric irritation and their use (especially overuse) is commonly associated with development of gastritis and gastric ulcers.

3.6.1 STRUCTURE OF THE STOMACH





The stomach lies just below the diaphragm in the upper part of the abdominal cavity primarily to the left of the midline under a portion of the liver. The main divisions of the stomach are the following:

Cardia

The cardia is the portion of the stomach surrounding the cardioesophageal junction, or cardiac orifice (the opening of the esophagus into the stomach). Tumors of the cardioesophageal junction are usually coded to the stomach.

Fundus

The fundus is the enlarged portion to the left and above the cardiac orifice.

Body

The body, or corpus, is the central part of the stomach.

Pyloric antrum

The pyloric antrum is the lower or distal portion above the duodenum. The opening between the stomach and the small intestine is the pylorus, and the very powerfulsphincter, which regulates the passage of chyme into the duodenum, is called the pyloric sphincter.

The stomach is suspended from the abdominal wall by the lesser omentum. The greater omentum attaches the stomach to the transverse colon, spleen and diaphragm.

Layers of Stomach Wall

Layers of the stomach wall, among others, include serosa, muscularis, submucosa, mucosa. The three layers of smooth muscle consist of the outer longitudinal, the middle circular, and the inner oblique muscles. Construction of these muscles helps mix and break the contents into a suspension of nutrients called chyme and propels it into the duodenum.

3.6.2 FUNCTIONS OF THE STOMACH

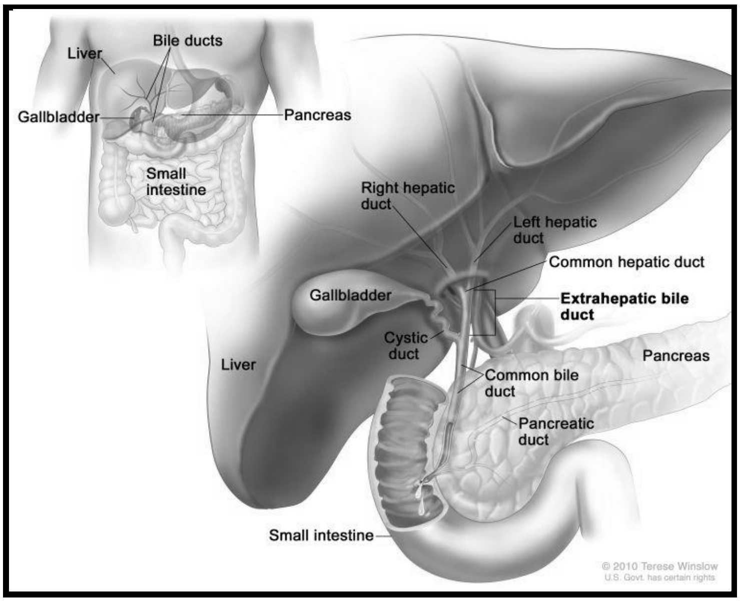
Bolus (masticated food) enters the stomach through the esophagus via the esophageal sphincter. The stomach releases proteases (protein-digesting enzymes such as pepsin) and hydrochloric acid, which kills or inhibits bacteria and provides the acidic pH of two for the proteases to work. Food is churned by the stomach through muscular contractions of the wall called peristalsis – reducing the volume of the fundus, before looping around the fundus[3] and the body of stomach as the boluses are converted intochyme (partially digested food). Chyme slowly passes through the pyloric sphincter and into the duodenum of the small intestine, where the extraction of nutrients begins. Depending on the quantity and contents of the meal, the stomach will digest the food into chyme anywhere between forty minutes and a few hours. The average human stomach can comfortably hold about a liter of food.

3.6.3 GASTRIC SECRETIONS

The stomach is famous for its secretion of acid, but acid is only one of four major secretory products of the gastric epithelium, all of which are important either to the digestive process or to control of gastric function:

- **Mucus:** The most abundant epithelial cells are mucous cells, which cover the entire lumenal surface and extend down into the glands as "mucous neck cells". These cells secrete a bicarbonate-rich mucus that coats and lubricates the gastric surface, and serves an important role in protecting the epithelium from acid and other chemical insults.
- **Acid:** Hydrochloric acid is secreted from parietal cells into the lumen where it establishes an extremely acidic environment. This acid is important for activation of pepsinogen and inactivation of ingested microorganisms such as bacteria.
- **Proteases:** Pepsinogen, an inactive zymogen, is secreted into gastric juice from both mucous cells and chief cells. Once secreted, pepsinogen is activated by stomach acid into the active protease pepsin, which is largely responsible for the stomach's ability to initiate digestion of proteins. In young animals, chief cells also secrete chymosin (rennin), a protease that coagulates milk protein allowing it to be retained more than briefly in the stomach.
- **Hormones:** The principle hormone secreted from the gastric epithelium is **gastrin**, a peptide that is important in control of acid secretion and gastric motility.
- A number of other enzymes are secreted by gastric epithelial cells, including a lipase and gelatinase. One secretory product of considerable importance in man is intrinsic factor, a glycoprotein secreted by parietal cells that is necessary for intestinal absorption of vitamin B12.

3.8 THE LIVER AND GALL BLADDER



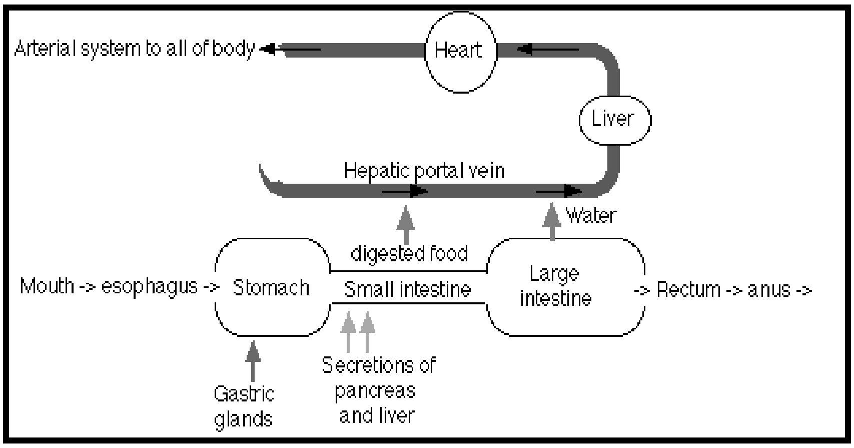
The liver is a roughly triangular accessory organ of the digestive system located to the right of the stomach, just inferior to the diaphragm and superior to the small intestine. The liver weighs about 3 pounds and is the second largest organ in the body. The liver has many different functions in the body, but the main function of the liver in digestion is the production of bile and its secretion into the small intestine. The gallbladder is a small, pear-shaped organ located just posterior to the liver. The gallbladder is used to store and recycle excess bile from the small intestine so that it can be reused for the digestion of subsequent meals.

The liver secretes **bile**. Between meals it accumulates in the gall bladder. When food, especially when it contains fat, enters the duodenum, the release of the hormonecholecystokinin (CCK) stimulates the gall bladder to contract and discharge its bile into the duodenum.

Bile contains:

- **bile acids**. These amphiphilic steroids emulsify ingested fat. The hydrophobic portion of the steroid dissolves in the fat while the negatively-charged side chain interacts with water molecules. The mutual repulsion of these negatively-charged droplets keeps them from coalescing. Thus large globules of fat (liquid at body temperature) are emulsified into tiny droplets (about 1 µm in diameter) that can be more easily digested and absorbed.
- **bile pigments**. These are the products of the breakdown of hemoglobin removed by the liver from old red blood cells. The brownish color of the bile pigments imparts the characteristic brown color of the feces.

The Hepatic Portal System



The capillary beds of most tissues drain into veins that lead directly back to the heart. But blood draining the intestines is an exception. The veins draining the intestine lead to a second set of capillary beds in the liver. Here the liver removes many of the materials that were absorbed by the intestine:

- Glucose is removed and converted into glycogen.
- Other monosaccharides are removed and converted into glucose.

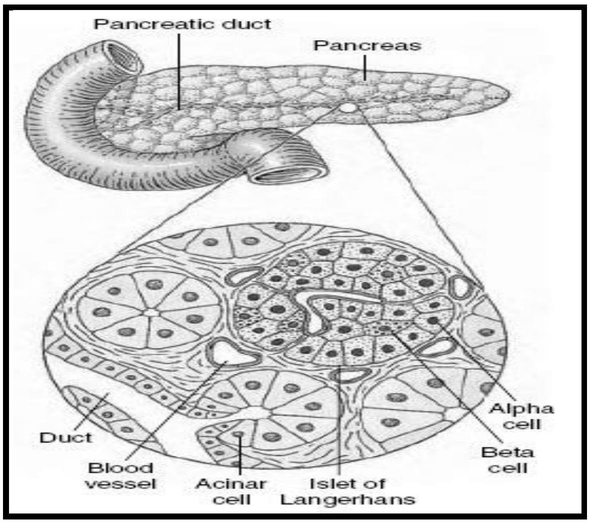
- Excess amino acids are removed and deaminated.
  - The amino group is converted into urea.
  - The residue can then enter the pathways of cellular respiration and be oxidized for energy.
- Many nonnutritive molecules, such as ingested drugs, are removed by the liver and, often, detoxified.

The liver serves as a gatekeeper between the intestines and the general circulation. It screens blood reaching it in the hepatic portal system so that its composition when it leaves will be close to normal for the body.

Furthermore, this homeostatic mechanism works both ways. When, for example, the concentration of glucose in the blood drops between meals, the liver releases more to the blood by

- converting its glycogen stores to glucose (glycogenolysis)
- converting certain amino acids into glucose (gluconeogenesis).

3.7 THE PANCREAS



The pancreas is a large gland located just inferior and posterior to the stomach. It is about 6 inches long and shaped like short, lumpy snake with its "head" connected to the duodenum and its "tail" pointing to the left wall of the abdominal cavity. The pancreas secretes digestive enzymes into the small intestine to complete the chemical digestion of foods.

The pancreas consists of clusters of endocrine cells (the islets of Langerhans) and exocrine cells whose secretions drain into the duodenum.

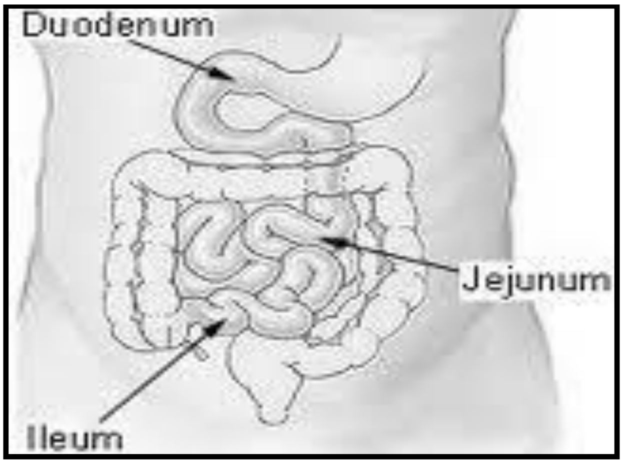
Pancreatic fluid contains:

- **sodium bicarbonate** ($NaHCO_3$). This neutralizes the acidity of the fluid arriving from the stomach raising its pH to about 8.
- **pancreatic amylase**. This enzyme hydrolyzes starch into a mixture of maltose and glucose.
- **pancreatic lipase**. The enzyme hydrolyzes ingested fats into a mixture of fatty acids and monoglycerides. Its action is enhanced by the detergent effect of bile.
- **4 "zymogens"** — proteins that are precursors to active proteases. These are immediately converted into the active proteolytic enzymes:
    - **trypsin.** Trypsin cleaves peptide bonds on the C-terminal side of arginines and lysines.
    - **chymotrypsin.** Chymotrypsin cuts on the C-terminal side of tyrosine, phenylalanine, and tryptophan residues (the same bonds as pepsin, whose action ceases when the $NaHCO_3$ raises the pH of the intestinal contents).
    - **elastase.** Elastase cuts peptide bonds next to small, uncharged side chains such as those of alanine and serine.
    - **carboxypeptidase.** This enzyme removes, one by one, the amino acids at the C-terminal of peptides.
- **nucleases**. These hydrolyze ingested nucleic acids (RNA and DNA) into their component nucleotides.

The secretion of pancreatic fluid is controlled by two hormones:

- secretin**,** which mainly affects the release of sodium bicarbonate, and
- cholecystokinin (**CCK**), which stimulates the release of the digestive enzymes.

3.9 THE SMALL INTESTINE



The [small intestine](#) is a long, thin tube about 1 inch in diameter and about 10 feet long that is part of the [lower gastrointestinal tract](#). It is located just inferior to the stomach and takes up most of the space in the abdominal cavity.

The entire small intestine is coiled like a hose and the inside surface is full of many ridges and folds. These folds are used to maximize the digestion of food and absorption of nutrients. By the time food leaves the small intestine, around 90% of all nutrients have been extracted from the food that entered it.

As the contents of the stomach become thoroughly liquefied, they pass into the **duodenum**, the first segment (about 10 inches [25 cm] long) of the small intestine. Most of our ingested vitamins and minerals are absorbed here.

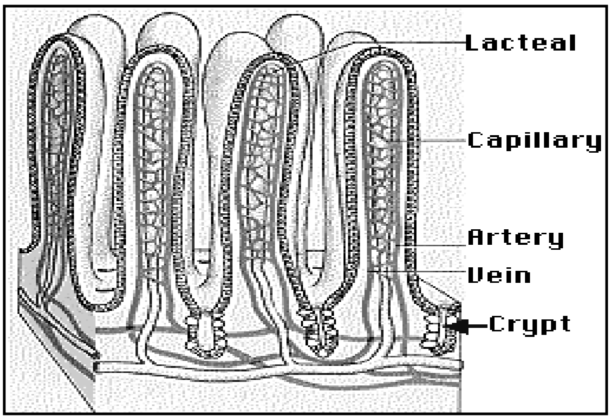
Two ducts enter the duodenum:

- one draining the gall bladder and hence the **liver**
- the other draining the exocrine portion of the **pancreas**.

The duodenum has 4 parts: superior, descending, horizontal, and ascending.

Digestion within the small intestine produces a mixture of [disaccharides](#), peptides, fatty acids, and monoglycerides. The final digestion and absorption of these substances occurs in the villi, which line the inner surface of the small intestine.

This scanning electron micrograph shows the villi carpeting the inner surface of the small intestine.



The crypts at the base of the villi contain [stem cells](#) that continuously divide by mitosis producing

- more stem cells
- Paneth cells, which secrete antimicrobial peptides that sterilize the contents of the small intestine and,
- cells that migrate up the surface of the villus while differentiating into
    1. [columnar epithelial cells](#) (the majority). They are responsible for digestion and absorption.
    2. **goblet cells**, which secrete mucus;
    3. **endocrine cells,** which secrete a variety of hormones;

The continuous production of new epithelial cells replace older cells that after about 5 days die by [apoptosis](#).

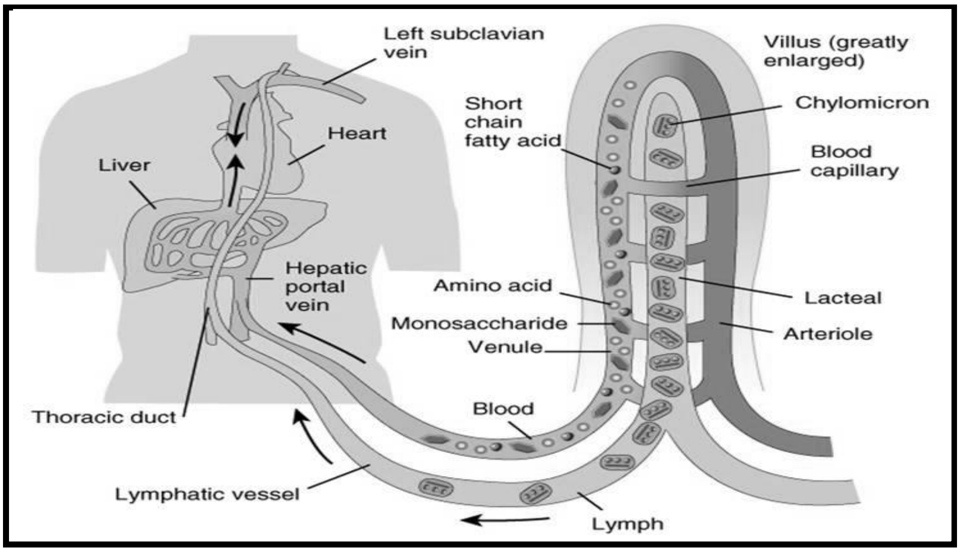
The villi increase the surface area of the small intestine to many times what it would be if it were simply a tube with smooth walls. In addition, the apical (exposed) surface of the epithelial cells of each villus is covered with microvilli (also known as a "brush border"). Because of these, the total surface area of the intestine is almost 200 square meters, about the size of the singles area of a tennis court and some 100 times the surface area of the exterior of the body.

Incorporated in the plasma membrane of the microvilli are a number of enzymes that complete digestion:

- **aminopeptidases** attack the amino terminal (N-terminal) of peptides producing amino acids.
- **disaccharidases** These enzymes convert disaccharides into their monosaccharide subunits.
    - **maltase** hydrolyzes maltose into glucose.
    - **sucrase** hydrolyzes sucrose (common table sugar) into glucose and fructose.
    - **lactase** hydrolyzes lactose (milk sugar) into glucose and galactose.

Fructose simply diffuses into the villi, but both glucose and galactose are absorbed by active transport.

- fatty acids **and** monoglycerides. These become resynthesized into fats as they enter the cells of the villus. The resulting small droplets of fat are then discharged by exocytosis into the lymph vessels, called lacteals, draining the villi.



Absorption in different parts of the small intestine:

The average total length of the normal small bowel in adults is about 7 meters/22 feet. The small intestine has 3 segments:

- the duodenum,
- the jejunum, and
- the ileum.

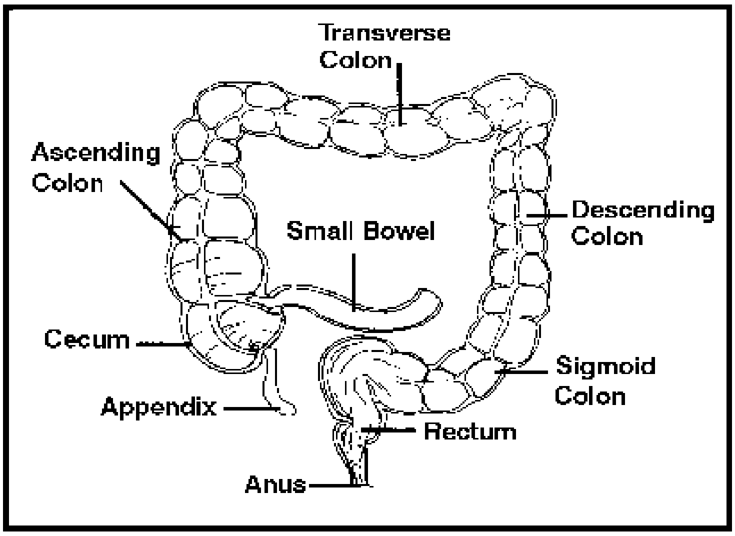
Each part or section performs an important role in nutrient absorption.

Duodenum – The chyme first enters into the duodenum where it is exposed to secretions that aid digestion. The secretions include bile salts, enzymes, and bicarbonate. The bile salts from the liver help digest fats and fat soluble vitamins (Vitamin A, D, E, and K). Pancreatic enzymes help digest carbohydrates and fats. Bicarbonate from the pancreas neutralizes the acid from the stomach.

Jejunum – The chyme is then further transited down into the second or middle part of the small intestine, the jejunum. Mainly in the first half of the jejunum, the majority (about 90%) of nutrient absorption occurs involving proteins, carbohydrates, vitamins, and minerals.

Ileum – The ileum is the last section of the small intestine and leads to the large intestine or colon. The ileum mainly absorbs water, bile salts, and vitamin B12.

3.10 THE LARGE INTESTINE



The large intestine is a long, thick tube about 2 ½ inches in diameter and about 5 feet long. It is located just inferior to the stomach and wraps around the superior and lateral border of the small intestine. It receives the liquid residue after digestion and absorption are complete. This residue consists mostly of water as well as any materials that were not digested.

The primary function of the large intestine or colon is to absorb fluids and electrolytes, particularly sodium and potassium, and to convert remaining luminal contents into more solid stool. The colon absorbs on average 1-1.5 liters (about 1-1.5 quarts) of fluid every day and has a capacity to adapt its fluid absorption to as much as 5 liters/quarts per day if needed. Another function of the colon is to break down (ferment) dietary fiber to produce short chain fatty acids – substances that can be absorbed and provide added nutrition.

The large intestine absorbs water and contains many symbiotic bacteria that aid in the breaking down of wastes to extract some small amounts of nutrients. Feces in the large intestine exit the body through the anal canal.

The colon contains an enormous (~10^{14}) population of microorganisms. (Our bodies consist of only ~10^{13} cells!). Most of the species live there perfectly harmlessly; that is, they are commensals. Some are actually beneficial, e.g.,

- by synthesizing vitamins and
- by digesting polysaccharides for which we have no enzymes (providing an estimated 10% of the calories we acquire from our food).

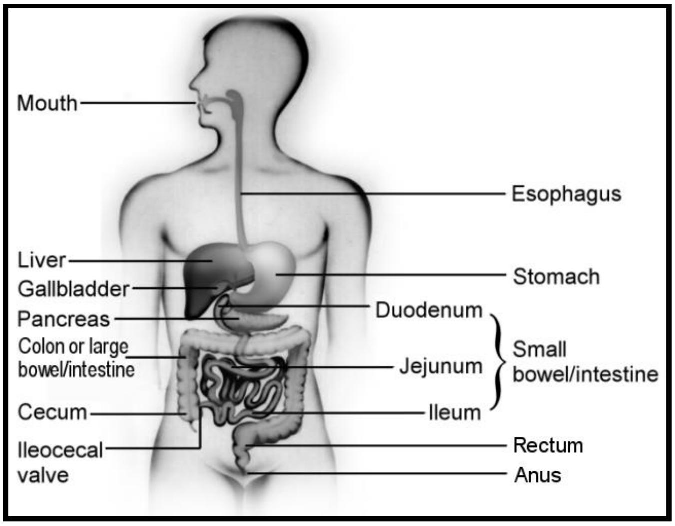
Bacteria flourish to such an extent that as much as 50% of the dry weight of the feces may consist of bacterial cells.

Reabsorption of water is the chief function of the large intestine. The large amounts of water secreted into the stomach and small intestine by the various digestive glands must be reclaimed to avoid dehydration.

If the large intestine becomes irritated, it may discharge its contents before water reabsorption is complete causing diarrhea. On the other hand, if the colon retains its contents too long, the fecal matter becomes driedout and compressed into hard masses causing constipation.

3.11THE MOVEMENTS OF THE GASTROINTESTINAL TRACT

Gut motility is the term given to the stretching and contractions of the muscles in the GI tract. The synchronized contraction of these muscles is called peristalsis. These movements enable food to progress along the digestive tract while, at the same time, ensuring the absorption of the important nutrients. The types of contraction in the gut differ depending on the region and the type of food which has been eaten. Some contractions cause onward movement of the food, others cause mixing and grinding. The passage of food through the gut, its conversion to chyme, and finally feces is all under involuntary control. Only the first part - ingestion and swallowing, and the last part - defecation are under voluntary control.

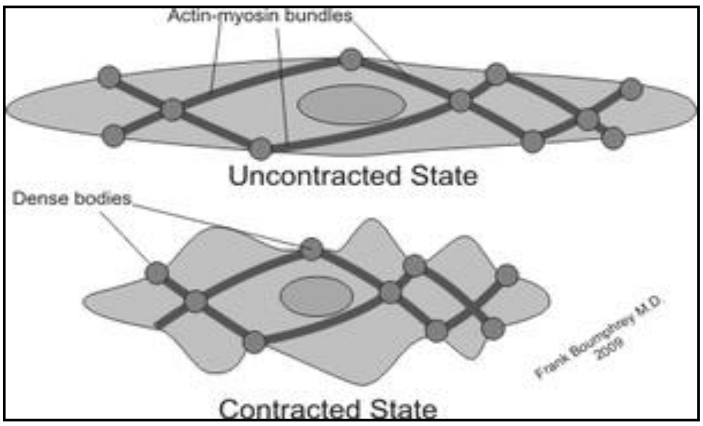


Smooth, also called involuntary or un-striated muscle is usually found in the walls of hollow organs, and have many unique characteristics. Contraction of these cells is dependent on the influx of Ca++ ions. Three types of contraction are seen in the gut. They are:

- Tonic sustained contractions(sphincters)
- Peristaltic contractions and
- Segmental contractions

Food and chyme move through the bowel due to a combination of these contractions.

Smooth or un-striated muscle cells contract by altering their shape. They contain numerous actin-myosin bundles. Some of the actin Strands attach to the cell, they are all anchored to dense bodies in the cytoplasm of the cell. On activation the actin strands slide over the myosin causing shortening of the actin-myosin bundle:

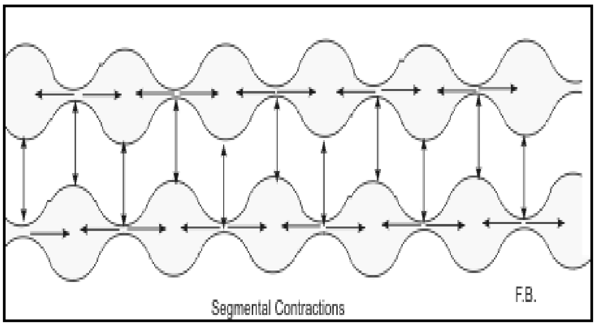


Muscle cells in the intestine communicate with each other through gap junctions, causing a series of function syncitial units. Thus an action potential in one cell will spread to other cells in the unit. The strength of contraction depends on the number of action potential triggered. Action Potentials cause an influx of Ca++ ions which release more Ca++ from the sarcoplasmic reticulum (The **sarcoplasmic reticulum** is a specialized SER that is involved in the storage of intracellular calcium and regulates the calcium ion concentration in the cytoplasm of striated muscle cells) Because the supply of Calcium in the sarcoplasmic reticulum is limited it must be replaced by Calium ions from outside the cell.

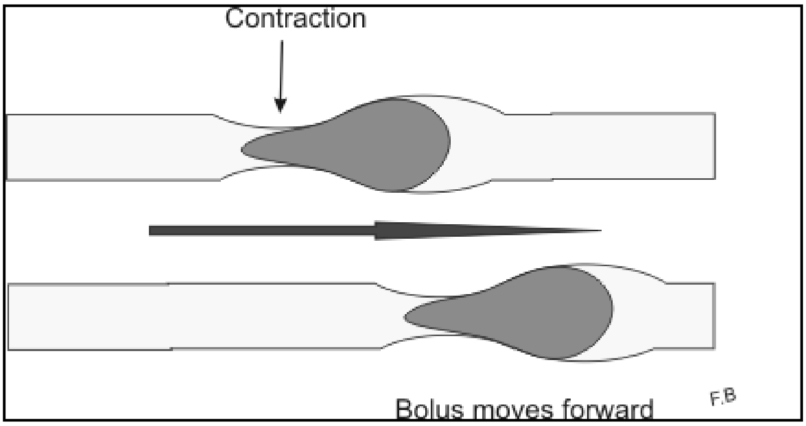
Sphincter contraction and relaxation: One characteristic of smooth muscle cells is their ability to maintained **tonic sustained contractions which means m**uscle that has this is said to maintain **tone**. This allows sphincters to maintain their tonicity, and to open by 'relaxing' their tone. As an example of the tone in the gut, the length of the small intestine is about 24 ft. in death, but is only half this length in life due to the tone in the longitudinal muscle bundles.

Peristalsis & Segmental Contractions

Food or chime is mixed and moved due to segmental contractions The circular muscles in adjacent segments of the intestine undergo alternate contraction and relaxation. The effect of this is not to move food along the lumen, but to churn it and mix it, especially with the digestive juices. Segmental contractions also bring the chyme into contact with the epithelial cells for absorption.



Peristaltic contractions move food and chyme down the lumen of the bowel. Circular muscles contract behind a bolus of food, the muscles in front of the bolus relax and this wave of contraction proceeds down the bowel propelling the bolus of food forward.



The passage of food through the gut, its conversion to chyme, and finally feces is all under involuntary control. Only the first part - ingestion and swallowing, and the last part - defecation are under voluntary control.

Chewing is extremely important part of the digestive process especially for fruits and vegetables as these have indigestible cellulose coats which must be physically broken down. Also digestive enzymes only work on the surfaces of food particles, so the smaller the particle, the more efficient the digestive process.

Swallowing

Swallowing is coordinated by the swallowing or deglutition center loated in the upper medullar and lower pons. Impulses are carried by the Trigeminal, Glossopharangeal, and Vagus nerves.

Esophagus

Food is carried down the esaphagus by peristaltic contractions. These are intiated by both the myenteric plexus and centrally.The muscle at the lower end of the esophagus thickens and is called the lower esophageal sphincter. This is usually tonically contracted, but relaxes when the peristaltic wave reaches it, allowing passage of food into the stomach.

Stomach

Food entering the stomach passes into the fundus of the stomach where it is stored. Weak peristaltic waves, known as mixing waves originate in the upper stomach and pass down to the antrum. These waves become stronger as they approach the antrum, and as they push the food against a closed pylorus they also act as mixing waves. Food in the antrum of the stomach is also thoroughly mixed with segmental contractions. The mixed fluid contents are called chyme, and small amounts of this are pushed through the pylorus into the duodenum with the stronger peristaltic contractions.

Control of Stomach Emptying

The rate of emptying of the stomach is controlled by various factors originating in the duodenum and stomach, of which the duodenal factors are the most important.

Gastric factors include increased volume of food in the stomach and stretching of the stomach wall. The hormone **Gastrin** also appears to promote stomach emptying.

Duodenal factors serve mainly to inhibit entering, thereby ensuring that the small intestine is not overwhelmed by a sudden influx of acidic chyme. They include **nervous reflexes** and **hormones**. The **nerve reflexes** are transmitted both by the enteric nervous system and through extrinsic nerves via the pre-vertebral sympathetic ganglia.

Factors that inhibit emptying include:

- Distension of the duodenum
- The degree of acidity of the duodenal chyme
- The osmolarity of the chyme
- Irritation of the duodenum

The reflexes are particularly sensitive to acidity and irritation which case rapid inhibition of stomach entering.

Hormones that inhibit emptying include **cholecystokinin**, **secretin**, and **Gastric Inhibitory Peptide (GIP)**. Secretin is secreted in response to acidity in the duodenum, Cholecystokinin and GIP in response to the presence of fats in the chyme.

All these factors ensure that the rate of stomach emptying is limited to what the small intestine can process.

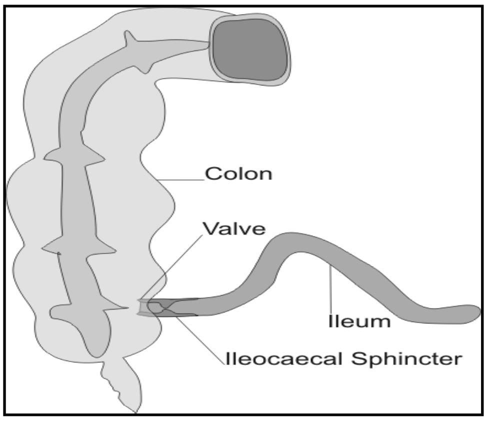
Small bowel

In the small intestine mixing with segmental contractions continues and the food is slowly passed through the intestine, finally passing through the ileocaecal sphincter to the large intestine. to a large extent the separation of segmental contractions from peristaltic contractions is artifical as both serve to move chyme forward, and both add to mixing. Chyme moves down the small intestine at the rate of about 1cm/min, so will reach the ileocaecal junction in 3-5 hours. It often stays there til the next meal the **gastroileal reflex** intensifies peristalsis in the distal ileum forcing chyme through the ileocaecal valve.

Intensity of peristalsis is controled by both neuronal reflexes and hormones. Neuronal factors include distension of the intestine wall, but also distension of the stomach will also cause increased small intestine peristalsis. Both of these reflexes are mediated by the myenteric plexus.

Hormonal factors *increasing* peristalsis include gastrin, CCK, insulin, motulin and seretonin. Glucagon and secretin *inhibit* peristalsis.

The *ileocecal valve* is a one way valve located between the ileum and the *cecum*, which is the first portion of the colon. This valve helps control the passage of contents into the colon and increases the contact time of nutrients and electrolytes (essential minerals) with the small intestine. It also prevents back-flow (reflux) from the colon up into the ileum, and minimizes the movement of bacteria from the large intestine up into the small bowel.



Large Intestine (Colon)

The principal function of the large intestine is to remove water and electrolytes from the chyme, and to store the resultant faeces until it can be eliminated.

In the colon the longitudinal muscle coat is condensed into three narrow bands called the **taenia coli.**

Thus mixing movements of the circular muscle coat called **haustrations** predominate in the large intestine. These also move the contents towards the rectum.

Much of the forward movement comes from these 'haustrations, but there is a third type of contraction called the **mass movement** which sends substantial amounts of material forward. These typically occur 2-3 times a day, usually after a meal called **gastrocolic reflex**, and last for about 20 minutes. They are responsible for the final formation of the faeces and the filling of the rectum.

Filling of the rectum is a signal for the relaxation of the Internal anal sphincter. However the external anal sphincter is under voluntary control.

All these actions are coordinated, and are under control of hormones, and the autonomic nervous system as well as the enteric nervous system, The result is that food products and chyme are moved forward at the optimal rate to allow for efficient digestion and absorption.

Rectum

The rectum (Latin for "straight") is an 8-inch chamber that connects the colon to the anus. It is the rectum's job to receive stool from the colon and to hold the stool until evacuation happens. When anything (gas or stool) comes into the rectum, sensors send a message to the brain. The brain then decides if the rectal contents can be released or not. If they can, the sphincters (muscles) relax and the rectum contracts, expelling its contents. If the contents cannot be expelled, the sphincters contract and the rectum accommodates, so that the sensation temporarily goes away.

Anus

The anus is the last part of the digestive tract. It consists of the pelvic floor muscles and the two anal sphincters (internal and external muscles). The lining of the upper anus is specialized to detect rectal contents. It lets us know whether the contents are liquid, gas, or solid. The pelvic floor muscle creates an angle between the rectum and the anus that stops stool from coming out when it is not supposed to. The anal sphincters provide fine control of stool. The internal sphincter keeps us from going to the bathroom when we are asleep, or otherwise unaware of the presence of stool. When we get an urge to go to the bathroom, we rely on our external sphincter to keep the stool in until we can get to the toilet.

3.12GASTROINTESTINAL HORMONES

The major hormones that control the functions of the digestive system are produced and released by cells in the mucosa of the stomach and small intestine. These hormones are released into the blood of the digestive tract, travel back to the heart and through the arteries, and return to the digestive system where they stimulate digestive juices and cause organ movement.

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

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

Additional hormones in the digestive system regulate appetite:

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

Both of these hormones work on the brain to help regulate the intake of food for energy. Researchers are studying other hormones that may play a part in inhibiting appetite, including glucagon-like peptide-1 (GPL-1), oxyntomodulin (+), and pancreatic polypeptide.

Nerve Regulators

Two types of nerves help control the action of the digestive system.

Extrinsic, or outside, nerves come to the digestive organs from the brain or the spinal cord. They release two chemicals, acetylcholine and adrenaline. Acetylcholine causes the muscle layer of the digestive organs to squeeze with more force and increase the “push” of food and juice through the digestive tract. It also causes the stomach and pancreas to produce more digestive juice. Adrenaline has the opposite effect. It relaxes the muscle of the stomach and intestine and decreases the flow of blood to these organs, slowing or stopping digestion.

The intrinsic, or inside, nerves make up a very dense network embedded in the walls of the esophagus, stomach, small intestine, and colon. The intrinsic nerves are triggered to act when the walls of the hollow organs are stretched by food. They release many different substances that speed up or delay the movement of food and the production of juices by the digestive organs.

Together, nerves, hormones, the blood, and the organs of the digestive system conduct the complex tasks of digesting and absorbing nutrients from the foods and liquids, we consume each day.

3.13ABSORPTION AND UTILIZATION OF NUTRIENTS

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

Carbohydrates. Carbohydrates supply 45 to 65 % of the daily calories required by us.. Foods rich in carbohydrates include bread, potatoes, dried peas and beans, rice, pasta, fruits, and vegetables. Many of these foods contain both starch and fiber.

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

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

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

Protein. Foods such as meat, eggs, and beans consist of giant molecules of protein that must be digested by enzymes before they can be used to build and repair body tissues. An enzyme in the juice of the stomach starts the digestion of swallowed protein. Then in the small intestine, several enzymes from the pancreatic juice and the lining of the intestine complete the breakdown of huge protein molecules into small molecules called amino acids. These small molecules can be absorbed through the small intestine into the blood and then be carried to all parts of the body to build the walls and other parts of cells.

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

Vitamins. Another vital part of food that is absorbed through the small intestine are vitamins. The two types of vitamins are classified by the fluid in which they can be dissolved: water-soluble vitamins (all the B vitamins and vitamin C) and fat-soluble vitamins (vitamins A, D, E, and K). Fat-soluble vitamins are stored in the liver and fatty tissue of the body, whereas water-soluble vitamins are not easily stored and excess amounts are flushed out in the urine.

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

3.14LET US SUM UP

Every morsel of food we eat has to be broken down into nutrients that can be absorbed by the body, which is why it takes hours to fully digest food. In humans, protein must be broken down into amino acids, starches into simple sugars, and fats into fatty acids and glycerol. The water in our food and drink is also absorbed into the bloodstream to provide the body with the fluid it needs.

The digestive system is made up of the **alimentary canal** and the other abdominal organs that play a part in digestion, such as the liver and pancreas. The alimentary canal (also called the **digestive tract**) is the long tube of organs — including the esophagus, the stomach, and the intestines — that runs from the mouth to the anus.

3.15 GLOSSARY

canine (also called cuspid) - a type of tooth with a single point (also called canine tooth) and a single root. Cuspid teeth are used to hold and tear food. Adults have 4 canine teeth (2 in the top jaw and 2 in the bottom jaw). Canine means, "of or like a dog."

cementum - a layer of tough, yellowish, bone-like tissue that covers the root of a tooth. It helps hold the tooth in the socket. The cementum contains the periodontal membrane.

crown - the visible part of a tooth.

dentin - the hard but porous tissue located under both the enamel and cementum of the tooth. Dentin is harder than bone.

enamel - the tough, shiny, white outer surface of the tooth.

gums - the soft tissue that surrounds the base of the teeth.

incisor - a type of tooth with a narrow edge (in humans, the front teeth). Incisors are used to cut food. An incisor has 1 root. Adult humans have 8 incisors (4 in the top jaw and 4 in the bottom jaw).

molar - a wide, flat tooth found in the back of mammal's mouths. Molars grind food during chewing. Molars in the top jaw have 3 roots; molars in the lower jaw have 2 roots. Adults have 12 molars (6 in the top jaw and 6 in the bottom jaw).

nerves - nerves transmit signals (conveying messages like hot, cold, or pain) to and from the brain.

periodontal membrane/ligament - the fleshy tissue between tooth and the tooth socket; it holds the tooth in place. The fibers of the periodontal membrane are embedded within the cementum.

premolar (also called bicuspid) - the type of tooth located between the canine and the molars in humans. A bicuspid tooth has 1 root. Bicuspids have two points (cusps) at the top. Adults have 8 premolars (4 in the top jaw and 4 in the bottom jaw).

pulp - the soft center of the tooth. The pulp contains blood vessels and nerves; it nourishes the dentin.

root - the anchor of a tooth that extends into the jawbone. The number of roots ranges from one to four.

Gastrointestinal tract:

abdomen - the part of the body that contains the digestive organs. In human beings, this is between the diaphragm and the pelvis

alimentary canal - the passage through which food passes, including the mouth, esophagus, stomach, intestines, and anus.

anus - the opening at the end of the digestive system from which feces (waste) exits the body. **appendix** - a small sac located on the cecum.

ascending colon - the part of the large intestine that run upwards; it is located after the cecum. **bile** - a digestive chemical that is produced in the liver, stored in the gall bladder, and secreted into the small intestine. **cecum** - the first part of the large intestine; the appendix is connected to the cecum. **chyme** - food in the stomach that is partly digested and mixed with stomach acids. Chyme goes on to the small intestine for further digestion.

descending colon - the part of the large intestine that run downwards after the transverse colon and before the sigmoid colon. **digestive system** - (also called the gastrointestinal tract or GI tract) the system of the body that processes food and gets rid of waste. **duodenum** - the first part of the small intestine; it is C-shaped and runs from the stomach to the jejunum.

epiglottis - the flap at the back of the tongue that keeps chewed food from going down the windpipe to the lungs. When you swallow, the epiglottis automatically closes. When you breathe, the epiglottis opens so that air can go in and out of the windpipe. **esophagus** - the long tube between the mouth and the stomach. It uses rhythmic muscle movements (called peristalsis) to force food from the throat into the stomach.

gall bladder - a small, sac-like organ located by the duodenum. It stores and releases bile (a digestive chemical which is produced in the liver) into the small intestine.

gastrointestinal tract - (also called the GI tract or digestive system) the system of the body that processes food and gets rid of waste.

ileum - the last part of the small intestine before the large intestine begins.

intestines - the part of the alimentary canal located between the stomach and the anus.

jejunum - the long, coiled mid-section of the small intestine; it is between the duodenum and the ileum.

liver - a large organ located above and in front of the stomach. It filters toxins from the blood, and makes bile (which breaks down fats) and some blood proteins.

mouth - the first part of the digestive system, where food enters the body. Chewing and salivary enzymes in the mouth are the beginning of the digestive process (breaking down the food).

pancreas - an enzyme-producing gland located below the stomach and above the intestines. Enzymes from the pancreas help in the digestion of carbohydrates, fats and proteins in the small intestine.

peristalsis - rhythmic muscle movements that force food in the esophagus from the throat into the stomach. Peristalsis is involuntary - you cannot control it. It is also what allows you to eat and drink while upside-down.

rectum - the lower part of the large intestine, where feces are stored before they are excreted.

salivary glands - glands located in the mouth that produce saliva. Saliva contains enzymes that break down carbohydrates (starch) into smaller molecules.

sigmoid colon - the part of the large intestine between the descending colon and the rectum.

stomach - a sack-like, muscular organ that is attached to the esophagus. Both chemical and mechanical digestion takes place in the stomach. When food enters the stomach, it is churned in a bath of acids and enzymes.

transverse colon - the part of the large intestine that runs horizontally across the abdomen.

3.16 Check your progress

1. What are the four accessory organs of digestion?
2. What are the three main functions of the digestive system?
3. What is a soft mass of chewed food ready to be swallowed called?
4. What is a wavelike contraction that occurs involuntarily in hollow tubes of the body, especially the alimentary canal called?
5. Write in short about the fate of food in the digestive canal.
6. Diagrammatically describe the tooth.
7. What are salivary glands? Describe them.
8. What is called the taste organ? Show diagrammatically.
9. What happens to food in the stomach?
10. What is the role of liver and pancreas in digestion?
11. What are the different types of gastrointestinal movements?

12. Describe the small intestine and its functions.
13. Describe the large intestine and its functions
14. What is the role of the large intestine in the digestive system?
15. What are sphincters? Where are they present and what are their functions?
16. What are the hormones involved in the process of digestion?

UNIT 5 THE URINARY SYSTEM

5.0 Objective

- discuss the mechanism of urine formation,
- explain the non-excretory functions of the kidneys, and
- describe the medical aspects related to the abnormal or non-functioning of the kidneys, such as dialysis and renal transplant.

5.1 Introduction

The body takes nutrients from food and converts them to energy. After the body has taken the food that it needs, waste products are left behind in the bowel and in the blood. The kidneys and urinary system keep chemicals, such as potassium and sodium, and water in balance and remove a type of waste, called urea, from the blood. Urea is produced when foods containing protein, such as meat, poultry, and certain vegetables, are broken down in the body. It is carried in the bloodstream to the kidneys, where it is removed. Other important functions of the kidneys include blood pressure regulation and the production of erythropoietin, which controls red blood cell production in the bone marrow.

5.2 The urinary system

The urinary system – also known as the renal system – produces, stores and eliminates urine, the fluid waste excreted by the kidneys. The urinary system includes two kidneys, two ureters, the bladder, two sphincter muscles and the urethra.

The urinary system works with the lungs, skin and intestines to maintain the balance of chemicals and water in the body. Adults eliminate about a quart and a half (1.42 liters) of urine each day, depending on the amount of fluid consumed and fluid lost through perspiring and breathing.

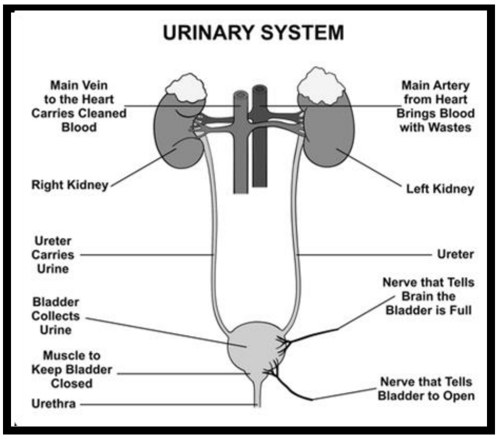
The principal function of the urinary system is to maintain the volume and composition of body fluids within normal limits. One aspect of this function is to rid the body of waste products that accumulate because of cellular metabolism and, because of this, it is sometimes referred to as the excretory system.

Although the urinary system has a major role in excretion, other organs contribute to the excretory function. The lungs in the respiratory system excrete some waste products, such as carbon dioxide and water. The skin is another excretory organ that rids the body of wastes through the sweat glands. The liver and intestines excrete bile pigments that result from the destruction of hemoglobin. The major task of excretion still belongs to the urinary system. If it fails, the other organs cannot take over and compensate adequately.

The urinary system maintains an appropriate fluid volume by regulating the amount of water that is excreted in the urine. Other aspects of its function include regulating the concentrations of various electrolytes in the body fluids and maintaining normal pH of the blood.

ORGANS OF THE URINARY SYSTEM:

The primary organs of the urinary system are the **kidneys**, which are bean-shaped organs that are located just below the rib cage in the middle of the back. The kidneys remove urea – waste product formed by the breakdown of proteins – from the blood through small filtering units called nephrons. From the kidneys, urine travels down two thin tubes, called **ureters**, to the bladder. The **bladder** is a hollow muscular organ shaped like a balloon. It sits in the pelvis and is held in place by ligaments attached to other organs and the pelvic bones. The bladder stores urine until you are ready to empty it. To prevent leakage, circular muscles called **sphincters** close tightly around the opening of the bladder into the **urethra**, the tube that allows urine to pass outside the body. Nerves in the bladder send signals when it needs to be emptied. The sensation to urinate becomes stronger as the bladder reaches its limit.



5.3 The kidneys

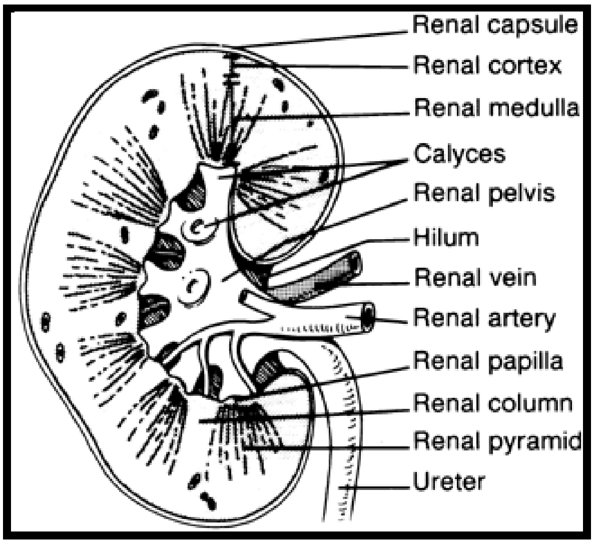
The kidneys are the primary organs of the urinary system. The kidneys are the organs that filter the blood, remove the wastes, and excrete the wastes in the urine. They are the organs that perform the functions of the urinary system. The other components are accessory structures to eliminate the urine from the body.

The paired kidneys are located between the twelfth thoracic and third lumbar vertebrae, one on each side of the vertebral column. The right kidney usually is slightly lower than the left because the liver displaces it downward. The kidneys are protected by the lower ribs. Each kidney is held in place by connective tissue, called renal fascia and is surrounded by a thick layer of adipose tissue, called perirenal fat, which helps to protect it. A tough fibrous, connective tissue renal capsule closely envelopes each kidney and provides support for the soft tissue that is inside.

5.3.1 Structure of kidneys and nephron

In the adult, each kidney is approximately 3 cm thick, 6 cm wide, and 12 cm long. It is roughly bean-shaped with an indentation, called the hilum, on the medial side. The hilum leads to a large cavity, called the renal sinus, within the kidney. The ureter and renal vein leave the kidney, and the renal artery enters the kidney at the hilum.

There are three major anatomical demarcations in the kidney: the cortex, the medulla, and the renal pelvis. The cortex receives most of the blood flow, and is mostly concerned with reabsorbing filtered material. The medulla is a highly metabolically active area, which serves to concentrate the urine. The pelvis collects urine for excretion.

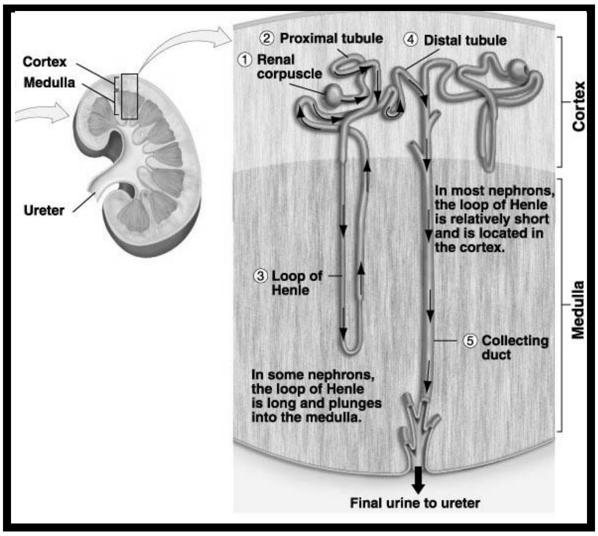


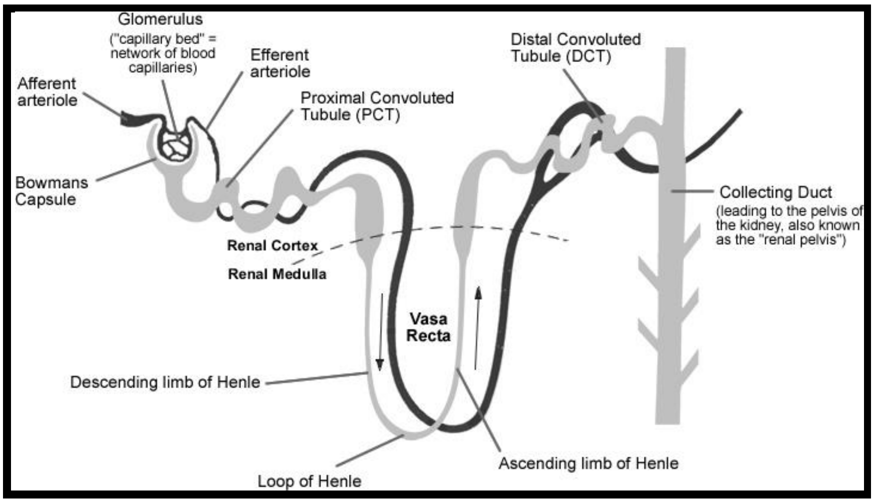
The Structure Of Nephron:

The functional unit of the kidney is the nephron. There are five parts of the nephron:

1. The glomerulus, which is the blood kidney interface, plasma is filtered from capillaries into the Bowman's capsule.
2. The proximal convoluted tubule, which reabsorbs most of the filtered load, including nutrients and electrolytes.
3. The loop of Henle, which, depending on it's length, concentrates urine by increasing the osmolality of surrounding tissue and filtrate.
4. The distal convoluted tubule, which reabsorbs water and sodium depending on needs,
5. The collecting system, which collects urine for excretion.

There are two types of nephrons, those localized to the cortex, and those extending into the medulla. The latter are characterized by long loops of Henle, and are more metabolically active.





5.3.2 Function of kidneys

The kidneys maintain the constancy of the body's internal environment by regulating the composition and volume (influences blood pressure) of the extracellular fluid. To accomplish this the kidneys perform the following:

1. Excretion of inorganic compounds (Na^+, K^+, Ca^{++}, Mg^{++}, H^+, HC_3^-, etc.)
2. Excretion of organic wastes (urea, uric acid, creatinine, bilirubin, etc.)
3. Excretion of foreign substances (drugs, pesticides, food additives, etc.)
4. Blood pressure regulation (release renin--major component of the renin-angiotensin-aldosterone mechanism)
5. Erythrocyte volume regulation (release of renal erythropoietic factor)
6. Vitamin D activation (converts this vitamin to its most biologically active form)

5.3.3 The working of the kidney

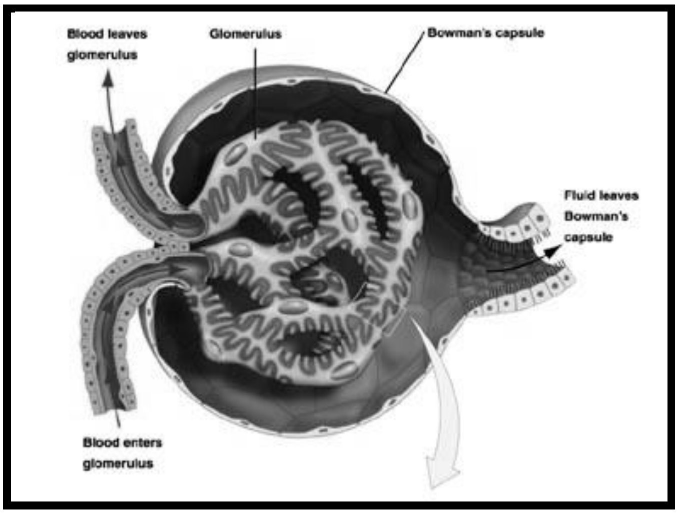
The kidney consists of an outer **cortex** and an inner **medulla**. It is composed of units called **nephrons**. Each nephron consists of a **glomerulus**, situated in the cortex of the kidney, and a long U-shaped tubule (the **loop of Henle**) that extends into the medulla of the kidney and connects to collecting tubules which eventually merge to join the ureter.

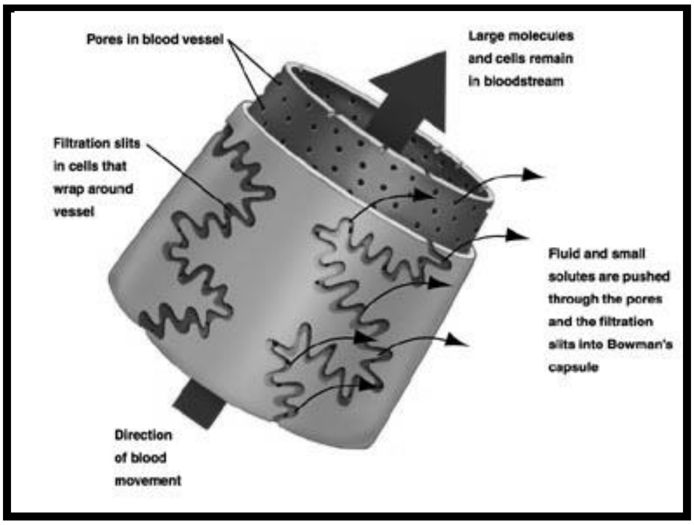
The kidney has an outer region called the cortex and an inner region called the medulla. As one progresses inward from the cortex to the inner medulla, the concentration of solutes increases from about 300 mosm/L to 1200 mosm/L.

Phase I - Filtration in Bowman's Capsule

The glomerulus consists of a cuplike structure, **Bowmans capsul**e, within which lies a cluster of capillaries, and a hairpin-shaped tubule that runs from Bowmans capsule into the medulla of the kidney and to collecting ducts in the medulla. The capillaries are extremely thin-walled, and significantly more permeable to plasma than ordinary capillaries. Moreover, the diameter of the arteriole as it leaves Bowmans capsule is less than its entering diameter. All of these factors combine to increase blood pressure and force large quantities of plasma out of the capillaries into the Bowmans capsule and down the tube of the nephron. Small solutes (especially salts and urea, but also other water soluble molecules) are also forced out of the bloodstream with the plasma. Larger proteins, and cells remain in the capillaries, creating a very hypertonic solution.

The general strategy here is this: the blood plasma is full of nutrients, proteins, ions, water, and other dissolved particles, some of which the body needs, some of which the body must remove. To remove the wastes, a large portion of the plasma is filtered from the blood and then the substances the body needs are put back into the blood. The substances that the body doesn't need are left behind and removed during urination.





Phase II - Reabsorption in the Proximal Tubule

The lumen wall of the epithelial cells of the proximal tubule is like the lumen wall of the small intestine - both are bordered with millions of microvilli to increase surface area. The role of these epithelial cells is to reabsorb ions, nutrients, and water and transport them to the blood vessels nearby.

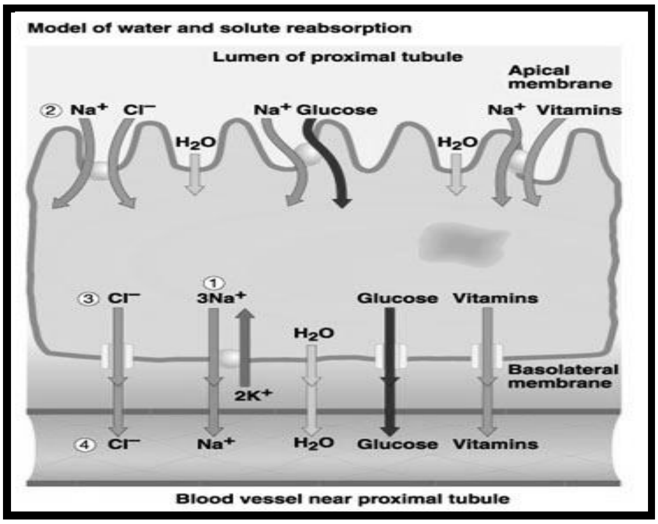
1. A Na+/K+ ATPase located on the basolateral membrane of the epithelial cell (the side of the cell opposite the lumen) actively pump Na+ out of the cell into the blood. This sets up a strong concentration gradient in the cell.

2. The gradient created by the Na+/K+ ATPase provides a potential to allow Na+ contransporters in the apical membrane to reabsorb nutrients and electrolytes. Water also flows in via osmosis.

3. Solutes exit the epithelial cells and enter the blood through channels.

4. Water flows from the epithelial cells into the blood via osmosis.

Note that because osmosis occurs, the osmolarity of the filtrate remains isotonic. The volume decreases .

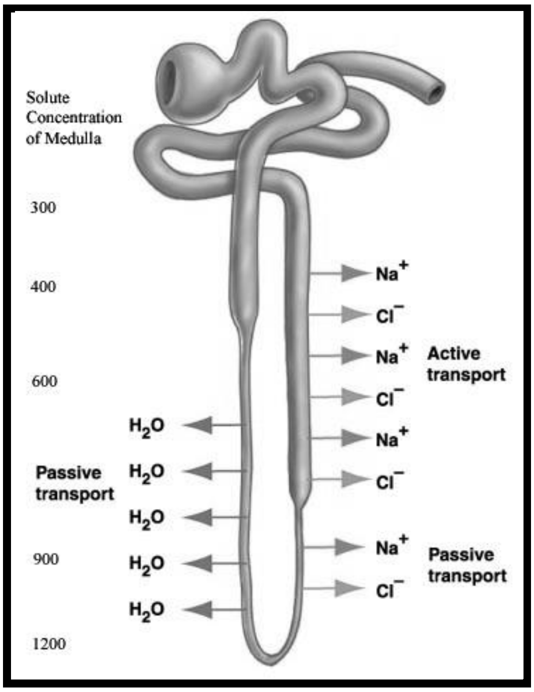


Phase III - Creation of an Osmotic Gradient in the Loop of Henle

The loop of Henle has three distinct regions, the thin-walled descending limb, the thin-walled lower portion of the ascending limb and the thick-walled upper portion of the ascending limb. The descending limb of the loop is highly permeable to water but almost completely impermeable to solutes. As the filtrate travels down the descending loop, water will flow from the loop into the surrounding medium via osmosis. When the filtrate reaches the hairpin turn, it is isotonic with the surroundig medium (about 1200 mosm/L)

The lower portion of the ascending branch of the loop of Henle, however, is highly permeable to Na+ and Cl-, moderately permeable to urea, and almost completely impermeable to water. As it travels up into the less-concentrated regions of the medulla, Na+ and Cl- will passively diffuse across the membrane. As the filtrate continues up the thick portion of the loop of Henle, Na+ and Cl- are actively pumped out of the filtrate into the surrounding medium. This requires energy, but helps to maintain the osmotic concentration gradient in the medulla.

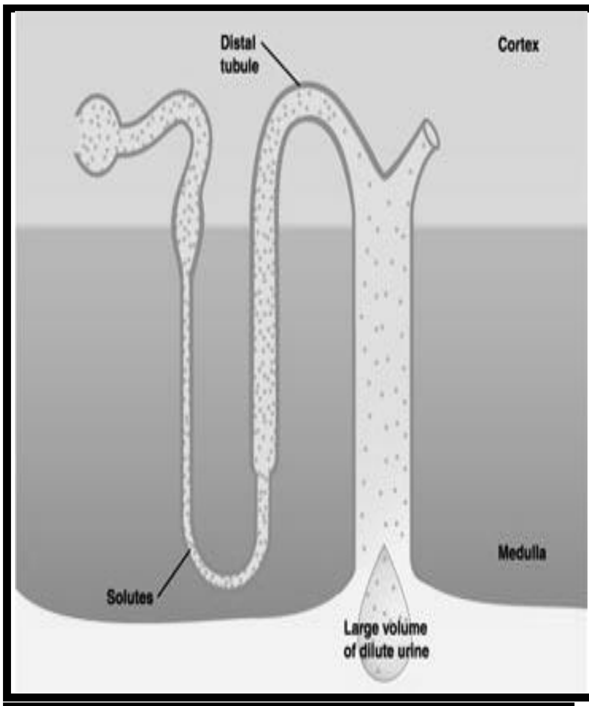
The water and solutes that flowed into the medulla can be reabsorbed by the vasa recta - a network of capillaries that surround the loop of Henle and reabsorb water and solutes filtered from the blood.

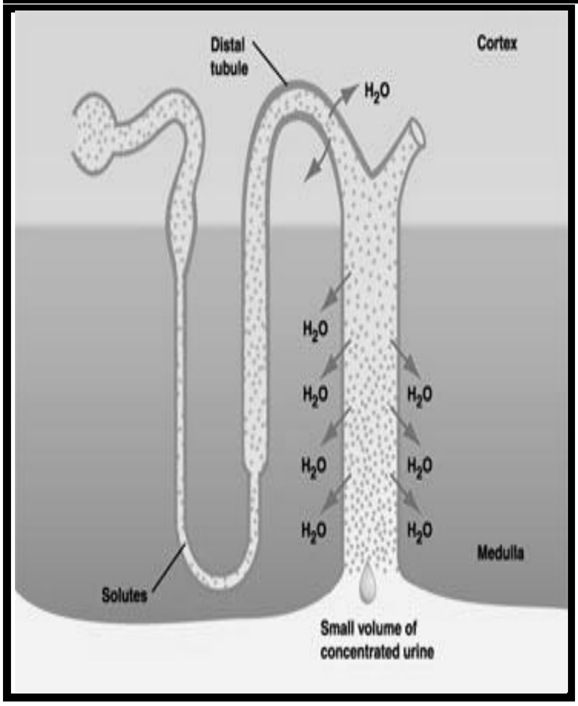


Phase IV - Regulating Water and Electrolyte Balance in the Distal Tubule and the Collecting Duct

The first three steps in urine formation, filtration, reabsorption, and establishment of an osmotic gradient, result in a fluid that is slightly hypotonic to blood. The major solutes still present in this fluid are urea and other wastes. Electrolytes and water are always absorbed by the distal tubule, the amount of Na+, Cl-, and water absorbed is variable. Regulation of these processes are under hormonal control.

If the Na+ levels in the blood are low, the hormone **aldosterone** is released. which leads to reabsorption of Na+ and Cl- in the distal tubule. Water will also flow into the tubule via osmosis. However, if a person is dehydrated, the hormone **ADH (antidiuretic hormone)** is released. This causes aquaporin channels to be inserted in the membrane of the collecting duct so that large quantities of water can be reabsorbed.





5.3.4 Other functions of the kidneys

Maintaining homeostasis of a large number of solutes and water is the main job of the kidney. But beyond that the kidneys also have other functions.

- **Endocrine functions.**

  1. The kidney is the sole source of erythropoietin

a. released in response to hypoxia; necessary to mobilize iron in bone marrow to produce hemoglobin for red blood cell production

b. the anemia caused by kidney failure can be corrected by administration of

exogenous erythropoietin

2. Kidney is also the only significant site of production of 1-_-hydroxylase

a. the final enzyme necessary to produce the active component of the vitamin D system, 1,25-(OH)2D3.

b. loss of renal mass leads to lack of active vitamin D and thus hypocalcemia

3. Also the sole source of rennin.

- **Paracrine substances** in the kidney that regulate homeostasis within the kidney

1. bradykinin
2. prostaglandins (esp. PGE2 and PGI2, natriuretic and vasodilatory)
3. endothelial factors

a. NO, which causes vasodilation and

b. endothelin

(1) also produced by endothelial cells, but usually only in response to injury

(2) the most potent vasoconstrictor known

- **Critical organ** in the maintenance of normal blood pressure for a number of reasons:

1. regulates water and sodium, so controls blood volume (most important mechanism for regulating blood pressure)
2. controls renin-angiotensin-aldosterone axis
3. produces some vasodilatory substances

- Involved in **catabolism of small peptide hormones** such as insulin
- Can produce glucose via **gluconeogenesis** during fasting
- Responsible for **elimination of many drugs.** Changes in kidney function will change plasma concentration of these drugs.
- **The concept of balance**

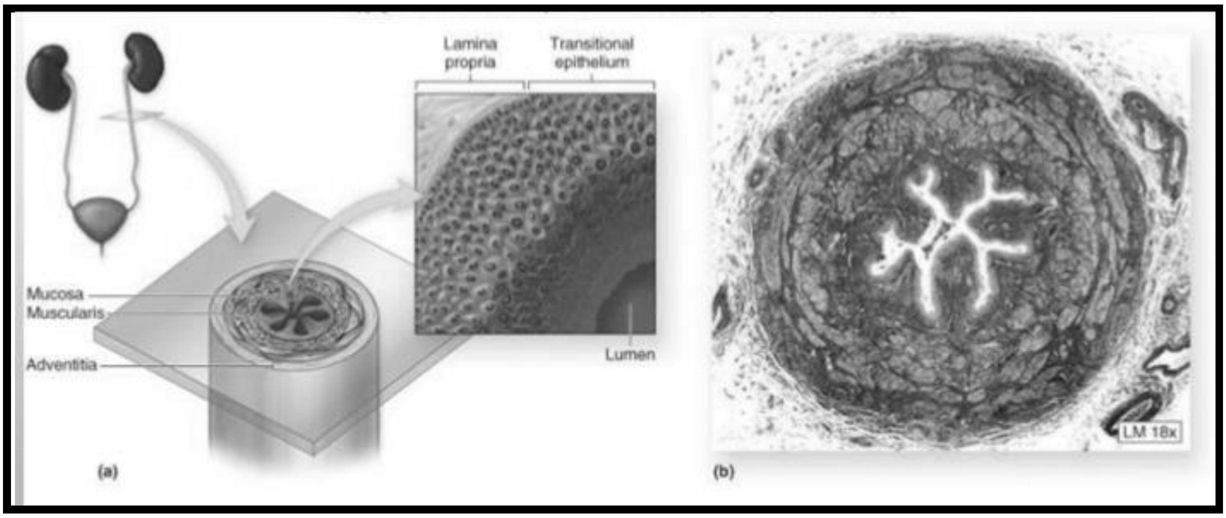
1. Neutral balance means dietary intake + endogenous production = excretion rate by the kidney. Total body content of the solute stays stable.
2. Positive balance means intake + endogenous production > excretion. Total body content increases.
3. Negative balance means intake + endogenous production < excretion. Total

body content decreases.

5.4 Ureters

Each ureter is a small tube, 25–30 cm long, that carries urine from the renal pelvis (the funnel-shaped expanded upper end of the ureter) in the kidney to the urinary bladder. It descends from the renal pelvis, along the posterior abdominal wall, behind the parietal peritoneum, and enters the urinary bladder on the posterior inferior surface. The ureters join the bladder via a tunnel in the bladder wall, which is angled to prevent reflux (backflow) of urine into the ureters when the bladder muscle contracts.

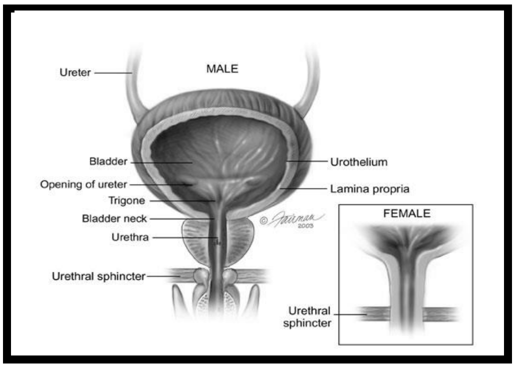
The ureter is roughly the same length as the esophagus and resembles it in having three constrictions along its course: (1) where the renal pelvis joins the ureter, (2) where it is kinked as it crosses the pelvic brim, and (3) where it pierces the bladder wall.



The wall of each ureter consists of three layers. The outer layer, the fibrous coat, is a supporting layer of fibrous connective tissue. The middle layer, the muscular coat, consists of inner circular and outer longitudinal smooth muscle. The main function of this layer is peristalsis to propel the urine. The inner layer, the mucosa, is transitional epithelium that is continuous with the lining of the renal pelvis and the urinary bladder. This layer secretes mucus which coats and protects the surface of the cells.

The ureter begins in the sinus of the kidney by the union of calyces. The initial section – the renal pelvis (or pelvis of the ureter – is dilated and emerges through the lower part of the hilum. It runs downward along the medial border of the kidney, tapering to become the ureter proper near the lower end of the kidney. The ureter proper descends over the back wall of the abdomen, with a slight medial inclination, and it crosses the origin of the external iliac artery to enter the true pelvis.

5.5 The urinary bladder and the urethra



The urinary bladder is a spherical organ with unique properties that enable it to store and empty urine. The bladder is composed of two functional layers an inner urothelial lining and an outer smooth muscle layer. In addition to the bladder, the bladder neck is a funnel-like outlet of the bladder which leads to the urethra. It is also known as the internal sphincter. The urethra tube-like structure which serves as a channel to carry urine from the bladder to the external surface, and the external urethral sphincters composed of striated muscles (group of muscles which surround the urinary passage distal to the bladder neck) complete the lower urinary tract.

The muscles and nerves of the urinary system must function in a coordinated fashion with the bladder in order to perform its two major functions of storage and elimination of urine. Nerves carry messages from the bladder to the brain and then from the brain to the muscles of the bladder telling them to tighten or release, allowing the bladder to empty during urination.

There are two main components to a normal micturition cycle of the bladder: storing and emptying. The bladder will initially fill (store urine) under a low pressure (high compliance). This requires both relaxation of the detrusor muscle along with its elastic properties of the bladder wall to enable the bladder to expand under low pressure. At the same time the striated sphincter is required to be contracted to maintain an elevated outlet resistance preventing urinary leakage. In order for the bladder to empty, the sphincter relaxes followed by a bladder contraction. Any abnormality in either component of the micturition cycle leads to bladder dysfunction.

5.7 Urethra

The final passageway for the flow of urine is the urethra, a thin-walled tube that conveys urine from the floor of the urinary bladder to the outside. The opening to the outside is the external urethral orifice. The mucosal lining of the urethra is transitional epithelium. The wall also contains smooth muscle fibers and is supported by connective tissue.

The internal urethral sphincter surrounds the beginning of the urethra, where it leaves the urinary bladder. This sphincter is smooth (involuntary) muscle. Another sphincter, the external urethral sphincter, is skeletal (voluntary) muscle and encircles the urethra where it goes through the pelvic floor. These two sphincters control the flow of urine through the urethra.

In females, the urethra is short, only 3 to 4 cm (about 1.5 inches) long. The external urethral orifice opens to the outside just anterior to the opening for the vagina.

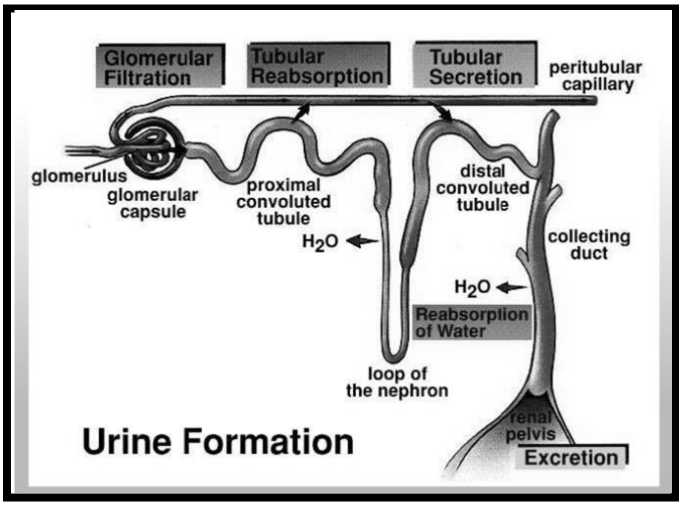
In males, the urethra is much longer, about 20 cm (7 to 8 inches) in length, and transports both urine and semen.

5.8 Urine

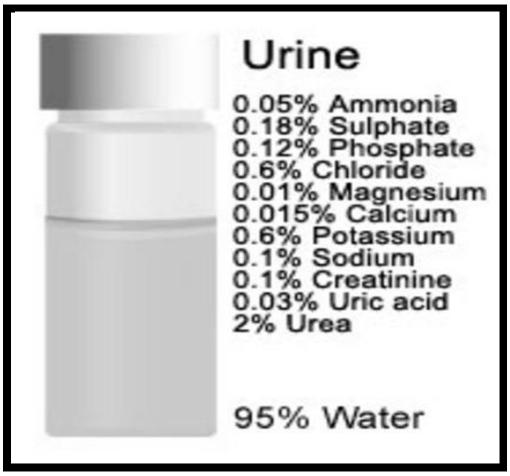
It is the liquid waste produced by the kidneys. It is a clear, transparent fluid that normally has an amber color. The average amount of urine excreted in 24 hours is between 5 to 8 cups or 40 and 60 ounces. Chemically, urine is mainly a watery solution of salt and substances called urea and uric acid. Normally, it contains about 960 parts water to 40 parts solid matter. Abnormally, it may contain sugar (in diabetes), albumin (a protein, as in some forms of kidney disease), bile pigments (as in jaundice), or abnormal quantities of one or another of its normal components.

Characteristic	Normal Range
pH	6.0 (range: 4.5–8)
Specific gravity	1.003–1.030
Osmotic concentration (osmolarity)	855–1335 mOsm/l
Water content	93–97 percent
Volume	1200 ml/day
Color	Clear yellow
Odor	Varies with composition
Bacterial content	Sterile

GENERAL CHARACTERISTICS OF NORMAL URINE



5.7.1 Constituents of urine



5.7.2 Examination of urine

"From a historical view, urinalysis was one of the original windows into what's happening in the body". That's because many of the substances circulating in our body, including bacteria, yeast, excess protein and sugar, eventually make their way into the urine.

When a sample of urine is submitted to a pathological laboratory, the following examinations are done:

Physical ExaminationVolume

- Normal volume of an early morning midstream sample is 50 – 300ml.
- If it is more than 500ml, it indicates diabetes or polyuria (frequent passing of urine).
- If it is less than 20ml, it indicates some kidney disorder.

Color

- The normal color of urine is pale yellow.
- If it is dark yellow to orange, it indicates some liver disorder.
- If it is white, it shows the presence of pus.
- If it is pink to red, it indicates the presence of red blood cells.
- If it is brownish black, it indicates the presence of melanin or homogenistic acid (a rare disorder).
- If it is blue to green, it is a liver disorder.

Sometimes, due to the intake of some food or medicines also, one could notice a change in the color or their urine e.g. the intake of beet imparts a reddish color to urine. The intake of vitamin B capsules gives a dark yellow color to it, if rimfamycin is taken, it gives an orange tinge to the urine.

Appearance

- Usually, it is clear, sometimes, it is cloudy.
- Sometimes, it is turbid due to the presence of WBCs (White Blood Cells), epithelial cells.
- Sometimes, it is hazy due to mucus.
- Smoky, due to red blood cells.
- Milky due to chyle (lymph).

Reaction

- Usually acidic pH range 4.5 – 7.5.
- If pH less than 4.7 it is more acidic.
- If pH more than 7.5 it is more alkaline.

Odor

- Usually, it is aromatic in normal conditions.
- It has a fruity odor in diabetes.
- Ammoniacal odor in cases of urine retention.

- Foul smelling due to urinary tract infection.

Sediment formation at the bottom of a container after collection

- Usually, there is no or very little formation of sediment in normal conditions.
- If pus cells, red blood cells, cysts or epithelial cells are present, the sedimentation rate ranges from moderate to high.

Specific Gravity

- Usually varies from 1.003 to 1.060.
- A low special gravity indicates diabetes insipidus or kidney infection (chronic).
- High specific gravity indicates diabetes mellitus or acute kidney infection.

Chemical Examination of UrineProtein

- Normally absent.
- Present in kidney disorders, dehydration, heart disease, and severe diarrhea.

Sometimes, due to an excessive muscular exercise, prolonged cold baths, excessive protein intake or vaginal discharge in the urine, the test shows the presence of protein.

Glucose

- Normally absent.
- If present, it indicates diabetes mellitus or hyperactivity of the endocrine glands.
- It can be present after brain injury or coronary thrombosis.

Ketone bodies

- Normally absent.
- If test shows ketones, it is due to severe diabetes mellitus, fevers, certain nervous disorders or prolonged diarrhea and vomiting.
- Even when a person starves, the urine shows a presence of ketone bodies.

Bile pigments

- Normally absent.
- Present in liver disorders.

Bile salts

- Normally absent.
- Present in liver disorders.

Urobilinogen

- Normally present in very low concentrations.
- Increased in liver disorders.

Blood

- Normally absent.
- Present in acute kidney infections, kidney cancer, tuberculosis of the kidneys, chronic infections, stone formation in the kidneys, severe burns or a reaction to blood transfusion.

Additional Chemical Tests

Non–glucose Sugars

- Lactose: May be present normally. It is present in lactating women.
- Fructose: Present in liver disorders.
- Pentoses: Are present due to drug therapy or hereditary conditions.

Non–glucose reducing substances

- Ascorbic acid: Present in Vitamin C therapy.
- Salicylic acid: Due to drugs having salicilates.
- Menthol: Due to the intake of food containing menthol.

Nitrite
Present due to bacterial infection

Indican

- It is present in very low concentrations.
- It is increased due to intestinal obstruction, cholera, typhoid fever or peritonitis.
- Sometimes, it is due to the intake of diets rich in proteins.

Microscopic Examination of Urine

Pus Cells

- Normally 2 to 3 pus cells are present in HPF (high power field of microscope).
- If more than 5 it indicates urinary tract infection or non infectious condition such as fever, stress, dehydration irritation to urethra, bladder or urethra.

Epithelial cells

- Normally two to three present in males.
- Normally two to five present in females.
- More than five epithelial cells per HPF indicates tubular damage, pyelonephritis or kidney transplant rejection.

Casts

- Normally absent.
- There are hyaline cysts, red cell cysts, white cell cysts, granular cysts, waxy cysts, and fatty cysts. They are present due to kidney disorders.
- Occasional Hyaline cysts may be present due to physical exercise and physiological dehydration.
- Granular cysts may be present after strenuous exercise for a short duration.

Amorphous Material

- Amorphous urates of sodium, potassium or calcium are present normally.
- Amorphous phosphates of calcium and magnesium are present normally.

Crystals

- Uric acid, calcium sulphate, calcium oxalate and ammonium magnesium phosphate (triple phosphate) crystals are indicative of the presence of kidney stones.
- Following crystals, found in acidic urine indicate abnormal metabolism – cystine, cholesterol, leucine, tyrosine, bilirubin, hematoidin and sulphonamides.

Bacteria

- Normally absent.
- If present indicates infection.

Yeast cells

- Normally absent.
- May be present in acidic urine containing sugar.

Parasites

- Normally absent.
- If present, they are Trichomonas Vaginalis (from vagina) or Trichononas Hominis (from rectum).

5.8 Patho physiology of kidney

Diseases of the urinary system

Kidney diseases are treated by a nephrologist, who completes a three-year residency in internal medicine after medical school. That is followed by a two-year (or longer) fellowship in nephrology.

Urologists treat ailments involving the urinary tract in both males and females, including the kidneys, adrenal glands, ureters, bladder and urethra. Urologists also treat the male reproductive organs, while gynecologists often treat urinary diseases or disorders in females, including yeast infections.

Nephrologists and urologists often work with endocrinologists or oncologists, depending on the disease.

Urinary tract infections (UTIs) occur when bacteria enters the urinary tract and can affect the urethra, bladder or even the kidneys. While UTIs are more common in women, they can occur in men. UTIs are typically treated with antibiotics.

Interstitial cystitis (IC), also called painful bladder syndrome, is a chronic bladder condition that doesn't have a known cause. It can cause bladder scarring, and can make the bladder less elastic. A typical result is that the bladder cannot hold as much urine.

Prostatitis is a swelling of the prostate gland and, therefore, can only occur in men. Often caused by advanced age, symptoms include urinary urgency and frequency, pelvic pain and pain during urination.

Kidney stones are clumps of calcium oxalate that can be found anywhere in the urinary tract. Kidney stones can cause pain in the back and sides, as well as blood in the urine.

Kidney failure, also called renal failure, can be a temporary (often acute) condition or can become a chronic condition resulting in the inability of the kidneys to filter waste from the blood. Acute cases may be caused by trauma or other damage, and may recover over time with treatment. However, renal disease may lead to chronic kidney failure, which may require dialysis treatments or even a kidney transplant.

Bladder cancer is more frequent in men. The symptoms, including back or pelvic pain, difficulty urinating and urgent/and or frequent urination, mimic other diseases or disorders of the urinary system.

5.9 Let us sum up

- The urinary system rids the body of waste materials, regulates fluid volume, maintains electrolyte concentrations in body fluids, controls blood pH, secretes erythropoietin, and renin.
- The components of the urinary system are the kidneys, ureters, urinary bladder, and urethra.
- The primary organs of the urinary system are the kidneys, which are located retroperitoneally between the levels of the twelfth thoracic and third lumbar vertebrae.
- The cortex and medulla make up the parenchyma of the kidney.
- The central region of the kidney is the renal pelvis, which collects the urine as it is produced.
- The functional unit of the kidney is a nephron, which consists of a renal corpuscle and a renal tubule.
- The ureters transport urine from the kidney to the urinary bladder.
- The urinary bladder is a temporary storage reservoir for urine.
- The urethra is the final passageway for the flow of urine.
- The flow of urine through the urethra is controlled by an involuntary internal urethral sphincter and voluntary external urethral sphincter.

5.10 Glossary

Acute Kidney (Renal) Failure: A sudden drop in kidney function that is often short-lived and can require dialysis. For those with previously healthy kidneys it seldom means staying on dialysis. Also known as Acute Kidney (Renal) Disease.

Albumin: A protein in your blood plasma, in the blood, albumin acts as a carrier and helps to maintain blood volume and blood pressure. (See Protein).

Albuminuria: When albumin is present in the urine. There are filters in the kidneys that prevent large molecules, such as albumin, from passing through. If these filters are damaged, albumin passes from the blood in to the urine. (See Albuminuria, Creatinine, Microalbuminuria, Macroalbuminuria).

Anaemia: When there are only a small number of red blood cells in the blood or the blood cells are not working properly. Red blood cells carry oxygen, so someone with anaemia can feel weak, tired and short of breath.

Bladder: A muscular, elastic sac or membrane inside the body that stores the urine.

Chronic Kidney (renal) Disease (CKD): Term used widely to describe kidney damage or reduced kidney function (irrespective of the cause) that persists for more than 3 months. Sometimes CKD leads to kidney failure, which requires dialysis or a kidney transplant to keep you alive.

Creatinine: Waste is made by the breakdown of muscles. It is usually removed from the blood by the kidneys and passes out in the urine. When the kidneys are not working very well, the creatinine stays in the blood and the measured level is elevated.

Diabetes: Is a chronic disease caused by problems with the production and/or action of insulin in the body.

Diabetes inspidus

It is disorder due to hormonal imbalance. Kidneys become overactive and a person urinates excessively. A person has a raging thirst and an increased appetite.

Diabetes mellitus

It is a disorder in which the body cannot make use of sugars and starches in a normal way.

Dialyser: Part of a dialysis machine that acts like a kidney to filter blood and remove waste products and excess fluid.

Dialysis: A treatment for kidney failure that removes waste products and extra water from the blood by filtering the blood through a special membrane to remove waste products. There are two main types of dialysis; haemodialysis and peritoneal dialysis. (See Haemodialysis, Peritoneal Dialysis, Continuous Ambulatory Peritoneal Dialysis).

eGFR: An estimation of glomerular filtration rate. (See Glomerular Filtration Rate)

End Stage Kidney (Renal) Disease (ESKD): The stage in kidney disease when a person's kidneys have stopped working so treatment is needed to sustain life, such as dialysis or a transplant. See Chronic Kidney (renal) Disease (CKD).

Endocrine glands :It is a ductless body organ which produces hormones. These hormones affect and help control various other organs.

Erythropoietin (EPO): A body chemical (hormone) mainly made by the kidneys that causes the bone marrow to make red blood cells. A lack of this hormone can cause anaemia.

Fistula: Produced when a vein and an artery in the arm or leg are joined together in an operation to make it easier to move blood in and out of the body during haemodialysis. Also known as an arterio-venous fistula.

Fluid allowance/restriction: Is a limit or daily total amount of fluid taken daily that is usually set by a doctor.

Fluid retention: When the body does not get rid of enough liquid (water). This can cause swollen or puffy ankles, face or hands or shortness of breath.

Glomerulus: A tiny set of blood vessels in the nephron.

Glycosylated haemoglobin: (See HbA1c)

Haematuria (or blood in the urine): Occurs when red blood cells leak into the urine. It can turn urine a red or dark cola colour, which is visible to the eye or may only be found by a urine test (microscopic haematuria). Blood in the urine is a common sign of urinary tract infections but can be the first sign of a problem with the kidneys or the bladder.

Haemodialysis (HD): A treatment for kidney failure. The patient's blood is pumped through special tubing to a haemodialysis machine. The machine acts like a kidney, filtering waste products from the blood before returning it to the patient. Haemodialysis usually lasts for 4-6 hours and is done 3 or more times a week. Haemodialysis can be performed at night. (See Home Dialysis, Nocturnal dialysis, Satellite centre).

Hypertension: Another word for high blood pressure. High blood pressure can cause chronic kidney disease and chronic kidney disease can cause high blood pressure.

IgA Nephropathy: A common type of glomerulonephritis. It causes blood in the urine and is often linked to sore throats and pain at the top of the legs.

Immunosuppressant: Medications taken following a transplant to prevent rejection.

Insulin: A chemical or hormone made by the pancreas that controls the level of glucose (sugar) in the blood.

Kidneys: Reddish, jelly bean-shaped body organs. Most people have two kidneys but people can live with one. The kidneys are in the lower back just under the bottom of the rib cage. A kidney is about the size of your fist. The kidneys are very important because they remove waste and fluid from the body and produce urine. They also help to:

- control blood pressure
- produce red blood cells
- keep our bones strong
- maintain the chemical balance of the blood
- change Vitamin D so that the body can use it
- get rid of drugs and poisons

Kidney Biopsy: A diagnostic test where a needle is used to remove a small piece from of tissue from a kidney. A biopsy helps to determine the cause of kidney disease.

Nephrologist: A doctor who specialises in kidney function.

Nephrology: The study of the kidneys.

Nephron: The tiny parts of the kidney that filter blood to make urine. There are over one million filters in each kidney.

Oedema: (See Fluid Retention).

Organs: Parts of the body that help us to stay alive, such as the kidneys, heart, lungs and liver.

Parathyroid glands: Produce parathyroid hormone, or PTH. PTH helps control calcium, phosphorous and vitamin D levels within the blood and bone. Kidney failure can cause the parathyroid glands to produce too much PTH.

Peritoneal cavity: The space in the abdomen (belly) holding the intestines and other organs.

Peritonitis
It is inflammation of the peritoneum – the membrane that lines the abdominal cavity and covers the abdominal organs.

Pyelonephritis
It is an inflammation of the kidney and the renal pelvis (the hollow cone into which urine flows from the kidney).

Proteinuria: Occurs when there are abnormal levels of protein in the urine. There are filters in the kidneys that prevent large molecules, such as protein, from passing through. If these filters are damaged, proteins pass from the blood in to the urine. The most common protein found in the urine is albumin. The appearance of protein in the urine may be the first sign of an otherwise silent kidney condition.

Recipient: A person who gets a new body organ, such as a kidney.

Renal: Another word for kidney or about the kidneys.

Renin: A chemical made by the kidneys that helps control blood pressure.

Occult blood :"Occult" means hidden. Here blood is present in very minute traces. It is not visible to the naked eyes.

Salt: Affects the amount of fluid the body retains and increases thirst. If you have a kidney problem, too much salt can make you drink more than your kidneys can remove and may cause:

- High blood pressure

- Swelling of ankles, feet, hands and puffiness under the eyes
- Shortness of breath
- **Sodium:** A mineral in the body which is often called "'salt". The kidneys help to control the amount of sodium in the body. Sodium helps to control the amount of water in the body.
- **Steroid:** A medicine that helps to stop allergic reactions and is used to prevent the body from rejecting a transplanted organ.

Tissue typing: A test to find out the level of compatibility or matching between the organs of a donor and a recipient. (See Blood group).

Tissue: A group of cells of the same type, such as a muscle.

Uraemia: A build up of waste products in the blood causing nausea, vomiting, tiredness, and problems with concentration.

Urea: A waste product which is made as the body as it uses protein breaks down protein. If you have a kidney problem, too much protein causes too much urea and can lead to nausea, vomiting, tiredness, headaches, a bad taste in the mouth, bad breath, and problems with memory and concentration.

Ureter: The tube that connects the kidneys to the bladder.

Urethra: The tube that takes urine out of the body from the bladder.

Urine: The name for extra fluid and waste products that are removed from your body by the kidneys.

Urinalysis: A test to measure the amount of protein, blood and other substances in the urine (wee).

Urine collection: You usually collect all your urine for 24 hours and store it in a special bottle. This urine sample is tested for protein, which helps to determine your kidney function.

Urology: The study of the urinary system.

Vein: A blood vessel returning blood to the heart.

Vitamin D: A vitamin that is made in your skin after you have been in the sun. The kidneys change Vitamin D so that your body can use it.

Water Retention: See fluid retention.

5.11 Check your progress

1. The urinary system is sometimes referred to as the excretory system because one aspect of its function is to rid the body of waste products.
   (•) True ( ) False
2. The organs of the urinary system are the only ones that contribute to the excretory function.
   ( ) True ( ) False
3. The urinary system controls red blood cell production by secreting the enzyme renin.
   ( ) True ( ) False
4. The kidneys are the organs that filter the blood, remove the wastes, and excrete the wastes in the urine.
   ( ) True ( ) False
5. The cortex and medulla make up the parenchyma, or functional tissue, of the kidney, which contains over a million nephrons.
   ( ) True ( ) False
6. The renal pelvis is a large cavity that collects the urine as it is produced.
   ( ) True ( ) False
7. The main function of the inner layer of the ureter, the mucosa, is peristalsis to propel the urine.
   ( ) True ( ) False
8. The internal and external urethral sphincters control the flow of urine through the urethra.
   ( ) True ( ) False

Choose the correct answer:

1. Which is not a major function of the kidney?

A.Regulation of blood ionic composition
B.Regulation of blood cell size
C.Regulation of blood volume
D.Reulation of blood pressure
E.Regulation of blood pH

2. This is the formation of a new glucose molecule.

A.Glycolysis
B.Gluconeogenesis
C.Glucosamine
D.Glucagon
E.Glycine

3. Which of the following is a waste product normally excreted by the kidneys?

A.Urea
B.Glucose
C.Insulin
D.Cholesterol
E.Carbon dioxide

4. This smooth dense irregular connective tissue is continuous with the outer coat of the ureter.

A.Adipose capsule
B.Renal capsule
C.Renal hilus
D.Renal cortex
E.Renal medulla

5. The portion of the kidney that extends between the renal pyramids is called the

A.Renal columns
B.Renal medulla
C.Renal pelvis
D.Calyces
E.Renal papilla

6. Which is the correct order of the blood flow?

A.Renal artery - segmental artery - interlobular artery - peitubular capillaries - afferent arterioles
B.interlobular areteries - arcuate arteries - glomerular capillaries - arcuate veins
C.Arcuate veins - arcuate arteries - glomerular capillaries - renal vein
D.Interlobar veins - afferent arterioles - efferent arterioles - glomerular capillaries
E.Renal vein - segmental arteries - interlobar arteries - efferent arterioles

7. Wihch is the correct order of the filtrate flow?

A.Glomerular capsule - PCT - loop of Henle - DCT - collecting duct
B.Loop of Henle - glomerular capsule - PCT - DCT - collecting duct
C.Ascending limb of the loop - PCT - DCT - collecting duct

D.Collecting duct - DCT - PCT - loop of Henle - glomerular capsule

E.PCT - glomerular capsule - DCT - collecting duct - loop of Henle

8. Which structure of the nephron reabsorbs the most substances?

A.Glomerular capsule

B.Loop of Henle

C.Ascending limb of the loop of Henle

D.Collecting duct

E.Proximal convoluted tubule

9. This is the structure of the nephron that filters blood.

A.Glomerular capsule

B.Loop of Henle

C.Ascending limb

D.Collecting duct

E.Renal corpuscle

10. This term means entry of substances into the body from the filtrate.

A.Reabsorption

B.Filtration

C.Secretion

D.Excretion

E.Absorption

11. This is a nephron process that results in a substance in blood entering the already formed filtrate.

A.Reabsorption

B.Filtration

C.Secretion

D.Excretion

E.Absorption

15. Once fluid enters the proximal convoluted tubule

A.It becomes less dense

B.It has a higher K+ concentration

C.It is called tubular fluid

D.All the Na+ is removed

E.It is headed to the ascending loop

16. The proximal convoluted tubules reabsrob what percentage of filtered water?

A.25%

B.40%

C.50%

D.65%

E.90%

18. Urea recycling can cause a build up of urea in the

A.Renal capsule

B.Loop of Henle

C.Ascending tubule

D.Renal medulla

E.Renal pelvis

19. Increased secretion of hydrogen ions would result in a ________________ of blood ________________.

A.Constant, pH

B.Decrease, volume

C.Increase, sodium levels

D.Decrease, pH

E.Increase, pH

20. Increased secretion of aldosterone would result in a ____________ of blood _____________.

A.Increase, potassium

B.Decrease, volume

C.Increase, calcium

D.Decrease, pH

E.Increase, sodium

21. The ascending loop of Henle is impermeable to

A.Urea

B.Water

C.Albumin

D.Sodium

E.Glucose

22. An analysis of the physical, chemical and microscopic properties of urine is called

A.Urinalysis

B.Microscopy, culture, sensitivity

C.Dipstick urine test

D.Midstream urine sample

E.Diuretic

23. In average, water accounts for what percentage of the total volume of urine?

A.25%

B.50%

C.70%

D.80%

E.95%

24. This is a test to measure kidney function.

A.Plasma creatinine

B.Renal study

C.Kidney assay

D.Renal clearance

E.Hilus study

25. This transports urine from the kidney to the bladder.

A.Urethra

B.Ureter

C.Descending loop of Henle

D.Renal hilus

E.Renal hilum

26. This layer of the ureter is composed of connective tissue, elastic and collagen fibres.

A.Mucosa

B.Transitional epithelium

C.Lamina propria

D.Adventitia

E.Lamina elastica

27. This lies in the anterior corner of the trigone of the bladder.

A.Urethral sphincter

B.Adventitia bundle

C.Ureter

D.Internal urethral orifice

E.Ureteral opening