Uttar Pradesh Rajarshi Tandon
Open University

PGBCH-105
Nutrition and Physiology

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BLOCK

1

NUTRITION AND NUTRITIONAL ELEMENTS

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Introduction

This is the first block on nutrition and physiology, consists of following two units:

Unit-1 Nutrition is the biological process to intake of food materials, considered in relation to the body's dietary needs. It is the science that interprets the interaction of nutrients and other substances in food in relation to maintenance, growth, reproduction, health and disease of an organism. The function of nutrients is the measurement of calorific value of food, basal metabolic rate (BMR) and the factors affecting BMR also discussed in this unit. The recommended dietary allowances and dietary recommendations of human nutritional needs have also been briefly discussed here.

Unit-2 Nutrients are the compounds which are present in the foods and that is essential for life and health, which provide us energy. The building blocks for repair and growth and these substances are necessary to regulate the chemical processes. In this unit we shall know about different types and source of nutrients. This unit also covers the various types and sources of nutrients. The dietary requirement of carbohydrates, lipids and proteins has been briefly discussed in this unit. The concepts of protein quality, micronutrients and macronutrients also have been determined. The essential amino acids, fatty acids and their physiological function cover in this unit.

UNIT : 1

Nutrition

Structure:

1.1. Introduction

Nutrition is process to intake of food, considered in relation to the body's dietary needs. Good nutrition is an adequate, well balanced diet combined with regular physical activity and it is a cornerstone of good health. In other words nutrition is the science of food and its relationship to health. Food is comprised of macronutrients including proteins, carbohydrates and fats that not only offer calories to fuel to the body and give energy but also play a specific role in maintaining health. Food plays an important role in health as well as in disease. Nutrition is double edged sword as both over and under nutrition is harmful to health.

Under nutrition is particularly harmful in early age groups i.e. childhood and over nutrition in adulthood and after-years but both forms are likely to affect all age groups in near future. Some important disease related to malnutrition is obesity which is caused by excess energy intake; anemia caused by insufficient intake of iron, thyroid deficiency disorders due to deficiency in iodine intake and impaired vision because of inadequate intake of vitamin A etc. There are two main types of nutrients, macronutrients and micronutrients. The three main categories of macronutrients include carbohydrates, proteins and fats.

Objectives:

- To study the different dietary sources of nutrition.
- To discuss about different types of nutrition.
- To know about basal metabolic rate (BMR).
- To discuss about role of nutrients in our body.

1.2. Nutrition overview

It is food which works in the body. It includes very important thing that happens from eating food to its usage in various functions of body. The food is a part of our existence, by knowing the food composition and the nutritional content is known. It mentions a good health throughout the life span. Food may be defined as any substance eaten or drunk which provide energy for metabolic activity, body building, regulation and protection of our body. It meets special needs of pregnancy and lactation and for recovery from the illness.

The adequate, optimum and good nutrition are those that indicate the right amount and proportion of nutrients for the proper utilization for achieving highest level of physical and mental health. State of body is a result of foods consumption and their utilization is considered as nutritional status. The nutritional status can be good or bad; it depends on the food that have consumed. The nutritional status can also depend on the nature of meal preparation. If you prepare the meal carefully the nutrition value of food will be maintained for long time.

The excessive intake of one or more nutrient creates a stress on the body function as a resultant it has adverse effect that is considered as malnutrition. The malnutrition can be caused an error in metabolism, interaction between nutrients or nutrients and drugs used for treatment. Nutrition that is essential for growth and development is received from diet. The diet refers to whatever we eat or drink each day. It includes normal diet that is consumed either individually or in group. Diets may be modified for making it suitable for sick individuals as a part of treatment which is also called therapeutic diet.

Nutrients are classified on the basis of their nutritional values. There are six types of nutrients which are classified on the part of human diet for their growth and developments these are as followings:

- Protein
- Carbohydrate
- Minerals
- Vitamins
- Fats
- Water

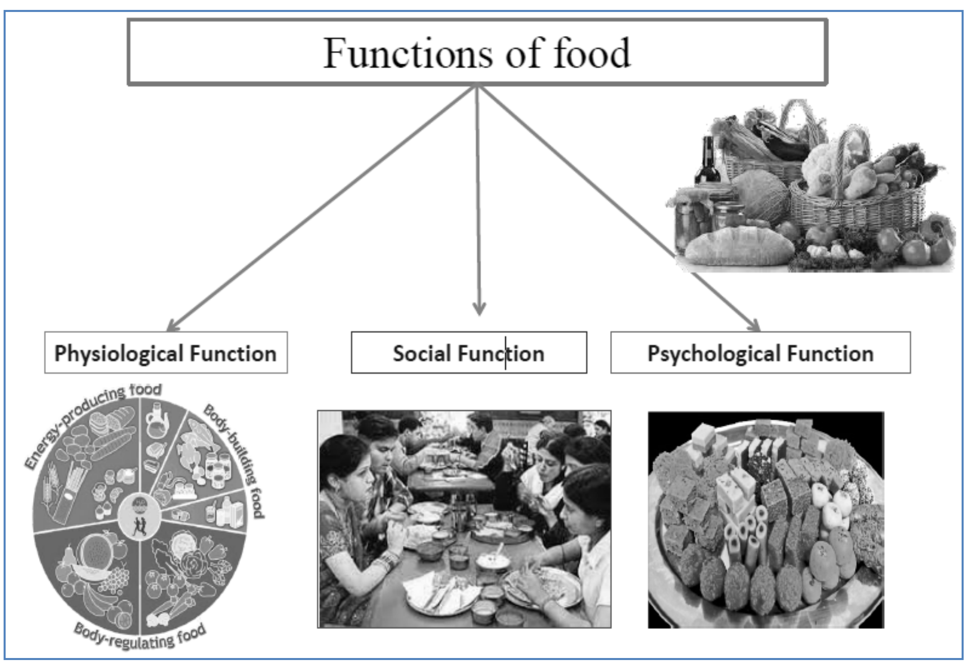

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Fig.1.1: Different functions of foods.

1.2.1. Dietary Proteins

Proteins are the one of the most important nutrient in human diet. Protein considered as building blocks of body because it is used for the replacement and repair of body cells, growth and development. We know that protein is the polymer of amino acids and also known as macronutrients. The protein provides shape and structure to the body, cell and also being a part of hormones and enzymes etc. In addition protein also provides energy as well as building, maintaining and replacing muscle. The main source of protein is our diet and it come form in eggs, milk, cheese and meat. The best animal sources are fish, seafood, chicken, beef, mutton, milk, meat, eggs, soy, quinoa, red beans or lentils, wholegrain rice or peanut butter, yogurt, nuts and seeds are vegetable sources.

Dietary protein provides amino acids for synthesis of body proteins and other biologically important nitrogenous compounds in the body. The dietary protein provides all eight essential amino acids. However, our body needs 22 amino acids to work properly. In order to maintained protein-energy malnutrition there are 9 essential amino acid are used by human in their diet which is phenylalanine, threoine, methionine, isoleucine, valine, tryptophan, leucine, histidine and lysine.

1.2.1.1. Types of protein

There are mainly two types of protein considered in diet which is complete protein and incomplete protein.

Complete proteins: The complete protein is obtained from the animal meat**.** However, the plant based foods include quinoa and soy also one considered a source of complete protein.

Fig.1.2: Sources of complete proteins

Incomplete proteins: The incomplete protein obtained from the plant sources that are combination of two incomplete protein food choices in order to get all of essential amino acids.

Fig.1.3: Sources of incomplete proteins

1.2.1.2. Digestions and absorptions of proteins

The digestion and absorption are obtained from two sources – dietary and endogenous. Dietary proteins are denatured on cooking and therefore, easily digested. Proteins are degraded by a class of enzymes namely hydrolases- which specifically cleave the peptide bonds, hence known as peptidases. They are divided into two groups-

A. **Endopeptidases (proteases):** Which attack the internal peptide bonds and release peptide fragments, e.g. pepsin, trypsin.

B. **Exopeptidases:** Which act on the peptide bonds of terminal amino acids. Exopeptidases are subdivided into carboxypeptidases (act on C-terminal amino acid) and amino peptidases (act on N-terminal amino acid).

The proteolytic enzymes are responsible for the digestion of proteins and produced by the stomach, pancreas and the small intestine. Proteins are not digested in the mouth due to the absence of proteases in saliva.

Digestion by gastric secretion: Protein digestion begins in the stomach. Gastric juice produced by the stomach, which contains hydrochloric acid and a protease proenzyme pepsinogen a facilitates digestive function. Hydrochloric acid performs two important functions.

A. Denaturation of proteins and killing of certain microorganisms. The denatured proteins are more susceptible to proteases for digestion. Pepsin is produced by the serous cells of the stomach as pepsinogen, to inactive zymogen or proenzyme.

B. Pepsin A is the most predominant gastric protease which cleaves peptide bonds formed by amino groups of phenylalanine or tyrosine or leucine. Pepsin digestion of proteins results in peptides and a few amino acids which act as stimulants for the release of the hormone cholecystokinin from the duodenum. Rennin enzyme, also called as chymosin, is found in the stomach of infants and children. It is involved in the curdling of milk. lt converts milk protein casein to calcium paracasinate which can be effectively digested by pepsin. Rennin is absent in adults.

Digestion by pancreatic proteases: The proteases of pancreatic juice are secreted as zymogens (proenzymes) and then converted to active forms. These processes are initiated by the release of two polypeptide hormones, namely cholecystokinin and secretin from the intestine. Trypsin, chymotrypsin and elastase are endopeptidases active at neutral pH. Gastric HCl is neutralized by pancreatic $NaHCO_3$ in the intestine and this creates favourable pH for the action of proteases. Trypsin cleaves the peptide bonds, the carbonyl (CO) group of which is contributed by arginine or lysine. The amino acid serine is essential at the active centre to bring about the catalysis of all the three pancreatic proteases; hence these enzymes are referred to as serine proteases. The pancreatic carboxypeptidases (A and B) are metalloenzymes that are dependent on Zn^{2+} for their catalytic activity hence, also called Zn proteases. Carboxypeptidase B acts on peptide bonds of -COOH terminal amino acid, the amino group of which is contributed by arginine or lysine.

Digestion by small intestinal enzymes: The luminal surface of intestinal epithelial cells contains aminopeptidases and dipeptidases. Aminopeptidase is a non-specific exopeptidase which repeatedly cleaves N-terminal amino acids one by one to produce free amino acids and smaller peptides. The dipeptidases act on different dipeptides to liberate amino acids. The free amino acids, dipeptides and to some extent tripeptides are absorbed by intestinal epithelial cells. The di- and tripeptides, after being absorbed are hydrolysed into free amino acids in the cytosol of epithelial cells. The activities of dipeptidases are high in these cells. Therefore, after a protein meal, only the free amino acids are found in the portal vein.

The small intestine possesses an efficient system to absorb free amino acids. L-Amino acids are more rapidly absorbed than D-amino acids. The transport of L-amino acids occurs by an active process (against a concentration gradient), in contrast to D-amino acids which takes place by a simple diffusion. Amino acids absorption mechanism is basically a Na^+ dependent active process linked with the transport of Na^+. As the Na^+ diffuses along the concentration gradient, the amino acid also enters the intestinal cell. Both Na^+ and amino acids share a common carrier and are transported together. The energy is supplied indirectly by ATP.

Health significance and functions of proteins

We know the proteins are building block of body because it provides growth especially to children, teens and pregnant women. In addition, protein also play important role in issue repair and immune function. Protein also releases four calories per gram. The main functions of proteins to perform as brick and mortar roles and are primarily responsible for structure and strength of body. For e.g., collagen and elastic found in bone matrix, vascular system and other organs and α-keratin present in epidermal tissues are considered as structural function of proteins. Proteins also performing dynamic functions are appropriately regarded as the working horses of cell. There are various functions of proteins are as under:

- Protein as an energy source
- Proteins as enzymes
- Proteins as carriers
- Proteins as biological buffers
- Proteins as lubricants
- Proteins in immune system

1.2.2. Dietary carbohydrates

Carbohydrate is organic compound formed by the process of photosynthesis in plant. It is the main source of human diet and also known as macronutrient. The carbohydrate consist of Carbon, Hydrogen, and oxygen and having empirical formula $(CH_2O)_n$. It is the single most dietary element which the produce dietary energy comprising about 50-70 % of the total energy intake in the different population. The 1 gram of carbohydrate releases 4 kcal of energy. Even the carbohydrate is not essential nutrients because the carbon skeleton of amino acids can be converted into glucose. However, the absence of dietary carbohydrate leads to ketone body production and degradation of body protein whose constituent amino acids provide carbon skeletons for glucogenesis.

The main sources of carbohydrates are vegetables, meat and milk where a carbohydrate exists in the form of starch fiber and sugar. The starch and fibers are complex in nature (-CHO), found in cereals grain, pulses, roots and tubes. Whereas sugar found in fruit, honey and milk sugar. Carbohydrates are derived from organic plant and animal and can be classified on their molecular size and digestive fats.

Glucose (normal fasting blood level 70-100 mg/dl) is the central molecule in carbohydrate metabolism, actively participating in a number of metabolic pathways--glycolysis, gluconeogenesls, glycogenesis, glgcogenolysis, hexose monophosphate shunt, uronic acid pathway etc.

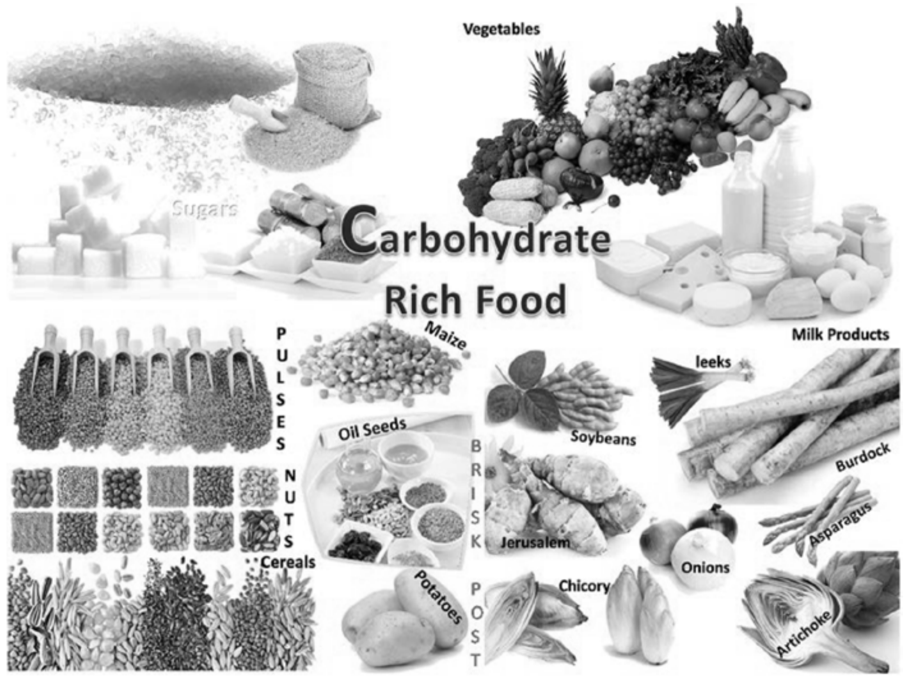

Fig.1.4: Different sources of carbohydrates

1.2.2.1. Types of Carbohydrates

On the bases of molecular size or degree of polymerization, the carbohydrates are grouped in to monosaccharides, diasachharide, oligosaccharides and polysaccharides.

- **Monosaccharides:** It consisting of one unit of sugar and also simple sugar.
- **Diasachharide:** It consisting of two unit of monosaccharide.
- **Oligosaccharides:** Each molecule consist two to nine units of monosaccharides.

Polysaccharides: Each molecule contains more than nine units of monosaccharide.

On the bases of digestive fats the carbohydrate can be available and unavailable carbohydrate. The digestive fats of carbohydrate depend on their inherent chemical nature and supramolecular structure within food.

Available carbohydrates: Available carbohydrate is those carbohydrate constituent which is digest in form for monosaccharides.

Unavailable: Those carbohydrates that are not digested by indigenous enzymes of the human intestine tract and not absorbed in the form of monosaccharides.

1.2.2.2. Digestion, absorption of carbohydrates

The principal dietary carbohydrates are polysaccharides (starch, glycogen), disaccharides (lactose, sucrose) and, to a minor extent, monosaccharides (glucose, fructose). The digestion of carbohydrates occurs briefly in mouth and largely in the intestine. The polysaccharides get hydrated during heating which is essential for their efficient digestion. The hydrolysis of glycosidic bonds is carried out by a group of enzymes called glycosidases. These enzymes are specific to the bond, structure and configuration of monosaccharide units.

- **Digestion in the mouth**: Carbohydrates are the only nutrients for which the digestion begins in the mouth to a significant extent. During the process of mastication, salivary a-amylase (ptyalin) acts on starch randomly and cleaves α-1, 4-glycosidic bonds. The products formed include α-limit dextrins (containing about 8 glucose units with one or more α-1, 6-glycosidic bonds) maltotriose and maltose.

- **Carbohydrates not digested in the stomach:** The enzyme salivary amylase is inactivated by high acidity (low pH) in the stomach.

- **Digestion in the small intestine:** The acidic dietary contents of the stomach, on reaching small intestine, are neutralized by bicarbonate produced by pancreas. The pancreatic α-amylase acts on starch and continues the digestion process. Amylase specifically acts on α-l, 4-glycosidic bonds and not on α-1, 6-bonds. The resultant products are disaccharides (maltose, isomaltose) and oligosaccharides.

The final digestion of di-and oligosaccharides to monosaccharides primarily occurs at the mucosal lining of the upper jejunum. This is carried out by oligosaccharidases (e.g. glucoamylase acting on amylase) and disaccharidases (e.g. maltase, sucrose, lactase). The enzyme sucrase is capable of hydrolysing a large quantity of table sugar (sucrose). In contrast, lactase (β-galactosidase) is the rate limiting and consequently, the utilization of milk sugar (lactose) is limited in humans.

The principal monosaccharides produced by the digestion of carbohydrates are glucose, fructose and galactose. Of these, glucose accounts for nearlv 80 o/o of the total monosaccharides. The absorption of sugars mostly takes place in the duodenum and upper jejunum of small intestine. There exists a considerable variation in the absorption of different monosaccharides. It is observed that hexoses are more rapidly absorbed than pentoses. Among the monosaccharides, galactose is most efficiently absorbed followed by glucose and fructose. Insulin has no effect on the absorption of sugars.

Different sugars possess different mechanisms for their absorption. Glucose is transported into the intestinal mucosal cells by a carrier mediated and energy requiring process. Glucose and Na^+ share the same transport system (symport) which is referred to as sodium dependent glucose transporter. The concentration of Na^+ is higher in the intestinal lumen compared to mucosal cells. Na^+, therefore, moves into the cells along its concentration gradient and simultaneously glucose is transported into the intestinal cells. This is mediated by the same carrier system. Thus, Na+ diffuses into the cell and it drags glucose along with it.

The mechanism of absorption of galactose is similar to that of glucose. The inhibitor phlorizin blocks the Na^+ dependent transport of glucose and galactose. Fructose absorption does not require energy and is independent of Na^+ transport. Fructose is transported by facilitated diffusion mediated by a carrier. Inside the epithelial cell, most of the fructose is converted to glucose. The latter then enters the circulation. Pentoses are absorbed by a process of simple diffusion.

The monosaccharide glucose is the central molecule in carbohydrate metabolism. Glucose is utilized as a source of energy, it is synthesized from non-carbohydrate precursors and stored as glycogen to release glucose as and when the need arises. The other important monosaccharides in carbohydrate metabolism are fructose, galactose and mannose.

1.2.2.3. Health significances and functions of carbohydrates

- **Sources of energy:** carbohydrates are the most abundant dietary source of energy (4 Cal/g) for all organisms. Carbohydrates also serve as the storage form of energy (glycogen) to meet the immediate energy demands of the body.
- **Protein sparing effects:** Carbohydrate (as glycoproteins and glycolipids) participates in the structure of cell membrane and cellular functions such as cell growth, adhesion and fertilization.
  - Anti-ketogenic effect:
  - Excretion of toxin:
  - Act as precursor:
  - Over all positive health:

1.2.3. Minerals

Minerals are called native elements and play a major role in metabolic process and maintain acid base, and water balance in our body. Minerals are organic nutrients that regulate many chemical reactions in living cells. Instead, ordinary kitchen salt is a chemical compound that is called rock salt, which is a mineral, formed of sodium and chlorine ions. Atoms, ions and molecules that form a mineral are present in the space in a tidy way and according to well-defined geometrical shapes, which are called crystal lattices.

Minerals found in the Earth's crust include things like salt, coal, iron, ore, shale, and diamonds, just to name a few. While there are a number of elements in the periodic table that can be extracted from the Earth's crust minerals are usually solid, inorganic, have a crystal. 2014 and does not agree. Brief about minerals are mentioned in unit 3. Most of the known and suggested mineral nutrients are of relatively low atomic weight, and are reasonably common on land, or for sodium and iodine, in the ocean: there are the 7 major minerals as under:

- Calcium.
- Chloride.
- Magnesium.
- Phosphorus.
- Potassium.
- Sodium.

1.2.4. Vitamins

Vitamins in the simplest term are known as vital amines. They form essential nutrients required to carry out basic metabolic function. An essential nutrient is a nutrient required for normal physiological function but that cannot be synthesized in the body; either at all or in sufficient quantities; and thus must be obtained from a dietary source. Apart from water, which is universally required for the maintenance of homeostasis in mammals, essential nutrients are indispensable for various cellular metabolic processes and maintaining tissue and organ function. In the case of humans, there are nine amino acids, two fatty acids, thirteen vitamins and fifteen minerals that are considered essential nutrients. Brief ideas about vitamins are mentioned in unit 3.

1.2.5. Fats

Called as lipids, oils provide excess energy 1gm provides 9 kcal of energy and help to absorb fat soluble vitamins. Fat is good storage form for energy source of essential fatty acids. Excess energy is converted to fat, classified as saturated, or unsaturated based on their structure. Saturated fats are associated with high cholesterol. Fats, oils, hormones and certain components of living beings membranes are come under the category of lipids. The lipids provide thermal insulation to body of living organisms. Triglycerides a form of lipid is sequestered as fat in adipose cells that serve as the energy-storage depot for organisms. The membranes of cells and organelles are microscopically thin structures formed from layers lipids which separate individual cells from their environments and to compartmentalize the cell interior into structures that carry out special functions.

1.2.6. Water

Required for survival Important for maintaining for solvent for many substances Regulates body temperature, transports many substances to all cells, is a lubricant Cells in the body require water to carry out their functions Almost 60% of the body is composed of water is lost from the body in the form of perspiration, exhalation and excretion for removing the waste products.

1.3. Measurement of caloric value of foods

On food labels, a Calorie is equal to 1000 calories. So, 1000 cal = 1 kcal = 1 Calorie. A calorie is a unit of energy. One calorie is the amount of energy needed to raise one gram of water by one degree Celsius. Essentially, the amount of calories a food produced is calculated by dehydrating it and burning it. The energy that it gives off is measured and used to calculate Calories. Food calorie is actually a kilocalorie. In other words it is the amount of energy needed to raise the temperature of one liter of water by one degree. Originally, the calorie content of a food was measured in a calorimeter. A known amount of food, which has had its water content evaporated, was placed in a container surrounded by a known amount of water. The container was sealed, oxygen piped in, and the food ignited. From the rise in temperature of the water, the calorie content of the food was calculated.

There were problems, however with this sort of calorie determination. Food can contain components such as fiber that will burn in a calorimeter but are not absorbed into the bloodstream and therefore do not contribute calories. The foodstuffs contain varying amounts of carbohydrates, fats, and proteins and therefore, the energy obtained from different foods varies. This can be determined by two methods – direct and indirect.

1.3.1. Direct method

The amount of food energy associated with a particular food could be measured by completely burning the dried food in a bomb calorimeter. In bomb calorimeter' where the oxygen is put in under considerable pressure. Since it requires a calorimeter of robust construction, it has been called a bomb calorimeter. Todays; producers use the Atwater indirect system to calculate calories by adding up the calories provided by the energy-containing nutrients: protein, carbohydrate, fat and alcohol. Because carbohydrates contain some fiber that is not digested and utilized by the body, the fiber component is usually subtracted from the total carbohydrate before calculating the calorie. However, the values given on food labels are not determined in this way. The reason for this is that direct calorimetry also burns the dietary fiber, and so does not allow for fecal losses; thus direct calorimetry would give systematic overestimates of the amount of fuel that actually enters the blood through digestion.

1.3.2. Indirect methods

The indirect methods of determination of caloric value is required volume of oxygen to burn the food sample is measured and the caloric value is calculated. The calculation is based on the principle that when 1 litre of oxygen is utilized in the oxidation of organic nutrients, approximately 4.8 Kcal of heat is liberated. The measurement of oxygen consumption which is a relatively simple technique is now universally employed to estimate the metabolic rate. This is indirect calorimetry.

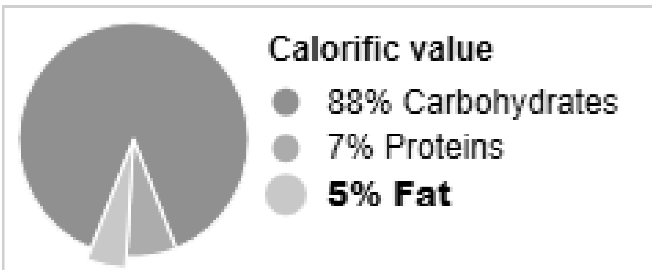

Fig.1.5: Chart of calorific values of nutrients

The energy obtained as a result of complete combustion is the potential energy but the energy liberated in the body is not the same, and this is called the physiological energy. Since carbohydrate and fats contain carbon, hydrogen and oxygen, they can be completely burnt to CO_2 and water and hence the potential energy is the same as the physiological energy. However, in the case of the proteins, the nitrogen is eliminated as urea etc. so the physiological energy is less than the potential energy. The total energy value of a food product results from the addition of the energy content of each nutrient components. These are defined as follows:

1 g fat	37 kJ (9 kcal)
1 g carbohydrates	17 kJ (4 kcal)
1 g protein	17 kJ (4 kcal)
1 g alcohol (ethanol)	29 kJ (7 kcal)
1 g polyhydric alcohols (polyols)	10 kJ (2.4 kcal)
1 g dietary fiber	8 kJ (2kcal)

1.4. Basal metabolic rates (BMR)

Basal metabolic rate (BMR) is the energy released when the subject is at complete mental and physical rest i.e. in a room with comfortable temperature and humidity, awake and sitting in a reclining position, 10-12 hours after the last meal. It is essentially the minimum energy required to maintain the heart rate, respiration, kidney function etc. The B.M.R. of an average Indian man is 1750-1900 Kcal/day. In terms of oxygen consumption it would amount to about 15 litre/hr. Heavily built persons have higher BMRs, but the BMR per unit body weight is higher in the smaller built individuals ex. although the BMR of a man as given above is higher than that of a boy of 15 kg body weight that spends about 800 Kcal/day for its basal metabolism, the BMR per kg/day of man is about 30 Kcal, while that of the boy is about 53 Kcal/kg/day. The variable that correlates most with the BMR is the surface area of the body. Thus in case of both boy and man the BMR is around 1000 Kcal/m^2 body surface/day.

The BMR is enough energy for the brain and central nervous system, heart, kidneys, liver, lungs, muscles, sex organs, and skin to function properly. People who are overweight or obese do not necessarily have a slow BMR. In fact, their BMR is usually faster to accommodate for extra fat and for their body to work harder to perform normal body functions. Building lean muscle mass can increase BMR, but there is a limit for both men and women as to how much lean muscle mass can be built. Some supplements may increase BMR, but also only to a limit, and they may have serious side effects.

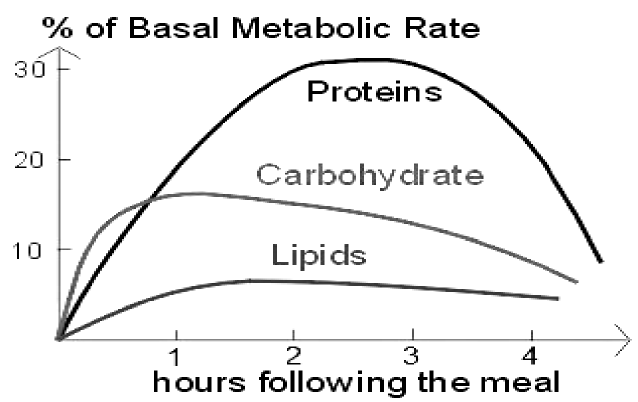

Fig.1.6: Basal metabolic rate

1.4.1. Concept of basal metabolic rate (BMR)

It is the rate of energy expenditure per unit time by endothermic animals at rest. It is reported in energy units per unit time ranging from watt (joule/second) to ml O_2/min or joule per hour per kg body mass J/(h·kg). Proper measurement requires a strict set of criteria be met. These criteria include being in a physically and psychologically undisturbed state, in a thermally neutral environment, while in the post-absorptive state (i.e., not actively digesting food). In brad metabolic animals, such as fish and reptiles, the equivalent term standard metabolic rate (SMR) is used. It follows the same criteria as BMR, but requires the documentation of the temperature at which the metabolic rate was measured. This makes BMR a variant of standard metabolic rate measurement that excludes the temperature data, a practice that has led to problems in defining "standard" rates of metabolism for many mammals.

Metabolism comprises the processes that the body needs to function. Basal metabolic rate is the amount of energy per unit time that a person needs to keep the body functioning at rest. Some of those processes are breathing, blood circulation, controlling body temperature, cell growth, brain and nerve function, and contraction of muscles. Basal metabolic rate (BMR) affects the rate that a person burns calories and ultimately whether that individual maintains, gains, or loses weight. The basal metabolic rate accounts for about 60 to 75% of the daily calorie expenditure by individuals. It is influenced by several factors. BMR typically declines by 1-2% per decade after age 20, mostly due to loss of fat-free mass, although the variability between individuals is high.

The body's generation of heat is known as thermogenesis and it can be measured to determine the amount of energy expended. BMR generally decreases with age, and with the decrease in lean body mass (as may happen with aging). Increasing muscle mass has the effect of increasing BMR. Aerobic (resistance) fitness level, a product of cardiovascular exercise, while previously thought to have effect on BMR, has been shown in the 1990s not to correlate with BMR when adjusted for fat-free body mass. But anaerobic exercise does increase resting energy consumption (aerobic vs. anaerobic exercise). Illness, previously consumed food and beverages, environmental temperature, and stress levels can affect one's overall energy expenditure as well as one's BMR.

BMR is measured under very restrictive circumstances when a person is awake. An accurate BMR measurement requires that the person's sympathetic nervous system not be stimulated, a condition which requires complete rest. A more common measurement, which uses less strict criteria, is resting metabolic rate (RMR). BMR may be measured by gas analysis through either direct or indirect calorimetry, though a rough estimation can be acquired through an equation using age, sex, height, and weight. Studies of energy metabolism using both methods provide convincing evidence for the validity of the respiratory quotient (RQ), which measures the inherent composition and utilization of carbohydrates, fats and proteins as they are converted to energy substrate units that can be used by the body as energy.

Glucose

Because the ratio of hydrogen to oxygen atoms in all carbohydrates is always the same as that in water-that is, 2 to 1- all of the oxygen consumed by the cells is used to oxidize the carbon in the carbohydrate molecule to form carbon dioxide. Consequently, during the complete oxidation of a glucose molecule, six molecules of carbon dioxide and six molecules of water are produced and six molecules of oxygen are consumed. The overall equation for this reaction is as under:

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

(38 ATP molecules)

Because the gas exchange in this reaction is equal, the respiratory quotient (R.Q.) for carbohydrate is unity or 1.0:

$$R.Q. = 6\ CO_2 / 6\ O_2 = 1.0$$

Fats

The chemical composition for fats differs from that of carbohydrates in that fats contain considerably fewer oxygen atoms in proportion to atoms of carbon and hydrogen. When listed on nutritional information tables, fats are generally divided into six categories: total fats, saturated fatty acid, polyunsaturated fatty acid, monounsaturated fatty acid, dietary cholesterol, and trans fatty acid. From a basal metabolic or resting metabolic perspective, more energy is needed to burn a saturated fatty acid than an unsaturated fatty acid.

The fatty acid molecule is broken down and categorized based on the number of carbon atoms in its molecular structure. The chemical equation for metabolism of the twelve to sixteen carbon atoms in a saturated fatty acid molecule shows the difference between metabolism of carbohydrates and fatty acids. Palmitic acid is a commonly studied example of the saturated fatty acid molecule. The overall equation for the substrate utilization of palmitic acid is:

$$C_{16}H_{32}O_2 + 23\ O_2 \rightarrow 16\ CO_2 + 16\ H_2O$$

Thus the R.Q. for palmitic acid is 0.696:

$$R.Q. = 16\ CO_2 / 23\ O_2 = 0.696$$

Proteins

Proteins are composed of carbon, hydrogen, oxygen, and nitrogen arranged in a variety of ways to form a large combination of amino acids. Unlike fat the body has no storage deposits of protein. All of it is contained in the body as important parts of tissues, blood hormones, and enzymes. The structural components of the body that contain these amino acids are continually undergoing a process of breakdown and replacement. The respiratory quotient for protein metabolism can be demonstrated by the chemical equation for oxidation of albumin:

$$C_{72}H_{12}N_{18}O_{22}S + 77\ O_2 \rightarrow 63\ CO_2 + 38\ H_2O + SO_3 + 9\ CO\ (NH_2)_2$$

The R.Q. for albumin is $63\ CO_2 / 77\ O_2 = 0.818$

The reason this is important in the process of understanding protein metabolism, is that the body can blend the three macronutrients based on the mitochondrial density, a preferred ratio can be established which determines how much fuel is utilized in which packets for work accomplished by the muscles. Protein catabolism (breakdown) has been estimated to supply 10% to 15% of the total energy requirement during a two-hour aerobic training session. This process could severely degrade the protein structures needed to maintain survival such as contractile properties of proteins in the heart, cellular mitochondria, myoglobin storage, and metabolic enzymes within muscles.

The oxidative system (aerobic) is the primary source of ATP supplied to the body at rest and during low intensity activities and uses primarily carbohydrates and fats as substrates. Protein is not normally metabolized significantly, except during long term starvation and long bouts of exercise (greater than 90 minutes.) At rest approximately 70% of the ATP produced is derived from fats and 30% from carbohydrates. Following the onset of activity, as the intensity of the exercise increases, there is a shift in substrate preference from fats to carbohydrates. During high intensity aerobic exercise, almost 100% of the energy is derived from carbohydrates, if an adequate supply is available.

1.4.2. Factors Influencing BMR

There are many factors that affect the BMR. These include body temperature, age, sex, race, emotional state, climate and circulating levels of hormones like catecholamine's (epinephrine and norepinephrine) and those secreted by the thyroid gland.

1. Genetics (Race)

Some people are born with faster metabolism and some with slower metabolism. Indians and Chinese seem to have a lower BMR than the Europeans. This may as well be due to dietary differences between these races. Higher BMR exists in individuals living in tropical climates. Ex. Singapore

2. Gender

Men have a greater muscle mass and a lower body fat percentage than women. Thus men have a higher basal metabolic rate than women. The BMR of females declines more rapidly between the ages of 5 and 17 than that of males.

3. Age

BMR reduces with age i.e. it is inversely proportional to age. Children have higher BMR than adults. After 20 years, it drops about 2 per cent, per decade.

4. Weight

The heavier the weight, the higher the BMR, ex. the metabolic rate of obese women is 25 percent higher than that of thin women.

5. **Body surface area**

This is a reflection of the height and weight. The greater the body surface area factor, the higher the BMR. Tall, thin people have higher BMRs. When a tall person is compared with a short person of equal weight, then if they both follow a diet calorie-controlled to maintain the weight of the taller person, the shorter person may gain up to 15 pounds in a year.

6. **Body fat percentage**

The lower the body fat percentage, the higher the BMR. The lower body fat percentage in the male body is one reason why men generally have a 10-15% higher BMR than women.

7. **Diet**

Starvation or serious abrupt calorie-reduction can dramatically reduce BMR by up to 30%. Restrictive low-calorie weight loss diets may cause BMR to drop as much as 20%. BMR of strict vegetarians is 11% lower than that of meat eaters.

8. **Body temperature/health**

For every increase of 0.5° C in internal temperature of the body, the BMR increases by about 7 percent. The chemical reactions in the body actually occur more quickly at higher temperatures. So a patient with a fever of 42° C (about 4° C above normal) would have an increase of about 50 percent in BMR. An increase in body temperature as a result of fever increases the BMR by 14-15% per degree centigrade which evidently, is due to the increased rate of metabolic reactions of the body.

9. **External temperature:**

Temperature outside the body also affects basal metabolic rate. Exposure to cold temperature causes an increase in the BMR, so as to create the extra heat needed to maintain the body's internal temperature. A short exposure to hot temperature has little effect on the body's metabolism as it is compensated mainly by increased heat loss. But prolonged exposure to heat can raise BMR.

10. **Glands:**

Thyroxine is a key BMR-regulator which speeds up the metabolic activity of the body. The more thyroxine produced, the higher the BMR. If too much thyroxine is produced (thyrotoxicosis) BMR can actually double. If too little thyroxine is produced (myxoedema) BMR may shrink to 30-40 percent of normal rate. Like thyroxine, adrenaline also increases the BMR but to a lesser extent. Anxiety and tension may not show on the face but they do produce an increased tensing of the muscles and release of norepinephrine even though the subject is seemingly quiet. Both these factors tend to increase the metabolic rate.

Significance of BMR

- The determination of BMR is the principal guide for diagnosis and treatment of thyroid disorders.
- If BMR is less than 10% of the normal, it indicates moderate hypothyroidism. In severe hypothyroidism, the BMR may be decreased to 40 to 50 percent below normal.
- BMR aids to know the total amount of food or calories required to maintain body weight.
- The BMR is low in starvation, under nutrition, hypothalamic disorders, Addison's disease and lipid nephrosis.
- The BMR is above normal in fever, diabetes insipidus, leukemia and polycythemia.

1.5. Dietary Recommendation (RDA)

Humans need a wide range of nutrients to lead a healthy and active life. The amount of each nutrient needed for an individual depends on age, body weight, physical activity, physiological state (pregnancy, lactation) etc. So basically the requirement for nutrients varies from individual to individual. The requirement for a particular nutrient is the minimum amount that needs to be consumed to prevent symptoms of deficiency and to maintain satisfactory level of the nutrient in the body. The first attempt to recommended dietary allowances of energy, protein, iron, calcium, vitamin A, thiamine, ascorbic acid and vitamin D for Indian was made by the nutrition advisory committee of the League of Nations in 1937. RDA is defined as the nutrient present in diet which satisfies the daily requirement of nearly all individual of population. This implies addition of safety factor amount to the estimated requirement to cover.

- Variation among individuals
- Losses drinking cooking
- Lack of precision in estimated requirement
- Recommended Dietary Allowances = Requirements + Safety factor

The recommended dietary allowances (RDA) are the levels of intake of the essential nutrients that are judged to be adequate or sufficient to meet the nutrient requirement of nearly all (97 to 98 percent) healthy individuals in a particular life stage and gender group. RDA of individuals depends on many factors likes such as:

- Age
- Sex

- Physical work
- Physiological stress

For the entire nutrient (except energy) estimates of allowances are arrived at by determining the average. Taking mean requirement of nutrients add adding to it twice the standard division of the mean.

$$\text{Requirement} = \text{mean} \pm 2SD$$

The value will meet more than 97.5% of the population which is composed of individuals with a satisfactory normal distribution of requirements.

Protein

Dietary protein provides amino acids for synthesis of body protein and other biologically important nitrogenous compounds. During pregnancy and lactation, lactation, additional proteins are required for

- Synthesis of foetal tissue protein.
- Synthesis of milk proteins.
- Dietary protein should provide all eight essential amino acids.

1.6. Public Health Nutrition: Basic Concept

Nutrition, as you may be aware, is one of the major determinants of the health and well-being of individuals in a society. So an area of study which emphasizes the application of food and nutrition knowledge, policy and research to the improvement of health of populations is called public health nutrition. It is primarily concerned with improving nutrition in population groups. Study of public health nutrition may, therefore, include an understanding of:

- The most critical social, behavioral and food and nutrition factors that affect health,
- Nature, causes and consequences of nutrition problems, malnutrition in a society,
- Nutritional requirements and dietary guidelines for populations,
- Design, planning, implementation and evaluation of nutritional programmers and how
- They can improve the nutritional status of the population.

1.7. Malnutrition

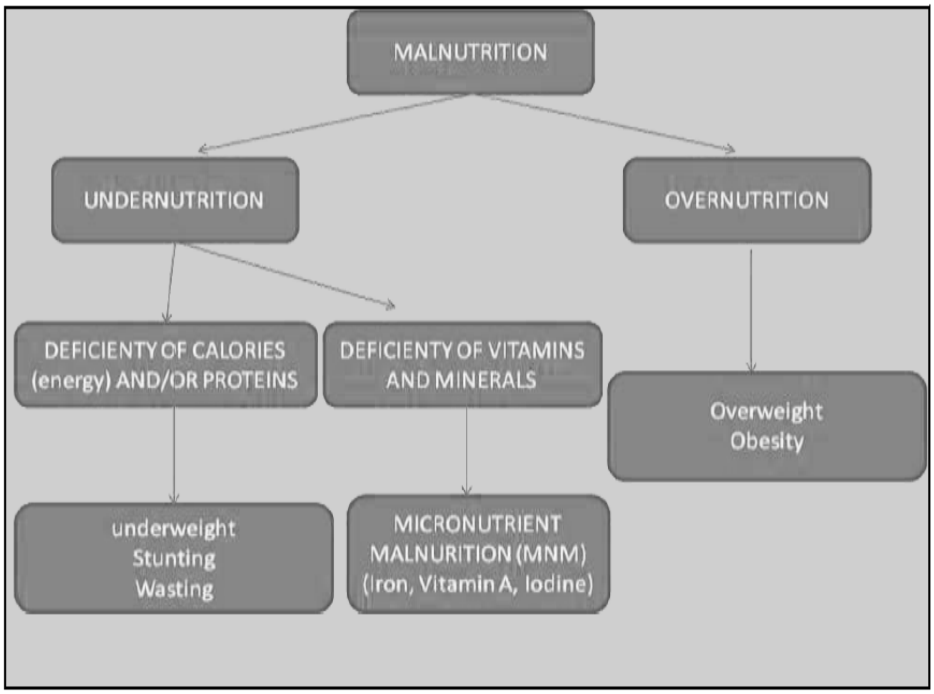

Fig.1.7: Flow chart of malnutrition

Malnutrition is often used to specifically refer to undernutrition where an individual is not getting enough calories, protein, or micronutrients. Malnutrition is a condition that results from eating a diet in which one or more nutrients are either not enough or are too much such that the diet causes health problems.

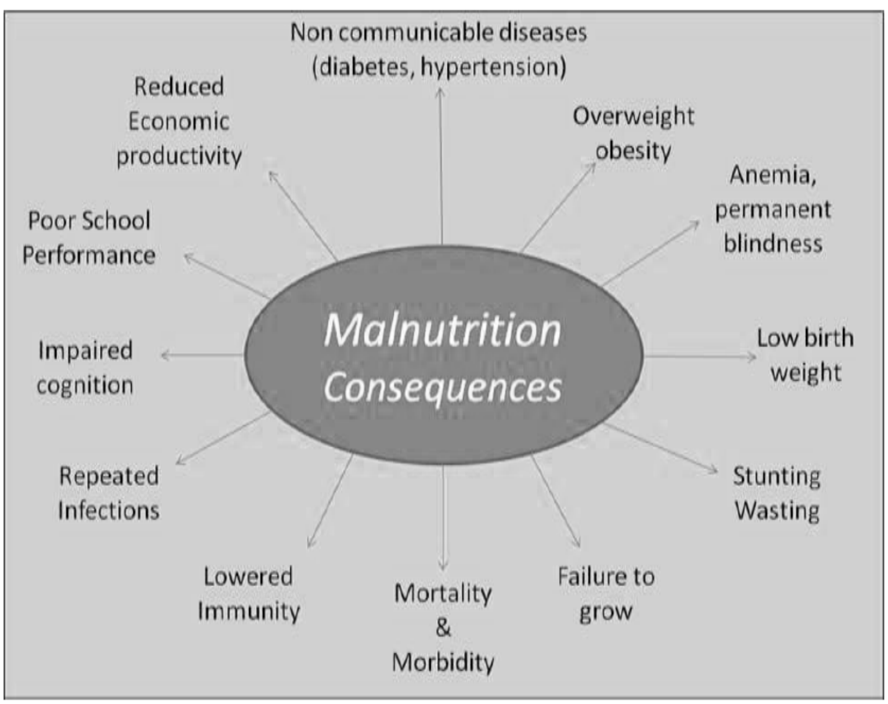

Fig1.8: Flow chart of malnutrition consequences

There are two main types of under nutrition: protein-energy malnutrition and dietary deficiencies. Protein-energy malnutrition has two severe forms: marasmus (a lack of protein and calories) and kwashiorkor (a lack of just protein). Common micronutrient deficiencies include: a lack of iron, iodine, and vitamin A. During pregnancy, due to the body's increased need, deficiencies may become more common. In some developing countries, overnutrition in the form of obesity is beginning to present within the same communities as undernutrition. Other causes of malnutrition include anorexia nervosa and bariatric surgery.

1.7.1. Under nutrition and over nutrition

Malnutrition is caused by eating a diet in which nutrients are not present in optimum range. They are either insufficient enough or is too much such that it causes health problems. It is a category of diseases that includes under nutrition and over nutrition. Over nutrition can result in obesity and being overweight. In some developing countries, over nutrition in the form of obesity is beginning to present within the same communities as undernutrition. However, the term malnutrition is commonly used to refer to undernutrition only. This applies particularly to the context of development cooperation. Therefore, malnutrition in documents by the World Health Organization, UNICEF, save the children or other international non-governmental organizations (NGOs) usually is equated to undernutrition.

1.7.2. Protein-energy malnutrition (PEM)

Undernutrition is sometimes used as a synonym of protein–energy malnutrition (PEM). While other include both micronutrient deficiencies and protein energy malnutrition in its definition. It differs from calorie restriction in that calorie restriction may not result in negative health effects. The term hypo alimentation means underfeeding. The term severe malnutrition or severe undernutrition is often used to refer specifically to PEM. PEM is often associated with micronutrient deficiency. Two forms of PEM are kwashiorkor and marasmus, and they commonly coexist.

The affected child (or adult) is very thin (skin and bones), most of the fat and muscle mass having been expended to provide energy. Marasmus is the most frequent form of PEM in conditions of severe food shortage. Associated signs of the condition are

- A thin old face
- Baggy pants (the loose skin of the buttocks hanging)
- Affected children may appear to be alert in spite of their condition.
- There is no edema of the lower extremities.
- Prominent ribs

Kwashiorkor usually affects children aged between 1-4 years. The main sign is edema, usually starting in the legs and feet and spreading, in more advanced cases, to the hands and face. Because of edema, children with kwashiorkor may look "fat" so that their parents regard them as well fed. Other signs of kwashiorkor are:

(a) Hair changes: loss of pigmentation; curly hair becomes straight, easy pluck-ability.

(b) Skin lesions and depigmentation: dark skin may become lighter in some places, especially in the skin folds; outer layers of skin may peel off (especially on legs), and ulceration may occur; the lesions may resemble burns.

(c) Children with kwashiorkor are usually apathetic, miserable, and irritable. They show no signs of hunger, and it is difficult to persuade them to eat.

1.7.3. Consequences of Malnutrition

The malnutrition can be occurs due to lack or excess of nutrients. Children under five years of age, adolescent, pregnant, lactating mothers, the elderly and the chronically ill occurs due consequence of malnutrition. In the long term chronic malnutrition during pregnancy and early childhood manifest as stunted growth (low height for age) and wasting (low weight for height). Children who are malnourished in the early years of life fail to grow and develop to their full potential, both physically and mentally. The consequences of stunting extend to adulthood increasing the risk of poor pregnancy outcome (i.e. the newborn is of low birth weight), impaired cognition that results in poor school performance, reduced economic productivity and earning.

1.7.3.1. Kwashiorkor

Kwashiorkor is mainly caused by inadequate protein intake. The main symptoms are edema, wasting, liver enlargement, hypoalbuminaemia, steatosis, and possibly depigmentation of skin and hair. Kwashiorkor is further identified by swelling of the belly, which is deceiving of actual nutritional status. The term means 'displaced child' and is derived from a Ghana language of West Africa, means the sickness the older one gets when the next baby is born, as this is when the older child is deprived of breast feeding and weaned to a diet composed largely of carbohydrates.

1.7.3.2. Marasmus

Marasmus is caused by an inadequate intake of protein and energy. The main symptoms are severe wasting, leaving little or no edema, minimal subcutaneous fat, severe muscle wasting, and non-normal serum albumin levels. Marasmus can result from a sustained diet of inadequate energy and protein, and the metabolism adapts to prolong survival. It is traditionally seen in famine, significant food restriction, or more severe cases of anorexia. Conditions are characterized by extreme wasting of the muscles and a gaunt expression. The basal metabolic rate (BMR) is the amount of energy that is expended at rest in a neutral environment after the digestive system has been inactive for about 12 hours. It is the rate of one's metabolism when waking in the morning after fasting during sleep.

1.8. Summary

We know that the nutrients are essential for our growth and development. Carbohydrates, fats, dietary fiber, minerals, proteins, vitamins and water are main source of our nutrients. The is considered main source of nutrient that is provide energy and fuel to the body to do daily activities as simple as walking and talking and as complex as running and moving heavy objects. Like carbohydrate he protein is also chief constituents of nutrients derived generally form animal sources like beef, pork and plants sources like soybeans legumes plants. Dietary fat, which is found in oils, poultry and fish etc., provides structure to cells and cushions membranes to help prevent damage. Vitamins aid in energy production, wound healing, bone formation, immunity, and eye and skin health.

Minerals help to maintain cardiovascular health and provide structure to the skeleton. Consuming a balanced diet including fruits, vegetables, dairy, protein foods and whole or enriched grains helps ensure the body has plenty of nutrients to use. Minerals found in the earth's crust include things like salt, coal, iron, ore, shale, and diamonds, just to name a few. Calorie is the amount of energy needed to raise the temperature of one liter of water by one degree. Basal metabolic rate is the number of calories required to keep your body functioning at rest. BMR is also known as your body's metabolism; therefore, any increase to your metabolic weight, such as exercise will increase your BMR. There are many factors that affect the BMR.

These include body temperature, age, sex, race, emotional state, climate and circulating levels of hormones. Malnutrition is a condition that results from eating a diet in which one or more nutrients are either not enough or are too much such that the diet causes health problems. Poor nutrition can lead to reduced immunity, increased susceptibility to disease, impaired physical and mental development, and reduced productivity.

1.9. Terminal questions

Q.1. What are the nutrients? Define the role of different nutrients.

Answer:--

Q.2. How carbohydrates are considered as a nutrient? Write a brief note on it.

Answer:---

Q.3. Discuss briefly about different nutrients for healthy body.

Answer:---

Q.4. What are food calories? Discuss briefly.

Answer:---

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Q.5. What is BMR? Discuss about various factors affecting on BMR.

Answer:---

Q.6. What are the malnutrietns? Define about under and over nutrients.

Answer:---

1.10. Further questions

1. Nutrition and Dietetics, by Shubhangini A. Joshi
2. The Great Indian Diet by Luke Coutinho and Shilpa Shetty
3. Clinical Dietetics and Nutrition, by Antia F P
4. David L. Nelson and Michael M. Cox, Lehninger Principles of Biochemistry 6th Edition
5. Jeremy M. Berg, John L. Tymockzo and Luber Stryer, Biochemistry 7th Edition
6. Reginald H. Garrett, Charles M. Grisham, Biochemistry by Reginald H Garrett 5th Edition.

UNIT : 2

ELEMENTS OF NUTRITION

Structure:

2.1. Introduction

The type and amount of carbohydrates consumed by a person may have important an implications for health. With widespread promotion of low-fat diet these is need of reduction in the percentage of dietary calories from fat and an increase in carbohydrate intake. Carbohydrate is the only macronutrient with no established minimum requirement. It is traditionally classified as simple starches or complex starches on the basis of the number of sugar molecules in their chemical structures. Our bodies need protein from the foods we eat to build and maintain bones, muscles and skin. We get proteins in our diet from meat, dairy products, nuts, and certain grains and beans. Dietary lipids for humans and other animals are animal and plant triglycerides, sterols, and membrane phospholipids.

The process of lipid metabolism synthesizes and degrades the lipid stores and produces the structural and functional lipids characteristic of individual tissues. Vitamins and minerals are divided into four categories: water-soluble vitamins, fat-soluble vitamins, and macrominerals and trace minerals are essential for human diet. *There are 2 important aspects of protein quality: 1) the characteristics of the protein and the food matrix in which it is consumed, and 2) the demands of the individual consuming the food, as influenced by age, health status, physiologic status, and energy balance.*

Objectives:

- To the Dietary requirement of carbohydrates, protein and lipids.
- To discuss the roles of macro and micronutrients in human health.
- To discuss the protein quality assessment.
- Discuss about essential fatty acids and their physiological functions.

2.2. Dietary requirements of carbohydrates

Carbohydrate is the only macronutrient with no established minimum requirement. Although many populations have thrived with carbohydrate as their main source of energy, others have done so with few if any carbohydrate containing foods throughout much of the year (e.g. traditional diets of the inuit, laplanders, and some native Americans). If carbohydrate is not necessary for survival, it raises questions about the amount and type of this macronutrient needed for optimal health, longevity, and sustainability. This review focuses on these current controversies, with special focus on obesity, diabetes, cardiovascular disease, cancer, and early death.

Carbohydrates are found in a wide array of both healthy and unhealthy foods such as breads, beans, milk, popcorn, potatoes, cookies, spaghetti, soft drinks, corn, and cherry pie. They also come in a variety of forms. The most common and abundant forms are sugars, fibers, and starches. Foods high in carbohydrates are an important part of a healthy diet. Carbohydrates provide the body with glucose, which is converted to energy used to support bodily functions and physical activity. But carbohydrate quality is important; some types of carbohydrate-rich foods are better than others**:**

Carbohydrates are subdivided into several categories on the basis of the number of sugar units and how the sugar units are chemically bonded to each other. Categories include sugars, starches, and fibers. Sugars are intrinsic in fruits and milk products. Sugars also are added to foods during processing and preparation or at the table. These added sugars (or extrinsic sugars) sweeten the flavor of foods and beverages and improve their palatability. Sugars are also used in food preservation and for functional properties such as viscosity, texture, body, and browning capacity. They provide calories but insignificant amounts of vitamins, minerals, or other essential nutrients. The nutrition facts label provides information on total sugars per serving but does not currently distinguish between sugars naturally present in foods and added sugars.

2.2.1. Types of carbohydrates

Carbohydrates are among the most abundant compounds on earth. They are normally broken down into five major classifications of carbohydrates:

- Monosaccharides
- Disaccharides
- Oligosaccharides
- Polysaccharides
- Nucleotides

2.2.1.1. Monosaccharides

The word monosaccharide is derived from mono, meaning one, and saccharide, meaning sugar. The common monosaccharides are glucose, fructose, and galactose. Each simple sugar has a cyclic structure and is composed of carbon, hydrogen and oxygen in ratios of 1:2:1 respectively. Although each sugar mainly exists as a cyclic compound, it is important to note that they are all in equilibrium to a small extent with their linear forms.

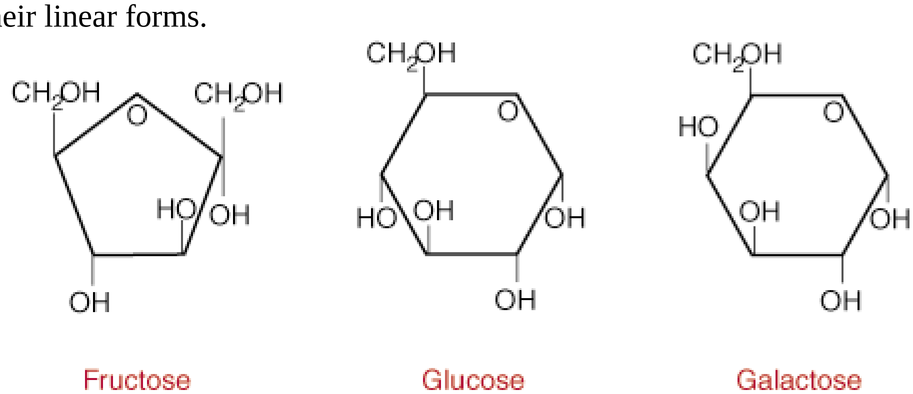
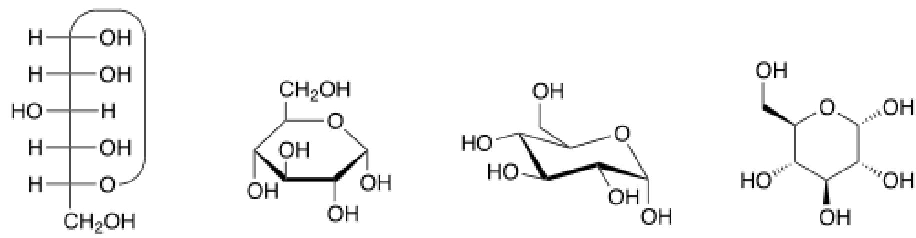


Fig. 2.1: Different types of monosaccharides

While galactose and glucose are composed of six-membered rings, fructose has only five carbon atoms bonded to each other in ring form.

Glucose

Glucose is the main sugar metabolized by the body for energy. The D-isomer of glucose predominates in nature and it is for this reason that the enzymes in our body have adapted to binding this form only. Since it is an important energy source, the concentration of glucose in the bloodstream usually falls within a narrow range of 70 to 115mg/100 ml of blood. Sources of glucose include starch, the major storage form of carbohydrate in plants.



1 2 3 4

Fig.2.2: Different structures of glucose (Aldose)

Galactose

Galactose is nearly identical to glucose in structure except for one hydroxyl group on carbon atom number four of the six-sided sugar. Since it differs in only one position about all six asymmetric centers in the linear form of the sugar, galactose is known as an epimer of glucose. Galactose is not normally found in nature in large quantities; however it combines with glucose to form lactose in milk. After being absorbed by the body, galactose is converted into glucose by the liver so that it can be used to provide energy for the body. Both galactose and glucose are very stable in solution because they are able to adopt chair and boat conformations.

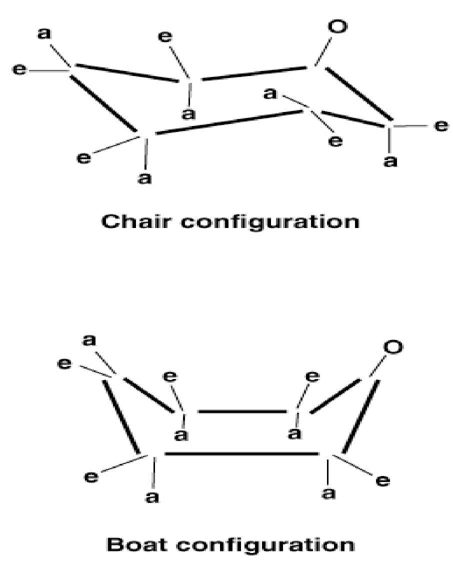


Fig. 2.3: Chair and Boat Conformations

These conformations are most stable because their OH groups are pointed away from the structure, preventing steric hindrance.

Fructose

Fructose is a structural isomer of glucose, meaning it has the same chemical formula but a completely different three-dimensional structure. The main difference is that fructose is a ketone in its linear form while glucose is an aldehyde. Through an intramolecular addition reaction with the C-5 OH group, glucose forms a six-membered ring while fructose forms a five-membered ring as seen in Figure 1. Upon consumption, fructose is absorbed and converted into glucose by the liver in the same manner as lactose. Sources of fructose include fruit, honey and high-fructose corn syrup.

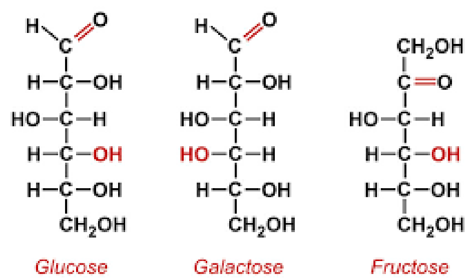


Fig. 2.4: Structures of Glucose, Galactose and Fructose

2.2.1.2. Disaccharides

Disaccharides, meaning two sugars, are commonly found in nature as sucrose, lactose and maltose. They are formed by a condensation reaction where one molecule of water condenses or is released during the joining of two monosaccharides. The type of bond that is formed between the two sugars is called a glycosidic bond.

2.3. Lipids

In biology and biochemistry, a lipid is a biomolecules that is soluble in nonpolar solvents.. Non-polar solvents are typically hydrocarbons used to dissolve other naturally occurring hydrocarbon lipid molecules that do not (or do not easily) dissolve in water, including fatty acids, waxes, sterols, fat-soluble vitamins (such as vitamins A, D, E, and K), monoglycerides, diglycerides, triglycerides, and phospholipids. The functions of lipids include storing energy, signaling, and acting as structural components of cell membranes. Lipids have applications in the cosmetic and food industries as well as in nanotechnology.

Scientists sometimes broadly define lipids as hydrophobic or amphiphilic small molecules; the amphiphilic nature of some lipids allows them to form structures such as vesicles, multilamellar/unilamellar liposomes, or membranes in an aqueous environment. Biological lipids originate entirely or in part from two distinct types of biochemical subunits or building-blocks: ketoacyl and isoprene groups.

Using this approach, lipids may be divided into eight categories: fatty acids, glycerolipids, glycerophospholipids, sphingolipids, saccharolipids,and polyketides (derived from condensation of ketoacyl subunits); and sterol lipids and phenol lipids (derived from condensation of isoprene subunits). Although the term lipid is sometimes used as a synonym for fats, fats are a subgroup of lipids called triglycerides. Lipids also encompass molecules such as fatty acids and their derivatives (including tri-, di-, monoglycerides, and phospholipids), as well as other sterol-containing metabolites such as cholesterol. Although humans and other mammals use various biosynthetic pathways both to break down and to synthesize lipids, some essential lipids can't be made this way and must be obtained from the diet.

2.3.1. Fatty acids

Fatty acids, or fatty acid residues when they are part of a lipid, are a diverse group of molecules synthesized by chain-elongation of an acetyl-CoA primer with malonyl-CoA or methylmalonyl-CoA groups in a process called fatty acid synthesis. They are made of a hydrocarbon chain that terminates with a carboxylic acid group; this arrangement confers the molecule with a polar, hydrophilic end, and a nonpolar, hydrophobic end that is insoluble in water. The fatty acid structure is one of the most fundamental categories of biological lipids, and is commonly used as a building-block of more structurally complex lipids.

The carbon chain, typically between four and 24 carbons long, may be saturated or unsaturated, and may be attached to functional groups containing oxygen, halogens, nitrogen, and sulfur. If a fatty acid contains a double bond, there is the possibility of either a cis or trans geometric isomerism, which significantly affects the molecule's configuration. Cis-double bonds cause the fatty acid chain to bend, an effect that is compounded with more double bonds in the chain. Three double bonds in 18-carbon linolenic acid.

2.3.2. Glycerolipids

Glycerolipids are composed of mono-, di-, and tri-substituted glycerol, the best-known being the fatty acid trimesters of glycerol, called triglycerides. The word triacylglycerol is sometimes used synonymously with "triglyceride". In these compounds, the three hydroxyl groups of glycerol are each esterified, typically by different fatty acids. Because they function as an energy store, these lipids comprise the bulk of storage fat in animal tissues. The hydrolysis of the ester bonds of triglycerides and the release of glycerol and fatty acids from adipose tissue are the initial steps in metabolizing fat. Additional subclasses of glycerolipids are represented by glycosylglycerols, which are characterized by the presence of one or more sugar residues attached to glycerol via a glycosidic linkage. Examples of structures in this category are the digalactosyl and diacylglycerols found in plant membrane and seminolipid from mammalian sperm cells.

2.3.3. Glycerophospholipids

Glycerophospholipids, usually referred to as phospholipids (though sphingomyelins are also classified as phospholipids), are ubiquitous in nature and are key components of the lipid bilayer of cells, as well as being involved in metabolism and cell signaling. Neural tissue (including the brain) contains relatively high amounts of glycerophospholipids, and alterations in their composition have been implicated in various neurological disorders. Glycerophospholipids may be subdivided into distinct classes, based on the nature of the polar head group at the sn-3 position of the glycerol backbone in eukaryotes and eubacteria, or the sn-1 position in the case of archaebacteria.

2.3.4. Sphingolipids

Sphingolipids are a complicated family of compounds that share a common structural feature, a sphingoid base backbone that is synthesized the novel from not the amino acid serine and a long-chain fatty acyl CoA, then converted into ceramides, phosphosphingolipids, glycosphingolipids and other compounds. The major sphingoid base of mammals is commonly referred to as sphingosine. Ceramides (N-acyl-sphingoid bases) are a major subclass of sphingoid base derivatives with an amide-linked fatty acid. The fatty acids are typically saturated or mono-unsaturated with chain lengths from 16 to 26 carbon atoms.

2.4. Dietary requirement of Proteins

Proteins are large biomolecules or macromolecules, consisting of one or more long chains of amino acid residues. Proteins perform a vast array of functions within organisms, including catalysing metabolic reactions, DNA replication, responding to stimuli, providing structure to cells and organisms, and transporting molecules from one location to another. Proteins differ from one another primarily in their sequence of amino acids, which is dictated by the nucleotide sequence of their genes, and which usually results in protein folding into a specific three-dimensional structure that determines its activity.

They are biological polymers composed of amino acids. Amino acids, linked together by peptide bonds, form a polypeptide chain. One or more polypeptide chains twisted into a 3-D shape form a protein. Proteins have complex shapes that include various folds, loops, and curves. Folding in proteins happens spontaneously. Chemical bonding between portions of the polypeptide chain aid in holding the protein together and giving it its shape.

There are two general classes of protein molecules: globular proteins and fibrous proteins. Globular proteins are generally compact, soluble, and spherical in shape. Fibrous proteins are typically elongated and insoluble. Globular and fibrous proteins may exhibit one or more of four types of protein structure.

A linear chain of amino acid residues is called a polypeptide. A protein contains at least one long polypeptide. Short polypeptides, containing less than 20-30 residues, are rarely considered to be proteins and are commonly called peptides, or sometimes oligopeptides. The individual amino acid residues are bonded together by peptide bonds and adjacent amino acid residues. The sequence of amino acid residues in a protein is defined by the sequence of a gene, which is encoded in the genetic code.

In general, the genetic code specifies 20 standard amino acids; however, in certain organisms the genetic code can include selenocysteine and-in certain archaea-pyrrolysine. Shortly after or even during synthesis, the residues in a protein are often chemically modified by post-translational modification, which alters the physical and chemical properties, folding, stability, activity, and ultimately, the function of the proteins. Sometimes proteins have non-peptide groups attached, which can be called prosthetic groups or cofactors. Proteins can also work together to achieve a particular function, and they often associate to form stable protein complexes.

2.4.1. Essential amino acids

The amino acids which cannot be synthesized by the body and, therefore, need to be supplied through the diet are called essential amino acids. They are required for proper growth and maintenance of the individual. The ten amino acids essential for humans are – Arginine, Valine, Histidine, lsoleucine, Leucine, Lysine, Methionine, Phenylalanine, Threonine, Tryptophan. Of the ten listed above, two amino acids namely Arginine and Histidine can be partly synthesized by adults and not by growing children, hence these are considered as semi-essential amino acids. Thus, 8 amino acids are absolutely essential while 2 are semi-essential.

2.4.2. Concept of protein quality

We know the protein is the biopolymer of amino acids that is the building block of living body. The assessment of protein quality is describes by its characteristics features related to their metabolic actions. However, the protein quality is discussed in context of a protein's ability to provide specific patterns of amino acids composition and their digestibility and bioavailability to satisfy the demands for synthesis of protein as measured by animal growth or, in humans, nitrogen balance.

It has long been known that proteins differ greatly in their nutritive value. This can be demonstrated grossly by any number of methods such as comparison of rates of growth, nitrogen retention, or other measures of physiological performance of animals or human subjects. New research reveals increasingly complex roles for protein and amino acids in regulation of body composition and bone health, gastrointestinal function and bacterial flora, glucose homeostasis, cell signaling, and satiety. There are 2 important aspects of protein quality:

1) *The characteristics of the protein and the food matrix in which it is consumed, and*

2) *The demands of the individual consuming the food, as influenced by age, health status, physiologic status, and energy balance.*

Methods of Estimating Protein Quality

There are several methods for estimation of protein quality in which some has been discussed as following:

a) ***Biological Value (BV)***

Biological value, as defined by Thomas and Mitchell has long been considered the method of choice for estimating the nutritive value of proteins. It has neen *defined as the "percentage of absorbed nitrogen retained in the body" and a complete evaluation of the dietary protein includes measurement of the Biological Value and the Digestibility. These values are obtained by measuring the fecal and urinary nitrogen when the test protein is fed and correcting for the amounts excreted when a nitrogen-free diet is fed. True digestibility is defined as the percentage of food nitrogen absorbed from the gut and biological value as*

$$\text{Digestibility} \quad \frac{I - (F - F_o)}{I}$$

$$BV = \frac{I - (F - F_o) - (U - U_o)}{I - (F - F_o)} \ \text{x} \ 100$$

Where

I = Nitrogen intake of test protein

F = Fecal nitrogen

Fo = Fecal nitrogen on nitrogen-free diet (Metabolic N)

U = Urinary nitrogen

Uo = Urinary nitrogen on nitrogen-free diet (Endogenous N)

b) ***Net Protein Utilization (NPU)***

Like Biological Value, NPU estimates nitrogen retention but in this case by determining the difference between the body nitrogen content of animals fed no protein and those fed a test protein. This value divided by the amount of protein consumed is the NPU which is defined as the "percentage of the dietary protein retained". Miller proposed a procedure which involved replicate groups of 4 weanling rats housed in group cages which were fed either the "protein-free" or the "test" diet for 10 days. These conditions were chosen empirically and the particular merits of these conditions remain to be demonstrated. Since both NPU and BV are based upon estimates of "retained nitrogen", they should measure the same thing except that in the calculation of NPU the denominator is the total protein eaten whereas in the calculation of BV it is the amount absorbed.

c) ***Protein Efficiency Ratio (PER)***

Protein Efficiency Ratio (PER) is most widely used methods of its simplicity. Osborne, Mendel and Ferry observed that young rats fed certain proteins gained little weight and ate little protein whereas those which were fed better quality proteins gained more weight and consumed more protein. In an attempt to compensate for the difference in food intake, they calculated the gain in weight per gram of protein eaten and this has been called PER. It is known that the PER for any protein is dependent upon the amount of protein incorporated in the test diet.

d) ***Net Protein Ration (NPR)***

Net Protein Ratio (NPR) is calculated as the overall difference in gain (gain in weight of the test group plus loss in weight of the protein-free group) divided by the protein eaten. It is apparent that if body composition is constant, this procedure is identical to NPU.

e) ***Amino Acid Score***

Block and Mitchell originally proposed that since all amino acids must be present at the site of protein synthesis in adequate amounts if protein synthesis is to proceed, a comparable deficit of any amino acid would limit protein synthesis to the same degree. Amino Acid Scores have been widely used since that time. Generally they have been calculated as the "percentage of adequacy" rather than as deficits. Amino Acid Scores be calculated from an amino acid pattern that is based upon estimates of amino acid requirements in man.

2.4.3. Physiological Function of Essential amino acids

Amino acids are compounds that combine to make proteins. When a person eats a food that contains protein, their digestive system breaks the protein down into amino acids. The body then combines the amino *acids in various ways to carry out bodily functions. There are several physiological functions of essential amino acids.*

- *Amino acids form our muscles, tissues, organs, and glands.*
- *Amino acids support human metabolism, protect the heart, and make it possible for our bodies to heal wounds and repair tissues.*
- *Amino acids are also essential for breaking down foods and removing waste from our bodies.*
- *Tryptophan and tyrosine are amino acids that produce neurotransmitters. Tryptophan produces the mood-regulating chemical serotonin and can make you sleepy.*
- *The amino acid arginine is essential to the production of nitric oxide which lowers blood pressure and helps to protect the heart.*
- *Histidine makes the enzymes needed to produce red blood cells and healthy nerves.*
- *Tyrosine is used in the production of thyroid hormones.*
- *Methionine makes a chemical called SAMe which is essential for the metabolism of DNA and neurotransmitters.*

2.5. Nutrients

2.5.1. Macronutrients

Macronutrients are defined in several ways.

- The chemical elements humans consume in the largest quantities are carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulphur, summarized as CHNOPS.
- The chemical compounds that humans consume in the largest quantities and provide bulk energy are classified as carbohydrates, proteins, and fats. Water must be also consumed in large quantities.
- Calcium, sodium, potassium, magnesium, and chloride ions, along with phosphorus and sulfur, are listed with macronutrients because they are required in large quantities compared to micronutrients, i.e., vitamins and other minerals, the latter often described as trace or ultratrace minerals.

Macronutrients provide energy:

- Carbohydrates are compounds made up of different types of sugar. They are classified according to their number of sugar units: monosaccharides (such as glucose and fructose), disaccharides (suchas sucrose and lactose), oligosaccharides,and polysaccharides (such as starch, glycogen, and cellulose).

- ❖ Proteins are organic compounds that consist of amino acids joined by peptide bonds. Since the body cannot manufacture some of the amino acids (termed essential amino acids), the diet must supply them. Through digestion, proteins are broken down by proteases back into free amino acids.

- ❖ Fats consist of a glycerin molecule with three fatty acids attached. Fatty acid molecules contain a -COOH group attached to unbranched hydrocarbon chains connected by single bonds alone (saturated fatty acids) or by both double and single bonds (unsaturated fatty acids).

- ❖ Fats are needed for construction and maintenance of cell membranes, to maintain a stable body temperature, and to sustain the health of skin and hair. Because the body does not manufacture certain fatty acids (termed essential fatty acids), they must be obtained through one's diet.

- ❖ Fat has an energy content of 9 kcal/g (~37.7 kJ/g) and proteins and carbohydrates 4 kcal/g (~16.7 kJ/g).

2.5.2. Micronutrients

Macronutrients, on the other hand, include proteins, fats and carbohydrates. Your body needs smaller amounts of micronutrients relative to macronutrients. That’s why they’re labeled “micro.” Human being must obtain micronutrients from food since your body cannot produce vitamins and minerals- for the most part. That’s why they’re also referred to as essential nutrients. Vitamins are organic compounds made by plants and animals which can be broken down by heat, acid or air. On the other hand, minerals are inorganic, exist in soil or water and cannot be broken down. When you eat, you consume the vitamins that plants and animals created or the minerals they absorbed.

The micronutrient content of each food is different, so it’s best to eat a variety of foods to get enough vitamins and minerals. An adequate intake of all micronutrients is necessary for optimal health, as each vitamin and mineral has a specific role in your body. Vitamins and minerals are vital for growth, immune function, brain development and many other important functions. Depending on their function, certain micronutrients also play a role in preventing and fighting disease).

2.5.2.1. Types and Functions of Micronutrients

Vitamins and minerals can be divided into four categories: water-soluble vitamins, fat-soluble vitamins, and macrominerals and trace minerals. Vitamins and minerals are absorbed in similar ways in your body and interact in many processes. Micronutrients act as cofactors and/or coenzymes in the liberation of energy from food. A limited intake can disturb energy balance and can lead to numerous side effects. Some factors that have been associated with attaining a negative energy balance include:

- Meal replacement supplements/super shakes
- Green tea
- Low energy density foods (veggies, fruits, lean proteins, whole grains, etc.)
- Dietary protein
- Avoidance of refined carbohydrates
- Adequate hydration
- Dietary fiber
- Fruits
- Vegetable
- Regular exercise
- Adequate sleep
- Positive social support
- Regular nut consumption

2.6. Summary

Dietary carbohydrates are carbohydrates present in food, including sugars, starches, celluloses and gums. Carbohydrates serve as a major energy source of animaldiets. They also come in a variety of forms. The most common and abundant forms are sugars, fibers, and starches. There are two types of carbohydrates: complex and simple. Foods rich in complex carbohydrates and fiber are called good carbohydrates. Proteins perform a vast array of functions within organisms, including catalyzing metabolic reactions, DNA replication, responding to stimuli, providing structure to cells and organisms, and transporting molecules from one location to another. The protein quality is discussed in context of a protein's ability to provide specific patterns of amino acids composition and their digestibility and bioavailability to satisfy the demands for synthesis of protein as measured by animal growth or, in humans, nitrogen balance. The nutrient uptake directly affects the growth of plants. This condition is described as nutrient toxicity and/or nutrient deficiency. Protein quality can be assess by biological value (BV), net protein utilization (NPU), protein efficiency ratio (PER),net protein ration (NPR) and amino acid score. Amino acids support human metabolism, protect the heart, and make it possible for our bodies to heal wounds and repair tissues.

2.7. Terminal Questions

Q.1. What is dietary carbohydrate? How it is useful in human diet.

Answer:---

Q.2. Discuss the role of dietary proteins in human health.

Answer:---

Q.3. What are micro and macro nutrients?

Answer:---

Q.4. Discuss about dietary requirement of proteins.

Answer:---

Q.5. What do you understand by protein quality? Discuss the various methods to determine the protein quality.

Answer:---

Q.6. Discuss the physiological function of proteins and amino acids.

Answer:---

2.8. Further readings

1. Biochemistry- Lehninger A.L.
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Nutrition and Physiology

Uttar Pradesh Rajarshi Tandon Open University

BLOCK

2

VITAMINS, MINERALS AND PHYSIOLOGY

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Introduction

The second block on nutrition and physiology consists of following two units:

Unit-3: Vitamins are nothing but vital amines and are essential dietary ingredients. In this unit we shall know more about vitamins based on solubility such as Fat Soluble and Water Soluble ones both contribute to better health, some are present in various food constituents and some are synthesized within the body. Those vitamins which are not synthesized are called essential and have to be supplemented externally. In short it covers sources, courses and essentiality of vitamins. In the later part most important minerals are elaborated with reference to its availability, requirement and pros and cons of deficiency and excesses.

Unit-4: This unit concern with concept of physiology particularly blood that has been discussed in two units: In this unit first we would discuss about concept of discipline of physiology, its profounder, secondly the most vital circulatory fluid i.e. Blood, its composition and function in the introduction and various types of blood cells, its importance in biology, medical and health sciences.

UNIT : 3

VITAMINS AND MINERALS

Structure:

3.1. Introduction

In the present chapter of vitamins and minerals, we shall learn about the types and sources of vitamins and their essential requirement in our diet and deficiencies arising due to them and the supplementary measures in the first half and about minerals theirs nature and properties and their essential requirements, in our diet and deficiencies causes by them and the supplementary measures in the second half.

Nutrition and diet affects your body metabolism. More energy is required to break down fats and proteins than carbohydrates; however, all excess calories that are ingested will be stored as fat or adipose tissue in the body. On average, a person requires 1500 to 2000 calories for normal daily activity, although routine exercise will increase that amount. If you ingest more than that, the remainder is stored for later use. Conversely, if you ingest less than that, the energy stores in your body will be depleted. Both the quantity and quality of the food you eat affects your metabolism and can affect your overall health. Eating too much or too little can result in serious medical conditions, including cardiovascular disease, cancer, and diabetes.

Vitamins and minerals are essential parts of the diet. They are needed for the proper function of metabolic pathways in the body. Vitamins are not stored in the body, so they must be obtained from the diet or synthesized from precursors available in the diet. Minerals are also obtained from the diet, but they are also stored, primarily in skeletal tissues.

Vitamins and minerals are required in minute quantities hence they are called as micronutrients. Some common vitamin deficiency diseases are Nightblindless, Beri beri, pellagra, Scurvy and Rickets whereas mineral deficiency diseases are Anaemia, Goitre, Dehydration, weak and brittle bones and teeth. Therefore, Vitamins are essential for the normal growth and development of a multicellular organism. Using the genetic blueprint inherited from its parents, a fetus develops from the nutrients it absorbs. It requires certain vitamins and minerals to be present at certain times. These nutrients facilitate the chemical reactions that produce among other things, skin, bone and muscle. If there is serious deficiency in one or more of these nutrients, a child may develop a deficiency disease. Even minor deficiencies may cause permanent damage.

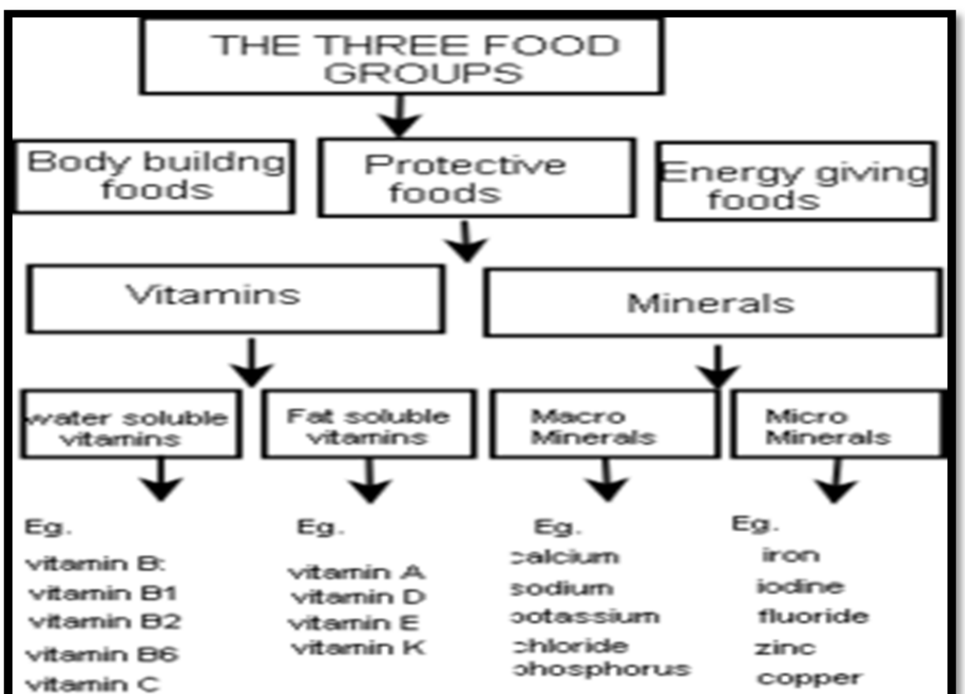
Objective

- Importance of nutrients and nutrition
- Control of dietary deficiency diseases(non communicable or non infectious)
- Underline the threshold of vitamins and minerals requirement in human population
- Enlist reasons why vitamins and minerals are critical to a healthy diet
- Regulatory issues

3.2. Vitamins on overview

Vitamins and minerals are as essential for living as air and water. Not only do they keep your body healthy and functional, they protect you from a variety of diseases. Vitamins and minerals get thrown together, but they are quite different. Vitamins are organic substances produced by plants or animals. They often are called "essential" because they are not synthesized in the body (except for vitamin D) and therefore must come from food. Minerals are inorganic elements that originate from rocks, soil, or water. However, you can absorb them indirectly from the environment or an animal that has eaten a particular plant.

Vitamins in the simplest term are known as vital amines. They form essential nutrients required to carry out basic metabolic functions. An essential nutrient is a nutrient required for normal physiological function but that cannot be synthesized in the body – either at all or in sufficient quantities and thus must be obtained from a dietary source. Apart from water, which is universally required for the maintenance of homeostasis in mammals, essential nutrients are indispensable for various cellular metabolic processes and maintaining tissue and organ function. In the case of humans, there are nine amino acids, two fatty acids, thirteen vitamins and fifteen minerals that are considered essential nutrients. In addition, there are several molecules that are considered conditionally essential nutrients since they are indispensable in certain developmental and pathological states. During early nineteenth century the main focus of research in biological chemistry was on identification of vitamins and like compounds essential to the health of humans and other vertebrates that cannot be synthesized by these animals must therefore be obtained in the diet.



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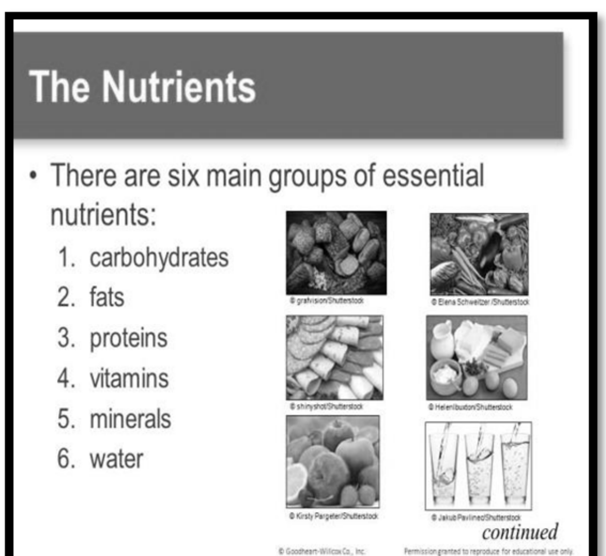
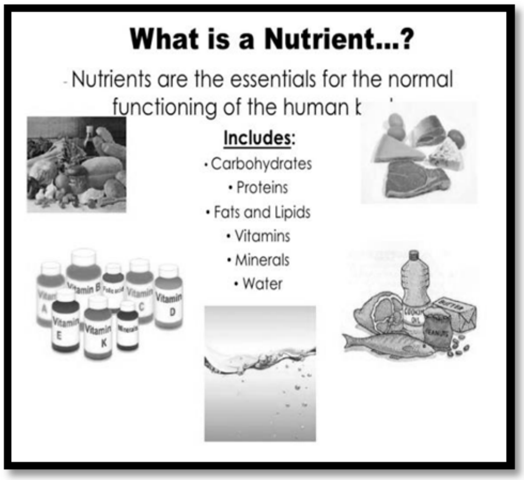
Diet plan:

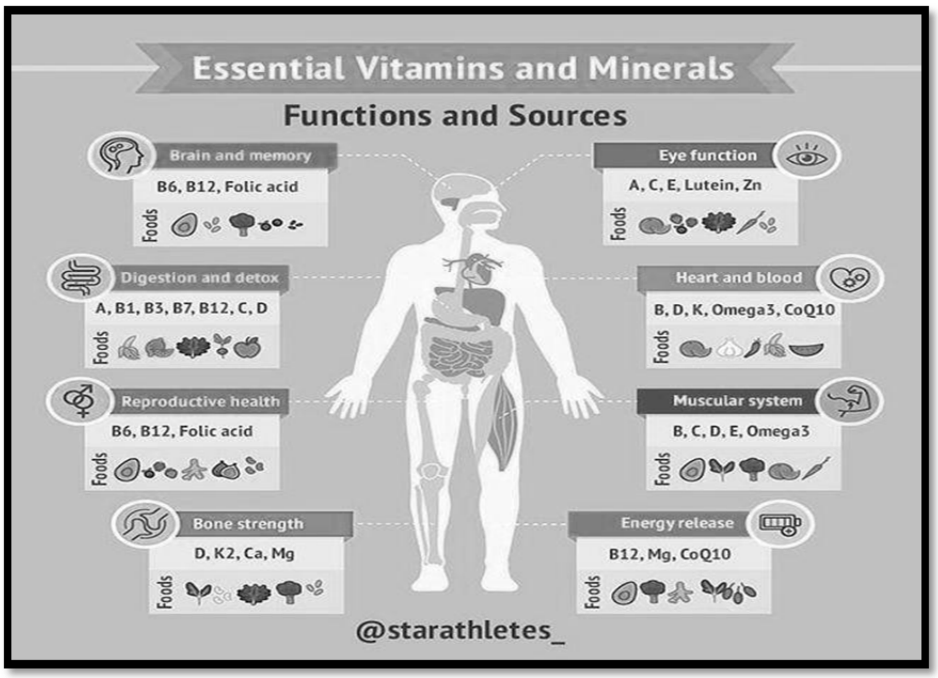
Nutrients	Food Items	Children (4-10 yrs)	Adult		Oldster	
			Men	Women	Men	Women
Calories		1200 – 1700KCal	2000 - 3000KCal	2000 - 2500KCal	2000 - 2500KCal	1700 - 1900KCal
Carbohydrates	Cereals and grains	175	400g	300g	285g	245g
Proteins	Fish, meat, egg, milk & soyabean	60g	70g	58g	68g	55g
Fats	Butter, oil, cheese & dry fruits	40g	80g	65g	58g	50g
Vitamins	Sprouts, fruits and vegetables	0.081g	0.115g	0.109gg	0.051g	0.048g
Dietary fibres	Fruits, vegetables and whole wheat bran	20g	30g	30g	20g	17g
Minerals	Sprouts, fruits and vegetables	10.20g	11.718g	10.65g	9.14g	8.14g

TABLE 1: VITAMINS AND MINERALS: A COMPARISON

	Vitamins	Minerals
Chemical Composition	Complicated, organic substances	Simple, inorganic substances
Source	Obtained from plants and animals	Found in soil and rock
Vulnerability	Destroyed easily by cooking with heat or chemical reagents	Minerals are not vulnerable to heat, sunlight, or chemical reactions
Nutritional requirement	All vitamins are necessary for the body to function properly	Not all minerals are required for nutrition







Thus of the micronutrients in the process of nutrition vitamins and minerals are of great significance to humankind.

Dietary minerals are generally trace elements, salts, or ions such as copper and iron. Some of these minerals are essential to human metabolism. Vitamins are organic compounds essential to the body. They usually act as coenzymes or cofactors for various proteins in the body and metabolic regulators or antioxidants. Vitamins are organic molecules essential for an organism that are not classified as amino acids or fatty acids. They commonly function as enzymatic cofactors.

Humans require thirteen vitamins in their diet, most of which are actually groups of related molecules (e.g. vitamin E includes tocopherols and tocotrienols). Vitamins A, C, D, E, K, thiamine (B_1), riboflavin (B_2), niacin (B_3), pantothenic acid (B_5), vitamin B_6 (e.g., pyridoxine), biotin (B_7), folate (B_9), cobalamin (B_{12}).

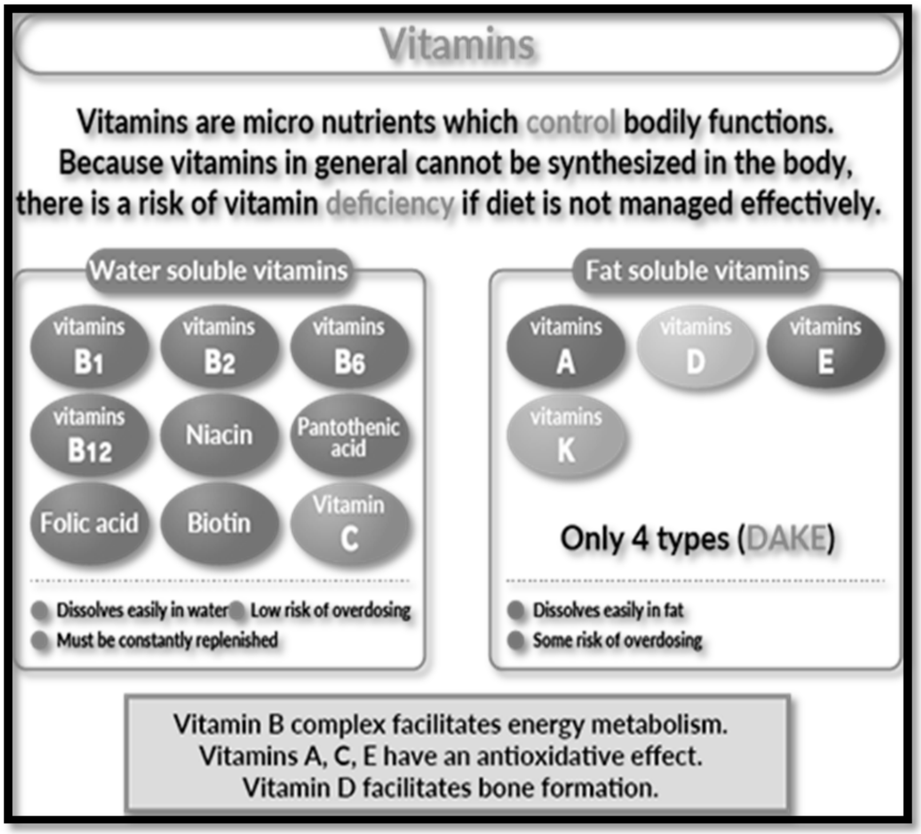
The requirement for vitamin D is conditional, as people who get sufficient exposure to ultraviolet light, either from the sun or an artificial source, synthesize vitamin D in the skin. Vitamins are the related set of molecules that an organisms needs in small quantities for the proper functioning of its metabolism. Essential nutrients cannot be synthesized in the organism, either at all or not in sufficient quantities, and therefore must be obtained through the food. Vitamins can be synthesized by some species but not by others; it is not a vitamin in the first instance but is in the second. The term *vitamin* does not include the three other groups of essential nutrients: minerals, essential fatty acids and essential amino acids. Most vitamins are not single molecules, but groups of related molecules called vitamers. For example, vitamin E consists of four tocopherols and four tocotrienols. The thirteen vitamins required by human metabolism are: vitamin A (as all-*trans*-retinol, all-*trans*-retinyl-esters, as well as all-*trans*-beta –carotene and other provitamin A carotenoids), vitamin B_1 (thiamine) vitamin B_2 (riboflavin), vitamin B_3 (niacin), vitamin B_5 (pantothenic acid), vitamin B_6 (pyridoxine) vitamin B_7 (biotin), vitamin B_9 (folic acid or folate) vitamin B_{12} (cobalamins) vitamin C (ascorbic acid), vitamin D (calciferol), vitamin E (tocopherols and tocotrienols) and vitamin K (quinones).

Vitamins have diverse biochemical functions. Vitamin A acts as a regulator of cell and tissue growth and differentiation. Vitamin D provides a hormone-like function, regulating mineral metabolism for bones and other organs. The B complex vitamins function as enzyme cofactors (coenzymes) or the precursors for them. Vitamins C and E function as antioxidants. Both deficient and excess intake of a vitamin can potentially cause clinically significant illness, although excess intake of water-soluble vitamins is less likely to do so.

Before 1935, the only source of vitamins was from food. If intake of vitamins was lacking, the result was vitamin deficiency and consequent caused due to deficiencies diseases. Then, commercially produced tablets of yeast-extract vitamin B complex and semi-synthetic vitamin C became available. This was followed in the 1950s by the mass production and marketing of vitamin supplements, including multivitamins, to prevent vitamin deficiencies in the general population. Governments mandated addition of vitamins to staple foods such as flour or milk, referred to as food fortification, to prevent deficiencies. Recommendations for folic acid supplementation during pregnancy reduced risk of infant neural tube defects. Although reducing incidence of vitamin deficiencies clearly has benefits, supplementation is thought to be of little value for healthy people who are consuming a vitamin-adequate diet.The term *vitamin* is derived from the word *vitamine*, coined in 1912 by Polish biochemist Casimir Funk, who isolated a complex of micronutrients essential to life, all of which he presumed to be amines. When this presumption was later determined not to be true, the "e" was dropped from the name. All vitamins were discovered (identified) between 1913 and 1948.

3.3. Classification of vitamin

Vitamins are classified as either water-soluble or fat-soluble. In humans there are 13 vitamins: 4 fat-soluble (A, D, E, and K) and 9 water-soluble (8 B vitamins and vitamin C). Water-soluble vitamins dissolve easily in water and, in general, are readily excreted from the body, to the degree that urinary output is a strong predictor of vitamin consumption. Because they are not as readily stored, more consistent intake is important.



Fat-soluble vitamins are absorbed through the intestinal tract with the help of lipids (fats). Vitamins A and D can accumulate in the body, which can result in dangerous hypervitaminosis. Fat-soluble vitamin deficiency due to malabsorption is of particular significance in cystic fibrosis.

Anti vitamins

Anti-vitamins are chemical compounds that inhibit the absorption or actions of vitamins. For example, avidin is a protein in raw egg whites that inhibits the absorption of biotin; it is deactivated by cooking. Pyrithiamine, a synthetic compound, has a molecular structure similar to thiamine, vitamin B_1, and inhibits enzymes that use thiamine.

3.4. Source of vitamin

VITAMIN SOURCES	
	WATER SOLUBLE:
1.	**B-1:** ham, soymilk, watermelon, acorn squash
2.	**B-2:** milk, yogurt, cheese, whole and enriched grains and cereals.
3.	**B-3:** meat, poultry, fish, fortified and whole grains, mushrooms, potatoes
4.	**B-5:** chicken, whole grains, broccoli, avocados, mushrooms
5.	**B-6:** meat, fish, poultry, legumes, tofu and other soy products, bananas
6.	**B-7:** Whole grains, eggs, soybeans, fish
7.	**B-9:** Fortified grains and cereals, asparagus, spinach, broccoli, legumes (black-eyed peas and chickpeas), orange juice
8.	**B-12:** Meat, poultry, fish, milk, cheese, fortified soymilk and cereals
9.	**Vitamin C:** Citrus fruit, potatoes, broccoli, bell peppers, spinach, strawberries, tomatoes, Brussels sprouts
	FAT SOLUBLE:
1.	**Vitamin A:** beef, liver, eggs, shrimp, fish, fortified milk, sweet potatoes, carrots, pumpkins, spinach, mangoes
2.	**Vitamin D:** Fortified milk and cereals, fatty fish
3.	**Vitamin E:** vegetables oils, leafy green vegetables, whole grains, nuts
4.	**Vitamin K:** Cabbage, eggs, milk, spinach, broccoli, kale
	MINERALS
	MAJOR:
1.	**Calcium:** yogurt, cheese, milk, salmon, leafy green vegetables
2.	**Chloride:** salt
3.	**Magnesium:** Spinach, broccoli, legumes, seeds, whole-wheat bread
4.	**Potassium:** meat, milk, fruits, vegetables, grains, legumes
5.	**Sodium:** salt, soy sauce, vegetables
	TRACE:
1.	**Chromium:** meat, poultry, fish, nuts, cheese
2.	**Copper:** shellfish, nuts, seeds, whole-grain products, beans, prunes
3.	**Fluoride:** fish, teas
4.	**Iodine:** Iodized salt, seafood
5.	**Iron:** red meat, poultry, eggs, fruits, green vegetables, fortified bread
6.	**Manganese:** nuts, legumes, whole grains, tea
7.	**Selenium:** Organ meat, seafood, walnuts
8.	**Zinc:** meat, shellfish, legumes, whole grains

3.5. Biochemical functions

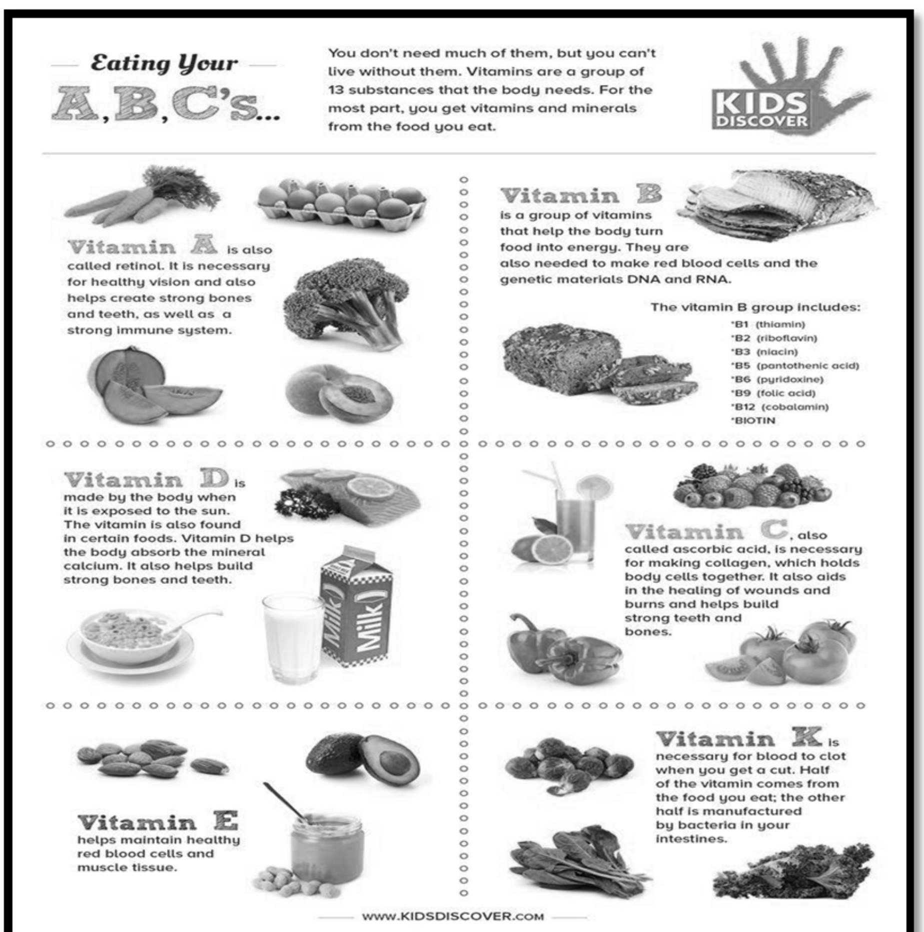
Each vitamin is typically used in multiple reactions, and therefore most have multiple functions

On fetal growth and childhood development

Vitamins are essential for the normal growth and development of a multicellular organism. Using the genetic blueprint inherited from its parents, a fetus develops from the nutrients it absorbs. It requires certain vitamins and minerals to be present at certain times. These nutrients facilitate the chemical reactions that produce among other things, skin, bone and muscle. If there is serious deficiency in one or more of these nutrients, a child may develop a deficiency disease. Even minor deficiencies may cause permanent damage.

On adult health maintenance

Once growth and development are completed, vitamins remain essential nutrients for the healthy maintenance of the cells, tissues, and organs that make up a multicellular organism; they also enable a multicellular life form to efficiently use chemical energy provided by food it eats, and to help process the proteins, carbohydrates, and fats required for cellular respiration.



3.5.1. Biochemical functions

For the most part, vitamins are obtained from the diet, but some are acquired by other means: for example, microorganisms in the gut flora produce vitamin K and biotin; and one form of vitamin D is synthesized in skin cells when they are exposed to a certain wavelength of ultraviolet light present in sunlight. Humans can produce some vitamins from precursors they consume: for example, vitamin A is synthesized from beta carotene; and niacin is synthesized from the amino acid tryptophan. The Food Fortification Initiative lists countries which have mandatory fortification programs for vitamins folic acid, niacin, vitamin A and vitamins B1, B2 and B12. Please see the table of dietary intake and causes to cater the nutritional requirement of vitamins below:

Vitamins	Vitamins (Chemical names)	Solubility	US Recommended dietary allowances	Deficiency disease	Excess syndrome/symptoms	Dietary sources
	Vitamers		(male/female, age 19–70)			
Vitamin A	all-*trans*-Retinol and	Fat	900 µg/700 µg	Night blindness	Hypervitaminosis A	from animal origin as Vitamin A / all-*trans*-Retinol: Fish in general, liver and dairy products;
	alternative provitamin A-functioning Carotenoids			Hyperkeratosis		from plant origin as provitamin A / all-*trans*-beta-carotene: orange, ripe yellow fruits, leafy vegetables, carrots, pumpkin, squash, spinach;
	including all-*trans*-beta-carotene			keratomalacia		
Vitamin B1	Thiamine	Water	1.2 mg/1.1 mg	Beriberi, Wernicke-Korsakoff syndrome	Drowsiness and muscle relaxation	Pork, oatmeal, brown rice, vegetables, potatoes, liver, eggs
Vitamin B2	Riboflavin	Water	1.3 mg/1.1 mg	Ariboflavinosis, glossitis, angular stomatitis		Dairy products, bananas, green beans, asparagus
Vitamin B3	Niacin,	Water	16 mg/14 mg	Pellagra	Liver damage (doses > 2g/day) and other problems	Meat, fish, eggs, many vegetables, mushrooms, tree nuts
	Niacinamide,					
	Nicotinamide riboside					

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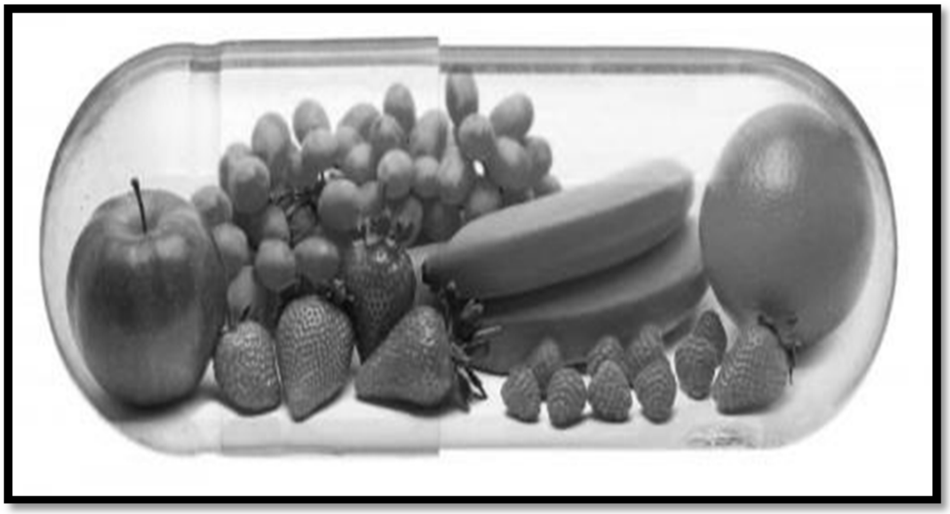
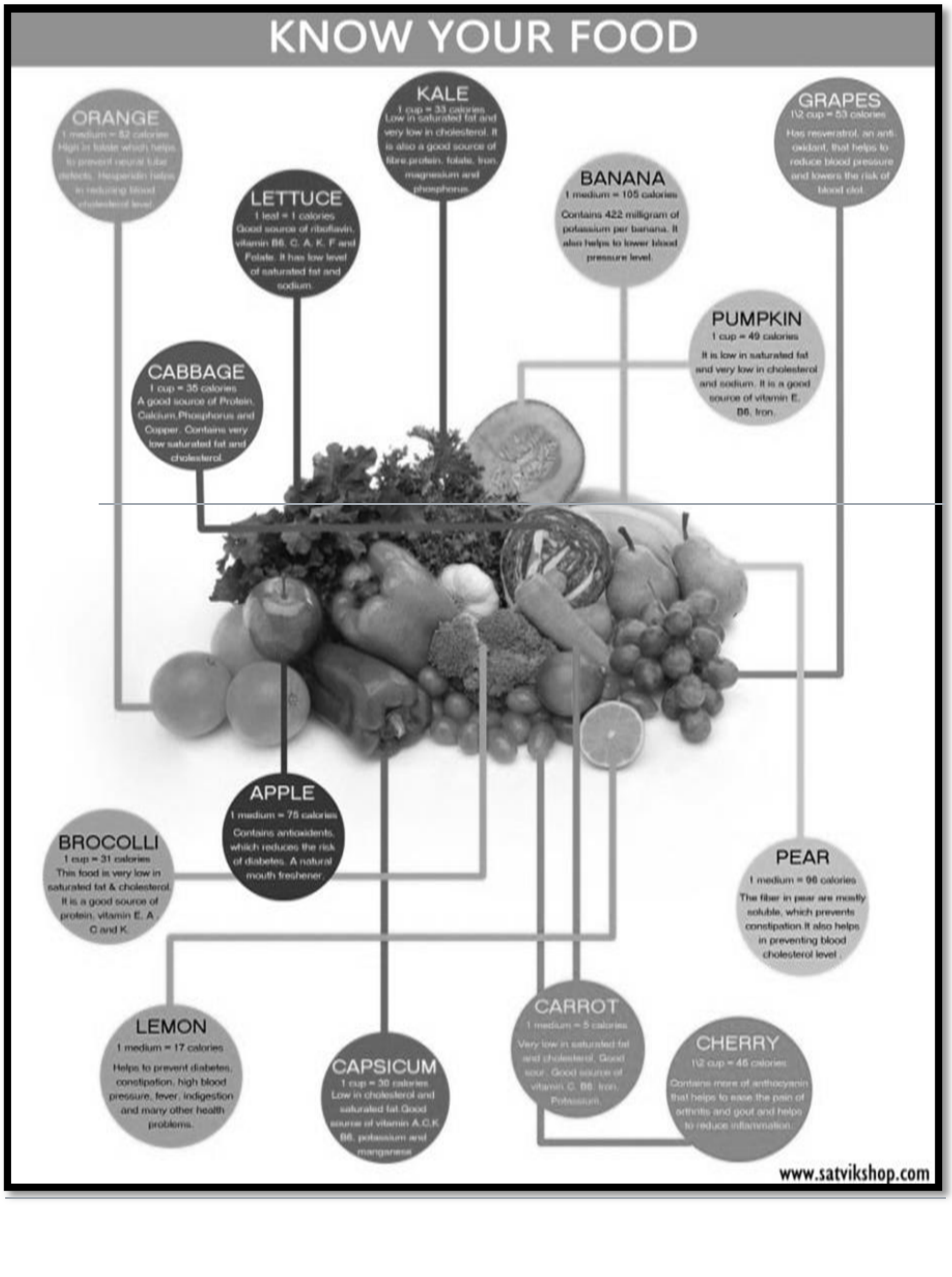
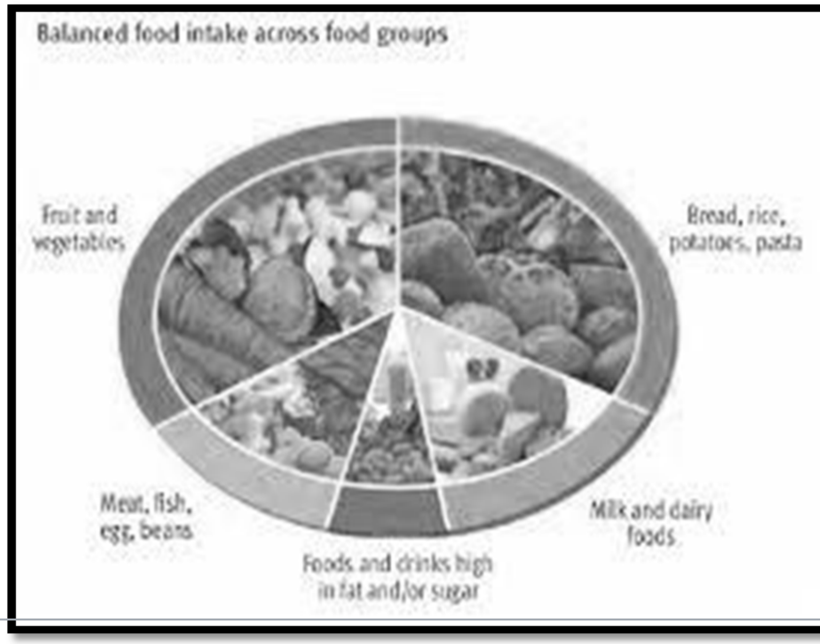
Vitamin B5	Pantothenic acid	Water	5 mg/5 mg	Paresthesia	Diarrhea; possibly nausea and heartburn.	Meat, broccoli, avocados
Vitamin B6	Pyridoxine, Pyridoxamine, Pyridoxal	Water	1.3–1.7 mg/1.2–1.5 mg	Anemia, Peripheral neuropathy	Impairment of proprioception, nerve damage (doses > 100 mg/day)	Meat, vegetables, tree nuts, bananas
Vitamin B7	Biotin	Water	AI: 30 µg/30 µg	Dermatitis, enteritis		Raw egg yolk, liver, peanuts, leafy green vegetables
Vitamin B9	Folates, Folic acid	Water	400 µg/400 µg	Megaloblastic anemia and deficiency during pregnancy is associated with birth defects, such as neural tube defects	May mask symptoms of vitamin B12 deficiency; other effects.	Leafy vegetables, pasta, bread, cereal, liver
Vitamin B12	Cyanocobalamin, Hydroxocobalamin, Methylcobalamin, Adenosylcobalamin	Water	2.4 µg/2.4 µg	Pernicious anemia	None proven	Meat, poultry, fish, eggs, milk
Vitamin C	Ascorbic acid	Water	90 mg/75 mg	Scurvy	None known	Many fruits and vegetables, liver
Vitamin D	Cholecalciferol (D3), Ergocalciferol (D2)	Fat	15 µg/15 µg	Rickets and osteomalacia	Hypervitaminosis D	Lichen, eggs, liver, certain fish species such as sardines, certain mushroom species such as shiitake
Vitamin E	Tocopherols, Tocotrienols	Fat	15 mg/15 mg	Deficiency is very rare; mild hemolytic anemia in newborn infants	Possible increased incidence of congestive heart failure.	Many fruits and vegetables, nuts and seeds, and seed oils
Vitamin K	Phylloquinone, Menaquinones	Fat	AI: 110 µg/120 µg	Bleeding diathesis	Decreased anticoagulation effect of warfarin.	Leafy green vegetables such as spinach; egg yolks; liver

3.5.2. Deficient Intake

The body stores for different vitamins vary widely. Vitamins A, D, and B_{12} are stored in significant amounts, mainly in the liver and an adult's diet may be deficient in vitamins A and D for many months and B_{12} in some cases for years, before developing a deficiency condition. However, vitamin B_3 (niacin and niacinamide) is not stored in significant amounts, so stores may last only a couple of weeks. For vitamin C, the first symptoms of scurvy in experimental studies of complete vitamin C deprivation in humans, have varied widely, from a month to more than six months, depending on previous dietary history that determined body stores. Deficiencies of vitamins are classified as either primary or secondary. A primary deficiency occurs when an organism does not get enough of the vitamin in its food. A secondary deficiency may be due to an underlying disorder that prevents or limits the absorption or use of the vitamin, due to a "lifestyle factor", such as smoking, excessive alcohol consumption, or the use of medications that interfere with the absorption or use of the vitamin. People who consume a varied diet are unlikely to develop a severe primary vitamin deficiency, but may be consuming less than the recommended amounts; a national food and supplement survey conducted in the US over 2003-2006 reported that over 90% of individuals who did not consume vitamin supplements were found to have inadequate levels of some of the essential vitamins, notably vitamins D and E. Well-researched human vitamin deficiencies involve thiamine (beriberi), niacin (pellagra), vitamin C (scurvy), folate (neural tube defects) and vitamin D (rickets). In much of the developed world these deficiencies are rare; this is due to A) an adequate supply of food and B) the addition of vitamins to common foods (fortification). In addition to these classical vitamin deficiency diseases, some evidence has also suggested links between vitamin deficiency and a number of different disorders.




KNOW YOUR FOOD
ORANGE
High in folate which helps to prevent neural tube defects. Hesperidin helps in reducing blood cholesterol level.
KALE
1 cup = 33 calories
Low in saturated fat and very low in cholesterol. It is also a good source of fibre,protein, folate, Iron, magnesium and phosphorus.
GRAPES
1\2 cup = 53 calories
Has resveratrol, an anti-oxidant, that helps to reduce blood pressure and lowers the risk of blood clot.
LETTUCE
1 leaf = 1 calories
Good source of riboflavin, vitamin B6, C, A, K, F and Folate. It has low level of saturated fat and sodium.
BANANA
1 medium = 105 calories
Contains 422 milligram of potassium per banana. It also helps to lower blood pressure level.
PUMPKIN
1 cup = 49 calories
It is low in saturated fat and very low in cholesterol and sodium. It is a good source of vitamin E, B6, Iron.
CABBAGE
1 cup = 35 calories
A good source of Protein, Calcium,Phosphorus and Copper. Contains very low saturated fat and cholesterol.
APPLE
1 medium = 75 calories
Contains antioxidents, which reduces the risk of diabetes. A natural mouth freshener.
BROCOLLI
1 cup = 31 calories
This food is very low in saturated fat & cholesterol. It is a good source of protein, vitamin E, A, C and K.
PEAR
1 medium = 96 calories
The fiber in pear are mostly soluble, which prevents constipation.It also helps in preventing blood cholesterol level .
LEMON
1 medium = 17 calories
Helps to prevent diabetes, constipation, high blood pressure, fever, indigestion and many other health problems.
CAPSICUM
1 cup = 30 calories
Low in cholesterol and saturated fat.Good source of vitamin A,C,K B6, potassium and manganese
CARROT
1 medium = 5 calories
Very low in saturated fat and cholesterol. Good source of vitamin C, B6, Iron, Potassium.
CHERRY
1\2 cup = 46 calories
Contains more of anthocyanin that helps to ease the pain of arthritis and gout and helps to reduce inflammation.
www.satvikshop.com



3.5.3. Excess intake

Some vitamins have documented acute or chronic toxicity at larger intakes, which is referred to as hyper toxicity. The European Union and **the** governments of several countries have established Tolerable upper intake levels (ULs) for those vitamins which have documented toxicity (see table). The likelihood of consuming too much of any vitamin from food is remote, but excessive intake (vitamin poisoning) from dietary supplements does occur. In 2016, overdose exposure to all formulations of vitamins and multi-vitamin/mineral formulations was reported by 63,931 individuals to the American Association of Poison Control Centers with 72% of these exposures in children under the age of five. In the US, analysis of a national diet and supplement survey reported that about 7% of adult supplement users exceeded the UL for folate and 5% of those older than age 50 years exceeded the UL for vitamin A.

Effects of cooking on materials

The USDA has conducted extensive studies on the percentage losses of various nutrients from different food types and cooking methods. Some vitamins may become more "bio-available" – that is, usable by the body – when foods are cooked. The table below shows whether various vitamins are susceptible to loss from heat—such as heat from boiling, steaming, frying, etc. The effect of cutting vegetables can be seen from exposure to air and light. Water-soluble vitamins such as B and C dissolve into the water when a vegetable is boiled, and are then lost when the water.

Vitamin	Soluble in Water	Stable to Air Exposure	Stable to Light Exposure	Stable to Heat Exposure
Vitamin A	no	partially	partially	relatively stable
Vitamin C	very unstable	yes	no	no
Vitamin D	no	no	no	no

Vitamin E	no	yes	yes	no
Vitamin K	no	no	yes	no
Thiamine (B_1)	highly	no	?	> 100 °C
Riboflavin (B_2)	slightly	no	in solution	no
Niacin (B_3)	yes	no	no	no
Pantothenic Acid (B_5)	quite stable	no	no	yes
Vitamin B_6	yes	?	yes	?
Biotin (B_7)	somewhat	?	?	no
Folic Acid (B_9)	yes	?	when dry	at high temp
Cobalamin (B_{12})	yes	?	yes	no

3.6 Recommended levels

In setting human nutrient guidelines, government organizations do not necessarily agree on amounts needed to avoid deficiency or maximum amounts to avoid the risk of toxicity. For example, for vitamin C. Recommended intakes range from 40 mg/day in India is up to 155 mg/day for the European Union. The table below shows U.S. Estimated Average Requirements (EARs) and Recommended Dietary Allowances (RDAs) for vitamins, PRIs for the European Union (same concept as RDAs), followed by what three government organizations deem to be the safe upper intake. RDAs are set higher than EARs to cover people with higher than average needs. Adequate Intakes (AIs) are set when there is not sufficient information to establish EARs and RDAs. Governments are slow to revise information of this nature. For the U.S. values, with the exception of calcium and vitamin D, all of the data date to 1997-2004.

1. **EAR** US Estimated Average Requirements.
2. **RDA** US Recommended Dietary Allowances; higher for adults than for children, and may be even higher for women who are pregnant or lactating.
3. **AI** US and EFSA Adequate Intake; AIs established when there is not sufficient information to set EARs and RDAs.
4. **PRI** Population Reference Intake is European Union equivalent of RDA; higher for adults than for children, and may be even higher for women who are pregnant or lactating. For Thiamin and Niacin the PRIs are expressed as amounts per MJ of calories consumed. MJ = mega joule = 239 food calories.
5. **Upper Limit** Tolerable upper intake levels.
6. **ND** ULs have not been determined.
7. **NE** EARs have not been established.

5.7. Nomenclature of Vitamins

Nutrient	U.S. EAR	Highest U.S. RDA or AI	Highest EU PRI or AI	Upper limit		
				U.S.	EU	Japan
Vitamin A	625	900	1300	3000	3000	2700
Vitamin C	75	90	155	2000	ND	ND
Vitamin D	10	15	15	100	100	100
Vitamin K	NE	120	70	ND	ND	ND
α-Tocopherol (Vitamin E)	12	15	13	1000	300	650-900
Thiamin (Vitamin B_1)	1	1.2	0.1 mg/MJ	ND	ND	ND
Riboflavin (Vitamin B_2)	1.1	1.3	2	ND	ND	ND
Niacin (Vitamin B_3)	12	16	1.6 mg/MJ	35	10	60-85
Pantothenic acid (Vitamin B5)	NE	5	7	ND	ND	ND
Vitamin B_6	1.1	1.3	1.8	100	25	40-60
Biotin (Vitamin B_7)	NE	30	45	ND	ND	ND
Folate (Vitamin B9)	320	400	600	1000	1000	900-1000
Cyanocobalamin (Vitamin B12)	2	2.4	5	ND	ND	ND

The reason that the set of vitamins skips directly from E to K is that the vitamins corresponding to letters F–J were either reclassified over time, discarded as false leads, or renamed because of their relationship to vitamin B, which became a complex of vitamins. At the time, most (but not all) of the letters from F through to J were already designated, so the use of the letter K was considered quite reasonable. The table Nomenclature of reclassified vitamins lists chemicals that had previously been classified as vitamins, as well as the earlier names of vitamins that later became part of the B-complex. There are other missing B vitamins which were reclassified or determined not to be vitamins. For example, B9 is folic acid and five of the folates are in the range B11 through B16, forms of other vitamins already discovered, did not require nomenculture as a nutrient by the entire population like B10, PABA for internal use, biologically inactive, toxic, or with unclassifiable effects in humans, or not generally recognized as vitamins by science, such as the highest-numbered, which some naturopath practitioners call B21 and B22. There are also nine lettered B complex vitamins (e.g., Bm). There are other D vitamins also now getting recognized as other substances, which are sources of the same type number up to D7. The controversial cancer treatment laetrile was at one point lettered as vitamin B17. There appears to be no consensus on any vitamins Q, R, T, V, W, X, Y or Z, nor are there substances officially designated as vitamins N or I, although the latter may have been another form of one of the other vitamins or a known and named nutrient of another type.

3.8. History of vitamin

The value of eating certain foods to maintain health was recognized long before vitamins were identified. The ancient people knew that feeding liver to a person may help with night blindness an illness now known to be caused by a vitamin A deficiency. The advancement of ocean voyages during the Renaissance resulted in prolonged periods without access to fresh fruits and vegetables, and made illnesses from vitamin deficiency common among ships' crews. In 1747, the Scottish surgeon James Lind discovered that citrus foods helped prevent scurvy a particularly deadly disease in which collagen is not properly formed, causing poor wound healing, bleeding of the gums, severe pain, and death. In 1753, Lind published his *Treatise on the Scurvy*, which recommended using lemons and limes to avoid scurvy, which was adopted by the British Royal Navy. This led to the nickname *limey* for British sailors. Lind's discovery, however, was not widely accepted by individuals in the Royal Navy's Arctic expeditions in the 19th century, where it was widely believed that scurvy could be prevented by practicing good hygiene, regular exercise, and maintaining the morale of the crew while on board, rather than by a diet of fresh food. As a result, Arctic expeditions continued to be plagued by scurvy and other deficiency diseases. In the early 20th century, when Robert Falcon Scott made his two expeditions to the Antarctic, the prevailing medical theory at the time was that scurvy was caused by "tainted" canned food. During the late 18th and early 19th centuries, the use of deprivation studies allowed scientists to isolate and identify a number of vitamins. Lipid from fish oil was used to cure rickets in rats, and the fat-soluble nutrient was called "anthracitic A". Thus, the first "vitamin" bioactivity ever isolated, which cured rickets, was initially called "vitamin A"; however, the bioactivity of this compound is now called vitamin D. In 1881, Russian medical doctor Nikolai I. Lunin [ru] studied the effects of scurvy at the University of Tartu. He fed mice an artificial mixture of all the separate constituents of milk known at that time, namely the proteins, fats, carbohydrates, and salts.

The discovery dates of the vitamins and their sources		
Year of discovery	**Vitamin**	**Food source**
1913	Vitamin A (Retinol)	Cod liver oil
1910	Vitamin B_1 (Thiamine)	Rice bran
1920	Vitamin C (Ascorbic acid)	Citrus, most fresh foods
1920	Vitamin D (Calciferol)	Cod liver oil
1920	Vitamin B_2 (Riboflavin)	Meat, dairy products, eggs
1922	Vitamin E (Tocopherol)	Wheat germ oil,
		unrefined vegetable oils
1929	Vitamin K_1 (Phylloquinone)	Leaf vegetables
1931	Vitamin B_5 (Pantothenic acid)	Meat, whole grains,
		in many foods
1931	Vitamin B_7 (Biotin)	Meat, dairy products, Eggs
1934	Vitamin B_6 (Pyridoxine)	Meat, dairy products
1936	Vitamin B_3 (Niacin)	Meat, grains
1941	Vitamin B_9 (Folic acid)	Leaf vegetables
1948	Vitamin B12 (Cobalamins)	Meat, organs (Liver), Eggs

The mice that received only the individual constituents died, while the mice fed by milk itself developed normally. He made a conclusion that "a natural food such as milk must therefore contain, besides these known principal ingredients, small quantities of unknown substances essential to life." However, his conclusions were rejected by his advisor, Gustav von Bunge. A similar result by Cornelius Pekelharing appeared in a Dutch medical journal in 1905, but it was not widely reported. In East Asia, where polished white rice was the common staple food of the middle class, beriberi resulting from lack of vitamin B_1 was endemic. In 1884, Takaki Kanehiro, a British-trained medical doctor of the Imperial Japanese Navy, observed that beriberi was endemic among low-ranking crew who often ate nothing but rice, but not among officers who consumed a Western-style diet. With the support of the Japanese navy, he experimented using crews of two battleships; one crew was fed only white rice, while the other was fed a diet of meat, fish, barley, rice, and beans. The group that ate only white rice documented 161 crew members with beriberi and 25 deaths, while the latter group had only 14 cases of beriberi and no deaths. This convinced Takaki and the Japanese Navy that diet was the cause of beriberi, but they mistakenly believed that sufficient amounts of protein prevented it.[62] That diseases could result from some dietary deficiencies was further investigated by Christiaan Eijkman, who in 1897 discovered that feeding unpolished rice instead of the polished variety to chickens helped to prevent beriberi in the chickens. The following year, Frederick Hopkins postulated that some foods contained "accessory factors" — in addition to proteins, carbohydrates, fats *etc.* — that are necessary for the functions of the human body. Hopkins and Eijkman were awarded the Nobel Prize for Physiology or Medicine in 1929 for their discoveries. Jack Drummond's single-paragraph article in 1920 which provided structure and nomenclature used today for vitamins. In 1910, the first vitamin complex was isolated by Japanese scientist Umetaro Suzuki, who succeeded in extracting a water-soluble complex of micronutrients from rice bran and named it aberic acid (later *Orizanin*). He published this discovery in a Japanese scientific journal. When the article was translated into German, the translation failed to state that it was a newly discovered nutrient, a claim made in the original Japanese article, and hence his discovery failed to gain publicity. In 1912 Polish-born biochemist Casimir Funk, working in London, isolated the same complex of micronutrients and proposed the complex be named "vitamine". It was later to be known as vitamin B_3 (niacin), though he described it as "anti-beri-beri-factor" (which would today be called thiamine or vitamin B_1). Funk proposed the hypothesis that other diseases, such as rickets, pellagra, coeliac disease, and scurvy could also be cured by vitamins. Max Nierenstein a friend and reader of Biochemistry at Bristol University reportedly suggested the "vitamine" name (from "vital amine"). The name soon became synonymous with Hopkins' "accessory factors", and, by the time it was shown that not all vitamins are amines, the word was already ubiquitous. In 1920, Jack Cecil Drummond proposed that the final "e" be dropped to deemphasize the "amine" reference, after researchers began to suspect that not all "vitamines" (in particular, vitamin A) have an amine component. In 1930, Paul Karrer elucidated the correct structure for beta-carotene, the main precursor of vitamin A, and identified other carotenoids. Karrer and Norman Haworth confirmed Albert Szent-Györgyi's discovery of ascorbic acid and made significant contributions to the chemistry of flavins, which led to the identification of lactoflavin. For their investigations on carotenoids, flavins and vitamins A and B_2, they both received the Nobel Prize in Chemistry in 1937. In 1931, Albert Szent-Györgyi and a fellow researcher Joseph Svirbely suspected that "hexuronic acid" was actually vitamin C, and gave a sample to Charles Glen King, who proved its anti-scorbutic activity in his long-established guinea pig scorbutic assay. In 1937, Szent-Györgyi was awarded the Nobel Prize in Physiology or Medicine for his discovery. In 1943, Edward Adelbert Doisy and Henrik Dam were awarded the Nobel Prize in Physiology or Medicine for their discovery of vitamin K and its chemical structure. In 1967, George Wald was awarded the Nobel Prize (along with Ragnar Granit and Haldan Keffer Hartline) for his discovery that vitamin A could participate directly in a physiological process. In 1938, Richard Kuhn was awarded the Nobel Prize in Chemistry for his work on carotenoids and vitamins, specifically B_2 and B_6.

History of promotional marketing

Once discovered, vitamins were actively promoted in articles, advertisements and other media outlets. Marketers enthusiastically promoted cod-liver oil, a source of Vitamin D, as "bottled sunshine", and bananas as a "natural vitality food". They promoted foods such as yeast cakes, a source of B vitamins, on the basis of scientificallydetermined nutritional value, rather than taste or appearance. World War II researchers focused on the need to ensure adequate nutrition, especially in processed foods. Robert W. Yoder is credited with first using the term *vita mania*, in 1942, to describe the appeal of relying on nutritional supplements rather than on obtaining vitamins from a varied diet of foods. The continuing preoccupation with a healthy lifestyle has led to an obsessive consumption of additives the beneficial effects of which are questionable.

Governmental regulation

Most countries place dietary supplements in a special category under the general umbrella of *foods*, not drugs. As a result, the manufacturer, and not the government, has the responsibility of ensuring that its dietary supplement products are safe before they are marketed. Regulation of supplements varies widely by country. In the United States, a dietary supplement is defined under the Dietary Supplement Health and Education Act of 1994. There is no FDA approval process for dietary supplements, and no requirement that manufacturers prove the safety or efficacy of supplements introduced before 1994. The Food and Drug Administration must rely on its Adverse Event Reporting System to monitor adverse events that occur with supplements. In 2007, the US Code of Federal Regulations (CFR) Title 21, part III took effect, regulating Good Manufacturing Practices (GMPs) in the manufacturing, packaging, labeling, or holding operations for dietary supplements. Even though product registration is not required, these regulations mandate production and quality control standards (including testing for identity, purity and adulterations) for dietary supplements.

In the European Union, the Food Supplements Directive requires that only those supplements that have been proven safe can be sold without a prescription. For most vitamins, pharmacopoeia standards have been established. In the United States, the United States Pharmacopeia (USP) sets standards for the most commonly used vitamins and preparations thereof. Likewise, monographs of the European Pharmacopoeia regulate aspects of identity and purity for vitamins on the European market.

5.9. Supplementation

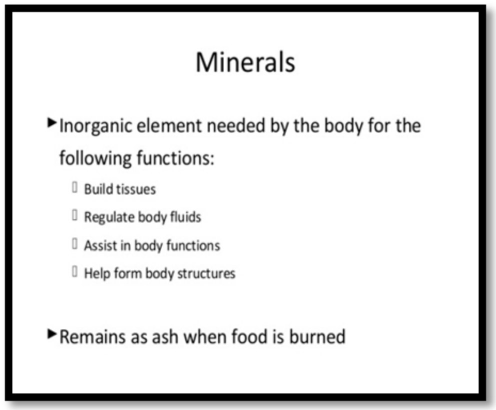
Calcium combined with vitamin D supplement tablets with fillers.

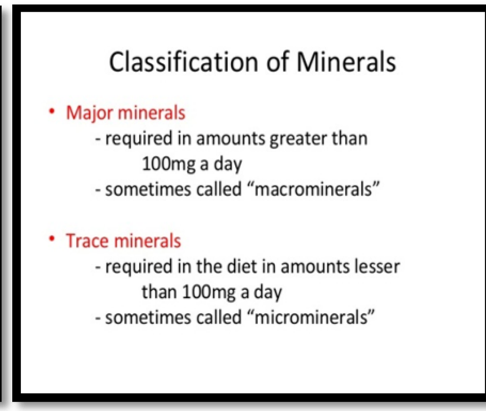
In those who are otherwise healthy, there is little evidence that supplements have any benefits with respect to cancer or heart diseases. Vitamin A and E supplements not only provide no health benefits for generally healthy individuals, but they may increase mortality, though the two large studies that support this conclusion included smokers for whom it was already known that beta- carotene supplements can be harmful. A 2018 meta-analysis found no evidence that intake of vitamin D or calcium for community-dwelling elderly people reduced bone fractures. In Europe there are regulations that define limits of vitamin (and mineral) dosages for their safe use as dietary supplements. Most vitamins that are sold as dietary supplements are not supposed to exceed a maximum daily dosage referred to as the tolerable upper intake level (UL). Vitamin products above these regulatory limits are not considered supplements and should be registered as prescription or non-prescription (over-the-counter drugs) due to their potential side effects. The European Union, United States, Japan establish recommended upper intake levels. Dietary supplements often contain vitamins, but may also include other ingredients, such as minerals, herbs, and botanicals. Scientific evidence supports the benefits of dietary supplements for persons with certain health conditions. In some cases, vitamin supplements may have unwanted effects, especially if taken before surgery, with other dietary supplements or medicines, or if the person taking them has certain health conditions. They may also contain levels of vitamins many times higher, and in different forms, than one may ingest through food.

5.10. Minerals Nutrients

Minerals are one of the four groups of essential **nutrients**, the others of which are vitamins, essential fatty acids, and essential amino acids. The five major **minerals** in the human body are calcium, phosphorus, potassium, sodium, and magnesium.

In the context of nutrition, a **mineral** is a chemical element required as an essential nutrient by organisms to perform functions necessary for life. However, the four major structural elements in the human body by weight (oxygen, hydrogen, carbon, and nitrogen), are usually not included in lists of major nutrient minerals (nitrogen is considered a "mineral" for plants, as it often is included in fertilizers). These four elements compose about 96% of the total weight of the human body, and major minerals (macrominerals) and minor minerals (also called trace elements) compose the remainder.





Minerals, being elements, cannot be synthesized biochemically by living organisms. Plants get minerals from soil. Most of the minerals in a human diet come from eating plants and animals or from drinking water. As a group, minerals are one of the four groups of essential nutrients, the others of which are vitamins, essential fatty acids, and essential amino acids. The five major minerals in the human body are calcium, phosphorus, potassium, sodium, and magnesium. All of the remaining elements in a human body are called "trace elements". The trace elements that have a specific biochemical function in the human body are sulfur, iron, chlorine, cobalt, copper, zinc, manganese, molybdenum, iodine and selenium.

Most chemical elements that are ingested by organisms are in the form of simple compounds. Plants absorb dissolved elements in soils, which are subsequently ingested by the herbivores and omnivores that eat them, and the elements move up the food chain. Larger organisms may also consume soil (geophagia) or use mineral resources, such as salt licks, to obtain limited minerals unavailable through other dietary sources. Bacteria and fungi play an essential role in the weathering of primary elements that results in the release of nutrients for their own nutrition and for the nutrition of other species in the ecological food chain. One element, cobalt, is available for use by animals only after having been processed into complex molecules (e.g., vitamin B12) by bacteria. Minerals are used by animals and microorganisms for the process of mineralizing structures, called "biomineralization", used to construct bones, seashells, eggshells, exoskeletons and mollusc shells.

Mineral nutrients (also called dietary elements and dietary minerals) are inorganic substances that are essential for life. While they're often referred to as minerals, mineral nutrients are correctly classified as elements. All living cells and organisms require these elements in addition to the four basic elements oxygen, hydrogen, nitrogen, and carbon. Mineral nutrients are naturally present on Earth, and many are found in soil and water. Plants and other vegetation obtain them primarily from soil. Animals, including humans, obtain them through the ingestion of plants and other animals. The mineral content of soil and water varies significantly depending on region; and modern food processing methods can rob our foods of minerals and vitamins. Supplementation can be a convenient alternative for ensuring adequate intake of these essential nutrients. Mineral nutrients are required for our skeletal structure, including teeth. They're essential components of bodily tissues and fluids and are also required for the normal function of all bodily enzyme systems. Almost every function of our body is in some way dependent on mineral nutrients.

5.9.1. Essential chemical elements for humans

At least twenty chemical elements are known to be required to support human biochemical processes by serving structural and functional roles as well as electrolytes.

Oxygen, hydrogen, carbon and nitrogen are the most abundant elements in the body by weight and make up about 96% of the weight of a human body. Calcium makes up 920 to 1200 grams of adult body weight, with 99% of it contained in bones and teeth. This is about 1.5% of body weight. Phosphorus occurs in amounts of about 2/3 of calcium, and makes up about 1% of a person's body weight. The other major minerals (potassium, sodium, chlorine, sulfur and magnesium) make up only about 0.85% of the weight of the body. Together these eleven chemical elements (H, C, N, O, Ca, P, K, Na, Cl, S, Mg) make up 99.85% of the body. The remaining ~18 ultra trace minerals comprise just 0.15% of the body, or about a gram in total for the average person.

Differences exist about opinion that the essential nature of various ultra trace elements in humans (and other mammals), are based on the same data. For example, there is no scientific consensus on whether chromium is an essential trace element in humans. The United States and Japan designate chromium as an essential nutrient, but the European Food Safety Authority (EFSA), representing the European Union, reviewed the question in 2014 and does not agree.

Most of the known and suggested mineral nutrients are of relatively low atomic weight, and are reasonably common on land, or for sodium and iodine, in the ocean:

What are the 7 major minerals?

The major minerals include:

- ***Calcium.***
- ***Chloride.***
- ***Magnesium.***
- ***Phosphorus.***
- ***Potassium.***
- ***Sodium.***

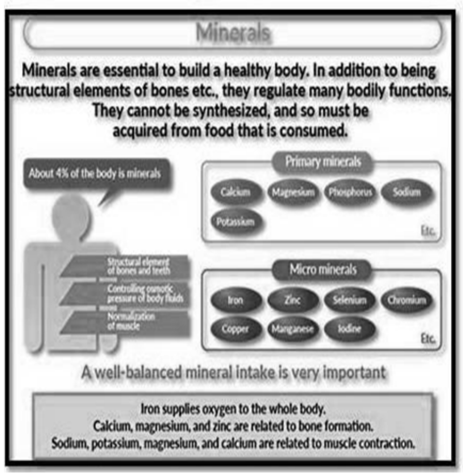
5.10.1. Blood concentrations of minerals

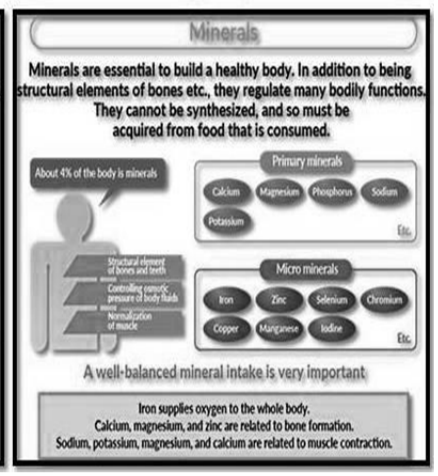
Minerals are present in a healthy human being's blood at certain mass and molar concentrations. The figure below presents the concentrations of each of the chemical elements discussed in this article, from center-right to the right. Depending on the concentrations, some are in upper part of the picture, while others are in the lower part.

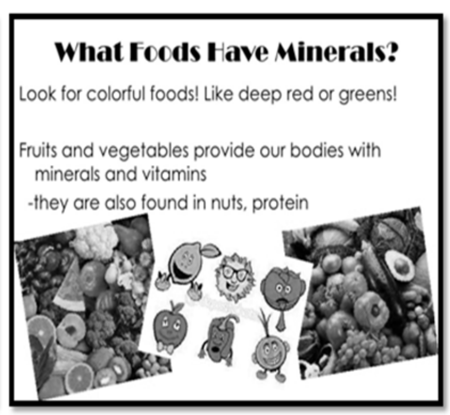
5.10.2. Dietary nutrition

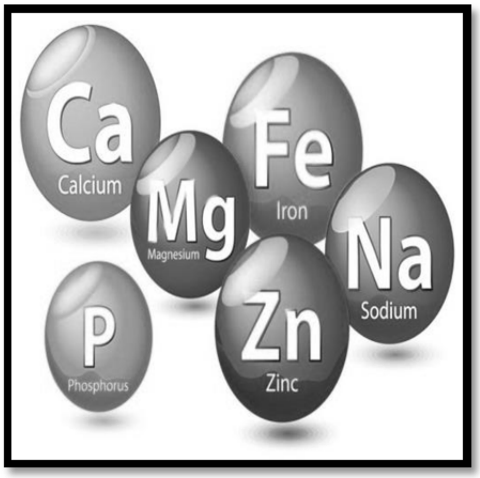
Dietitians may recommend that minerals are best supplied by ingesting specific foods rich with the chemical element(s) of interest. The elements may be naturally present in the food (e.g., calcium in dairy milk) or added to the food (e.g., orange juice fortified with calcium; iodized salt fortified with iodine). Dietary supplements can be formulated to contain several different chemical elements (as compounds), a combination of vitamins and/or other chemical compounds, or a single element (as a compound or mixture of compounds), such as calcium (calcium carbonate, calcium citrate) or magnesium (magnesium oxide), or iron (ferrous sulfate, iron bis-glycinate).

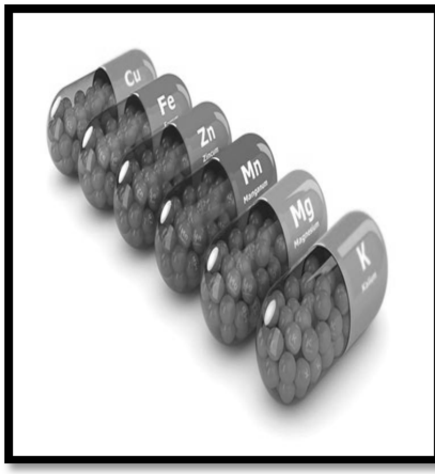
The dietary focus on chemical elements derives from an interest in supporting the biochemical reactions of metabolism with the required elemental components.[38] Appropriate intake levels of certain chemical elements have been demonstrated to be required to maintain optimal health. Diet can meet all the body's chemical element requirements, although supplements can be used when some recommendations are not adequately met by the diet. An example would be a diet low in dairy products, and hence not meeting the recommendation for calcium.



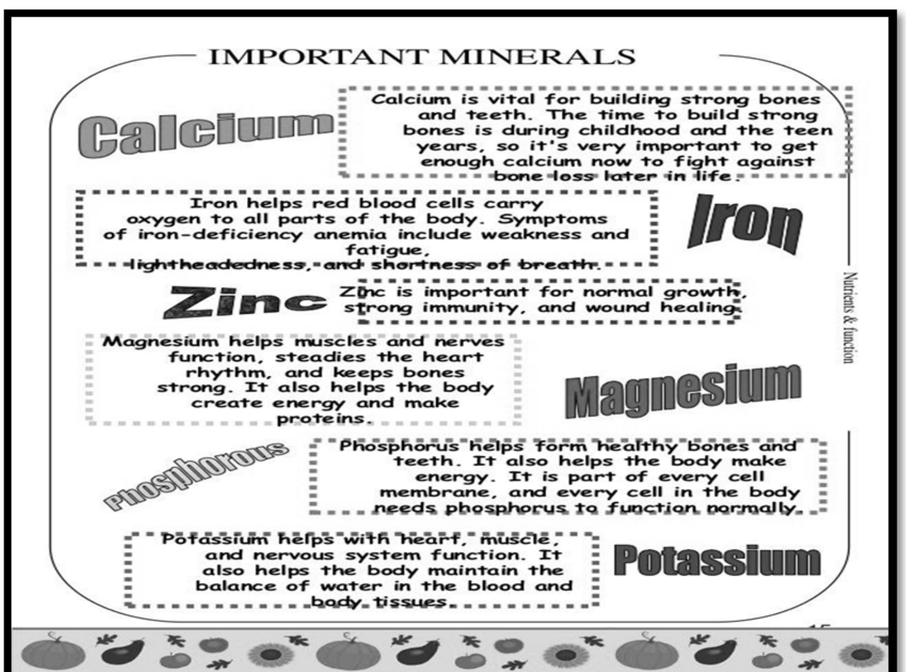



Ca
Calcium
Mg
Magnesium
Fe
Iron
Na
Sodium
P
Phosphorus
Zn
Zinc


Cu
Fe
Zn
Mn
Mg
K


Ca
Zn
Fe
P


IMPORTANT MINERALS
Calcium
Calcium is vital for building strong bones and teeth. The time to build strong bones is during childhood and the teen years, so it's very important to get enough calcium now to fight against bone loss later in life.
Iron helps red blood cells carry oxygen to all parts of the body. Symptoms of iron-deficiency anemia include weakness and fatigue, lightheadedness, and shortness of breath.
Iron
Zinc
Zinc is important for normal growth, strong immunity, and wound healing.
Magnesium helps muscles and nerves function, steadies the heart rhythm, and keeps bones strong. It also helps the body create energy and make proteins.
Magnesium
Phosphorous
Phosphorus helps form healthy bones and teeth. It also helps the body make energy. It is part of every cell membrane, and every cell in the body needs phosphorus to function normally.
Potassium helps with heart, muscle, and nervous system function. It also helps the body maintain the balance of water in the blood and body tissues.
Potassium
Nutrients & function

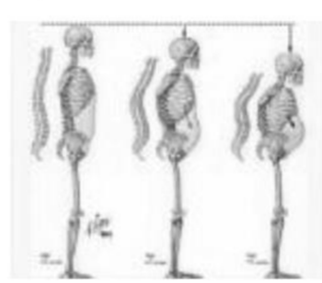
TYPES OF FOOD MINERALS……….

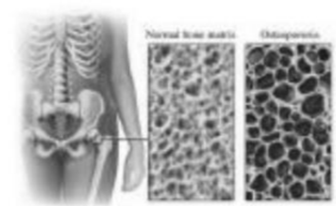
1. CALCIUM
Foods that have it: Milk, fortified nondairy alternatives like soy milk, yogurt, hard cheeses, fortified cereals, kale
How much you need:
Adults ages 19-50: 1,000 milligrams per day
Women age 51 and older: 1,200 milligrams per day
Men age 51 - 70: 1,000 milligrams per day
Men 71 and older: 1,200 milligrams per day
What it does: Needed for bone growth and strength, blood clotting, muscle contraction, and more
Don't get more than this a day: 2,500 milligrams per day for adults age 50 and younger, 2,000 mg per day for those 51 and older.

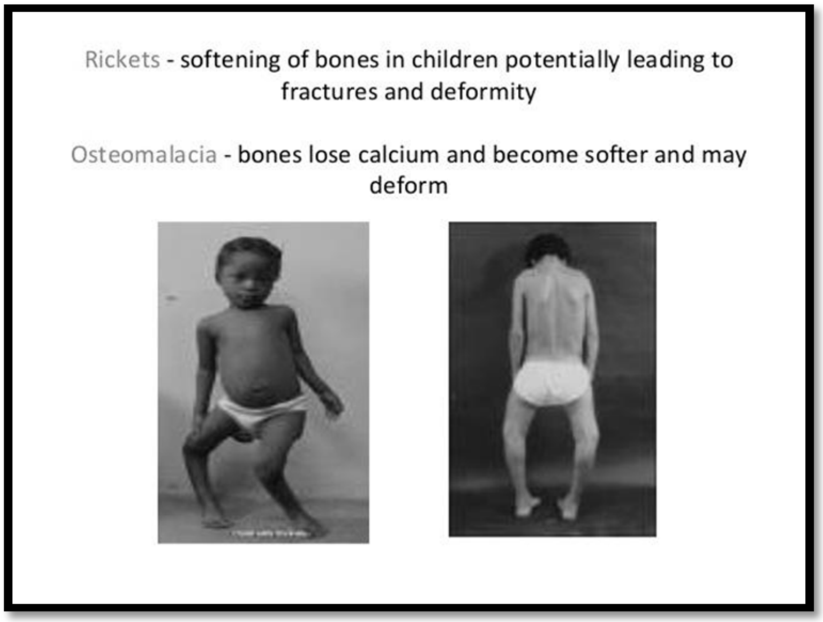
MAJOR MINERALS

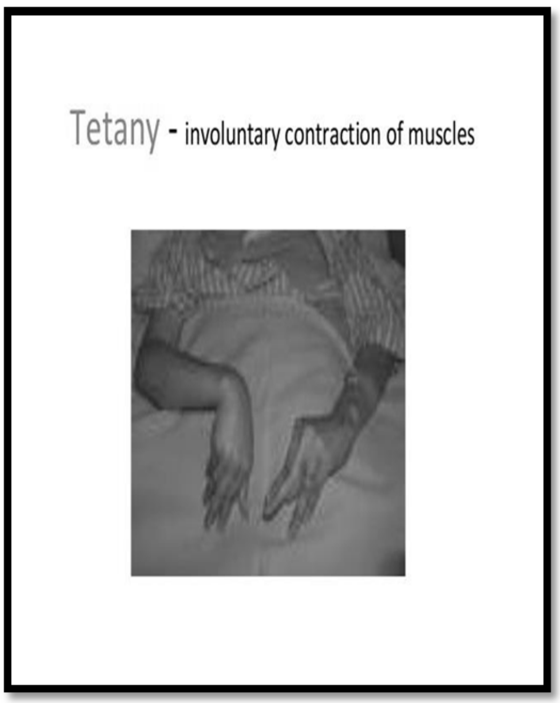
NAME	FOOD SOURCES	FUNCTIONS	DEFICIENCY/ TOXICITY
Calcium (Ca^{2+})	Milk, cheese, sardines, salmon, some dark green leafy vegetables	Development of bones and teeth Transmission of nerve impulses Blood clotting Normal heart action Normal muscle activity	Osteoporosis Osteomalacia Rickets Tetany Retarded growth Poor tooth and bone formation

Osteoporosis - means "porous bones"
- characterized by low bone density or mass (reduced amount of bone tissue) and fragile bones









2. CHOLINE
Foods that have it: Milk, liver, eggs, peanuts
How much you need:
Men: 550 milligrams per day
Women: 425 milligrams per day
What it does: Helps make cells
Don't get more than this much: 3,500 milligrams per day

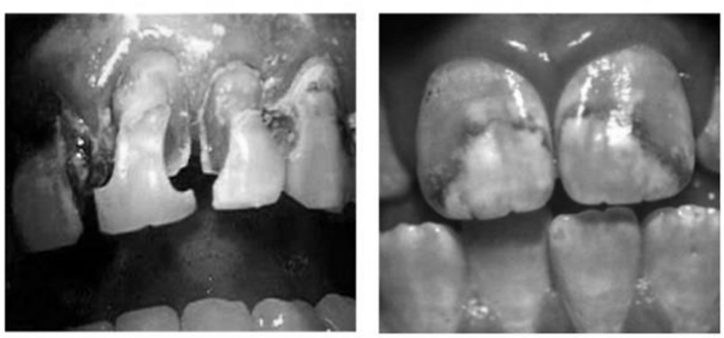
3. CHROMIUM
Foods that have it: Broccoli, potatoes, meats, poultry, fish, some cereals
How much you need:
Men ages 19-50: 35 micrograms per day
Women ages 19-50: 25 micrograms per day, unless pregnant
Pregnant women: 30 micrograms per day
Men age 51 and up: 30 micrograms per day
Women age 51 and up: 20 micrograms per day
What it does: Helps control blood sugar levels
Don't get more than this much: No upper limit known for adults

4. COPPER
Foods that have it: Seafood, nuts, seeds, wheat bran cereals, whole grains
How much you need:
Adults: 900 micrograms per day, unless pregnant
Pregnant women: 1,000 micrograms per day
What it does: Helps your body process iron
Don't get more than this much: 8,000 micrograms per day for adults

5. FIBER
Foods that have it: Plant foods, including oatmeal, lentils, peas, beans, fruits, and vegetables
How much you need:
Men ages 19-50: 38 grams per day
Women ages 19-50: 25 grams per day, unless pregnant
Pregnant women: 25 to 30 grams per day
Men age 51 and up: 30 grams per day
Women age 51 and up: 21 grams per day
What it does: Helps with digestion, lowers LDL ("bad") cholesterol, helps you feel full, and helps maintain blood sugar levels
Don't get more than this much: No upper limit from foods for adults

6. FLUORIDE
Foods that have it: Fluoridated water, some sea fish
How much you need:
Men: 4 milligrams per day
Women: 3 milligrams per day. This includes pregnant
What it does: Prevents cavities in teeth, helps with bone growth
Don't get more than this much: 10 milligrams per day for adults

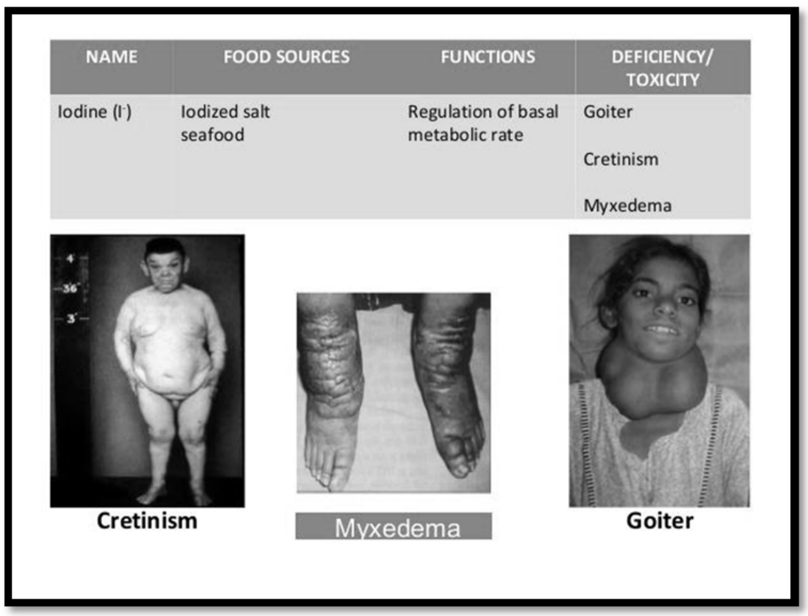
NAME	FOOD SOURCES	FUNCTIONS	DEFICIENCY/ TOXICITY
Fluoride (F^-)	Fluoridated water Seafood	Increases resistance to tooth decay Component of bones and teeth	Deficiency: Tooth decay Possibly osteoporosis Toxicity: Fluorosis - discoloration of teeth or mottling



Fluorosis

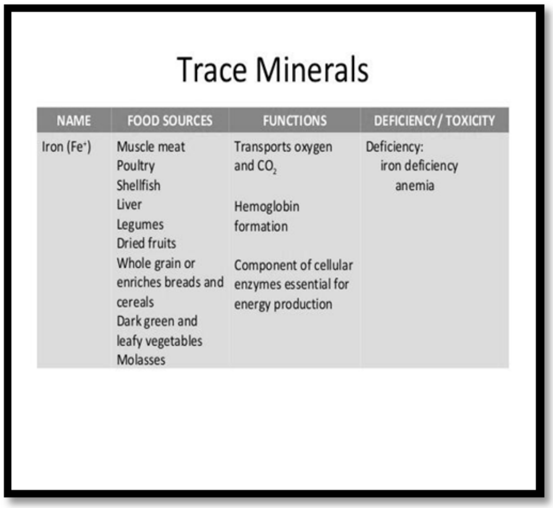
7. FOLIC ACID (FOLATE)
Foods that have it: Dark, leafy vegetables; enriched and whole grain breads; fortified cereals
How much you need:
Adults: 400 micrograms per day, unless pregnant
Pregnant women: 600 micrograms per day
What it does: Helps prevent birth defects, important for heart health and for cell development

Don't get more than this much: 1,000 micrograms per day for adults
8. IODINE
Foods that have it: Seaweed, seafood, dairy products, processed foods, iodized salt
How much you need:
Adults: 150 micrograms per day, unless pregnant or breastfeeding
Pregnant women: 209 micrograms per day
What it does: Helps make thyroid hormones
Don't get more than this much: 1,100 micrograms per day for adults



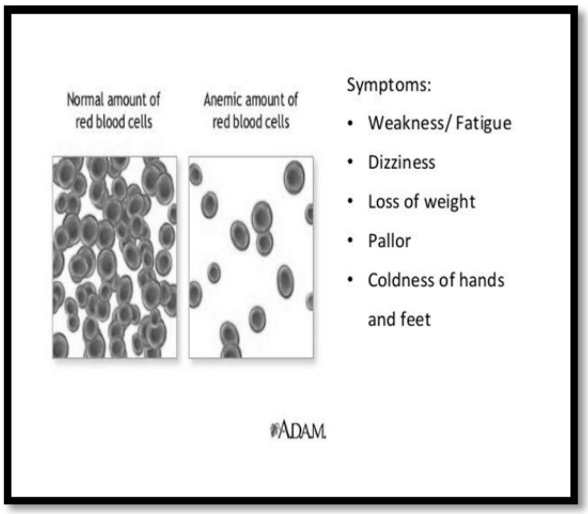
9. IRON
Foods that have it: Fortified cereals, beans, lentils, beef, turkey (dark meat), soy beans, spinach
How much you need:
Men age 19 and up: 8 milligrams per day
Women ages 19-50: 18 milligrams per day, unless pregnant or breastfeeding
Pregnant women: 27 milligrams per day
Women age 51 and up: 8 milligrams per day

What it does: Needed for red blood cells and many enzymes



Trace Minerals

NAME	FOOD SOURCES	FUNCTIONS	DEFICIENCY/ TOXICITY
Iron (Fe^{+})	Muscle meat Poultry Shellfish Liver Legumes Dried fruits Whole grain or enriches breads and cereals Dark green and leafy vegetables Molasses	Transports oxygen and CO_2 Hemoglobin formation Component of cellular enzymes essential for energy production	Deficiency: iron deficiency anemia



10. MAGNESIUM
Foods that have it: Green leafy vegetables, nuts, dairy, soybeans, potatoes, whole wheat, quinoa
How much you need:
Men ages 19-30: 400 milligrams per day
Men age 31 and up: 420 milligrams per day
Women ages 19-30: 310 milligrams per day, unless pregnant or breastfeeding
Women age 31 and up: 320 milligrams per day, unless pregnant or breastfeeding
Pregnant women: 350-360 milligrams per day
What it does: Helps with heart rhythm, muscle and nerve function, bone strength

Don't get more than this much: For the magnesium that's naturally in food and water, there is no upper limit.
For magnesium in supplements or fortified foods: 350 milligrams per day

NAME	FOOD SOURCES	FUNCTIONS	DEFICIENCY/ TOXICITY
Magnesium (Mg^{2+})	Green, leafy vegetables Whole grains, avocados, nuts, milk, legumes, bananas, nuts, seafood, chocolate, cocoa	Nerve transmission Synthesis of ATP Activation of metabolic enzymes Muscle activity Constituent of bones, muscles, and RBCs	Normally unknown Mental, emotional and muscle disorders

11. MANGANESE
Foods that have it: Nuts, beans and other legumes, tea, whole grains
How much you need:
Men: 2.3 milligrams per day
Women: 1.8 milligrams per day, unless pregnant
Pregnant women: 2.0 milligrams per day
What it does: Helps form bones and make some enzymes
Don't get more than this much: 11 milligrams per day for adults

12. MOLYBDENUM
Foods that have it: Legumes, leafy vegetables, grains, nuts
How much you need:
Adults: 45 micrograms per day, unless pregnant
Pregnant or breastfeeding women: 50 micrograms per day

What it does: Needed to make some enzymes
Don't get more than this much: 2,000 micrograms per day for adults

13. PHOSPHORUS
Foods that have it: Milk and other dairy products, peas, meat, eggs, some cereals and breads
How much you need:
Adults: 700 milligrams per day
What it does: Cells need it to work normally. Helps make energy. Needed for bone growth.
Don't get more than this much:
Adults up to age 70: 4,000 milligrams per day. The limit is lower if you're pregnant.
Pregnant women: 3,500 milligrams per day
Adults age 70 and older: 3,000 milligrams per day

NAME	FOOD SOURCES	FUNCTIONS	DEFICIENCY/ TOXICITY
Phosphorus (P)	Milk, cheese, lean meat, poultry, fish, whole-grain cereals, legumes, nuts	Development of bones and teeth Maintains normal pH of the blood Constituent of all body cells CHO, CHON and fat metabolism	Poor tooth and bone formation Weakness Anorexia General malaise

14. POTASSIUM
Foods that have it: Potatoes, bananas, yogurt, milk, yellow fin, tuna, soybeans, and a variety of fruits and vegetables.

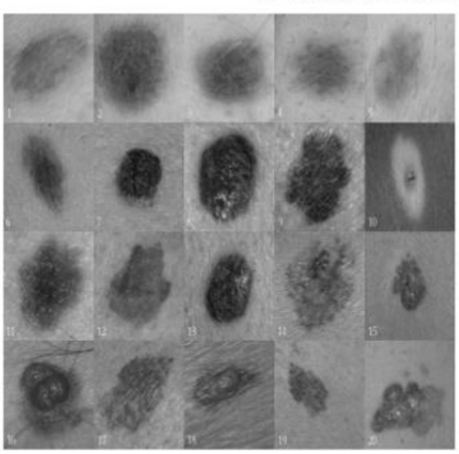
NAME	FOOD SOURCES	FUNCTIONS	DEFICIENCY/ TOXICITY
Potassium (K^+)	Oranges, bananas, dried fruits, vegetables, legumes, milk, cereals, meat	Contraction of muscles Maintenance of fluid balance Transmission of nerve impulses Regular heart rhythm Cell metabolism	Deficiency: hypokalemia muscle weakness confusion abnormal heartbeat Toxicity: hyperkalemia potentially life-threatening irregular heartbeats

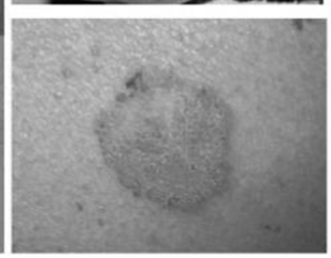
15. Zinc
Foods that have it: Red meats, some seafood, fortified cereals
How much you need:
Men: 11 milligrams per day
Women: 8 milligrams per day, unless pregnant or breastfeeding
Pregnant women: 11 milligrams per day
Breastfeeding women: 12 milligrams per day
What it does: Supports your immune system and nerve function. Also important for reproduction.
Don't get more than this amount: 40 mg per day for adults

NAME	FOOD SOURCES	FUNCTIONS	DEFICIENCY/ TOXICITY
Zinc (Zn^+)	Seafood, esp. oysters Liver Eggs Milk Wheat bran legumes	Formation of collagen Wound healing Taste acuity Essential for growth Immune reactions	Dwarfism Anemia Loss of appetite Skin changes Impaired wound healing Decreased taste acuity

dwarfism

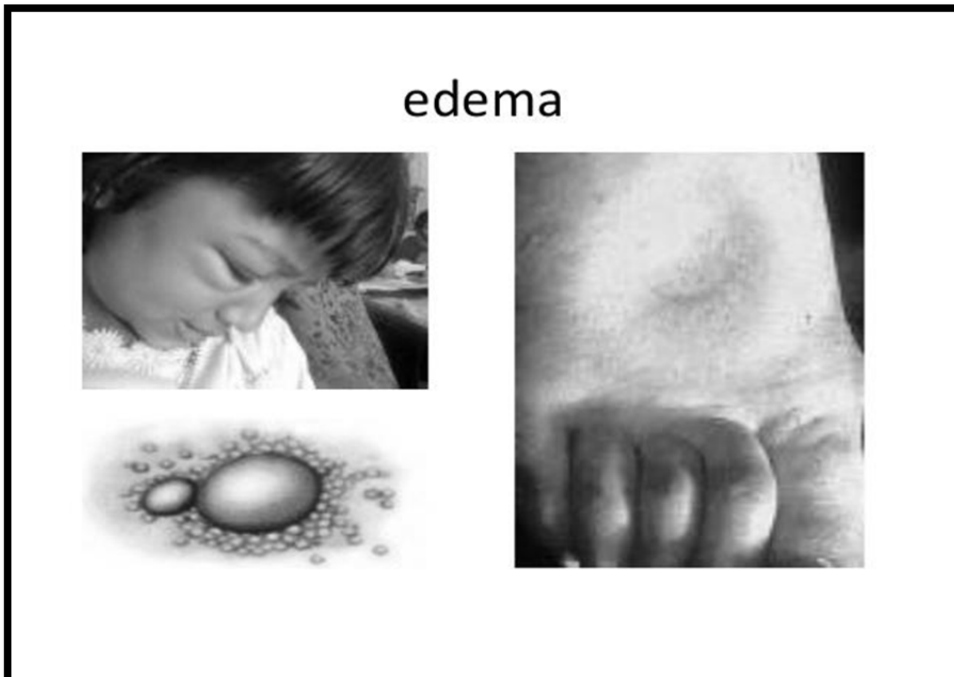
Skin lesions



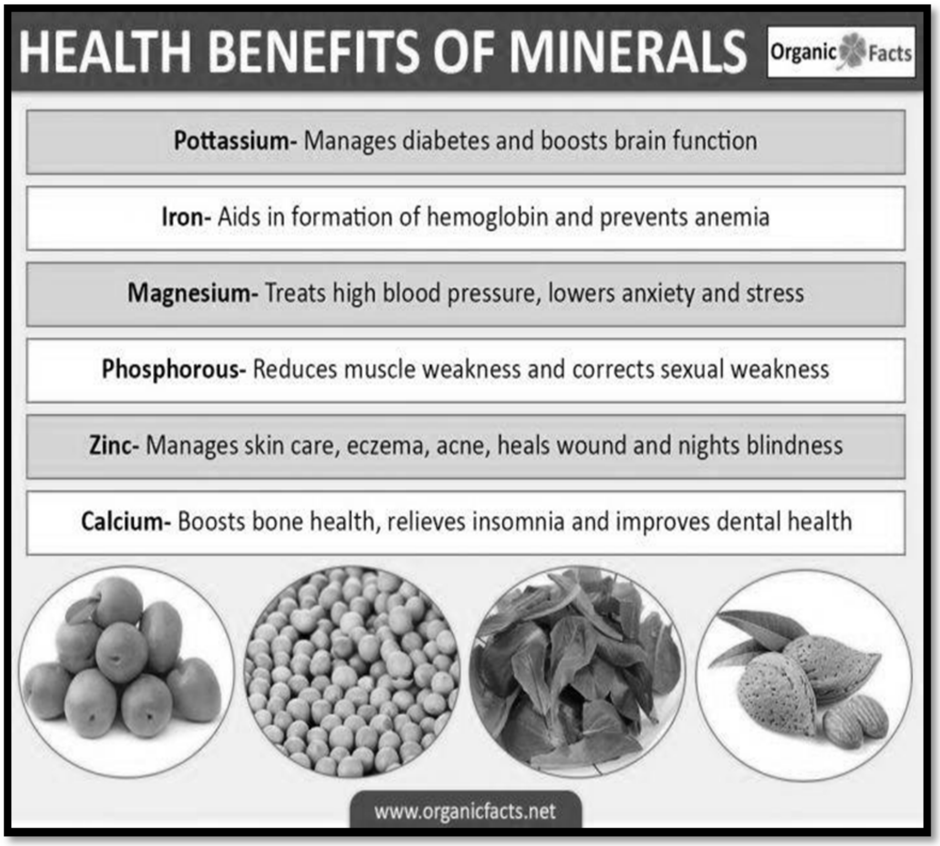


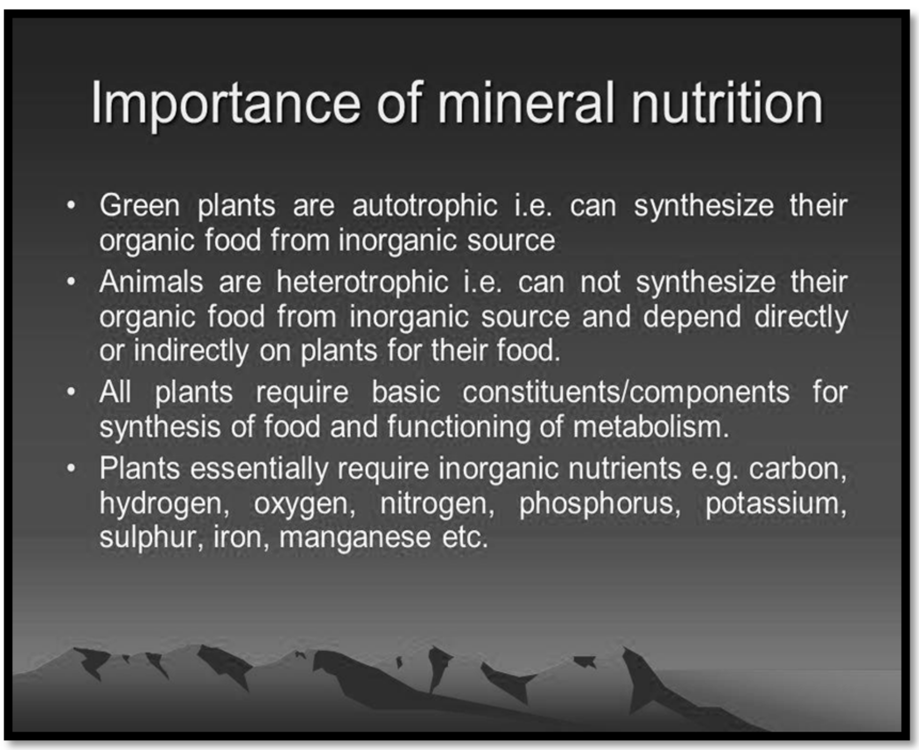
16. SODIUM

NAME	FOOD SOURCES	FUNCTIONS	DEFICIENCY/ TOXICITY
Sodium (Na^+)	Table salt, beef, eggs, poultry, milk, cheese, Soy sauce, moderate amounts in breads and vegetables, large amounts in processed foods	Maintenance of fluid balance Transmission of nerve impulses Acid-base balance Muscle contraction	Deficiency: nausea exhaustion muscle cramps Toxicity: hypertension edema



NAME	FOOD SOURCES	FUNCTIONS	DEFICIENCY/ TOXICITY
Chloride (Cl^-)	Table salt, eggs, seafood, milk	Gastric acidity Regulates acid-base balance in the body Maintains fluid and electrolyte balance Formation of hydrochloric acid	Imbalance in gastric acidity Imbalance in blood pH Nausea Exhaustion





5.11. Nutrients

Which are required by plants in very small amounts are termed as Micro Elements or macronutrients? Some of them include boron, copper, manganese, iron, chlorine, and molybdenum. Nutrients which are required by plants in larger amounts are termed as Macronutrients. Some of them include sulfur, nitrogen, carbon, phosphorous, calcium, potassium and magnesium.

Mineral Nutrition is defined as the naturally occurring inorganic nutrient found in the soil and food that is essential for the proper functioning of animal and plant body. Minerals are vital elements necessary for the body. Both the plants and animals require minerals essentially. For example, Zinc is necessary for the manufacture of protein and for cell division.

3.12. Role of nutrients

- **Balancing function:** Some salts or minerals act against the harmful effects of the other nutrients thus balancing each other.
- **Maintenance of osmotic pressure:** Several minerals cell sap is present in organic or inorganic form to regulate the organic pressure of the cell.
- **Influencing the pH of the cell sap:** Different anions and cations has an influence on the pH of the cell sap.
- **Construction of the plant body:** Carbon, Hydrogen, and Oxygen are elements that help to construct the plant body by entering protoplasm and constitution of the wall.
- **Catalysis of the biochemical reaction:** Certain elements like zinc, magnesium, calcium and copper act as metallic catalysts in biochemical reactions.
- **Effects of Toxicity:** Certain minerals like arsenic and copper have a toxic effect on the protoplasm under specific conditions.

5.12. Summary

The term micronutrient refers to vitamins and minerals, which can be divided into macro minerals, trace minerals and water- and fat-soluble vitamins. As it is our body requires micronutrients in specific amounts, deficiencies and surpluses of any one nutrient may lead to negative issues. If you're at a risk due to specific deficiency, talk to your doctor before starting supplements. Vitamins are needed for energy production, immune function, blood clotting and other functions while minerals benefit growth, bone health, fluid balance and other processes. To get an adequate amount of micronutrients, aim for a balanced diet containing a variety of foods. Minerals are inorganic substances required by the body in small amounts for a variety of different functions.

- Minerals are involved in the formation of bones and teeth; they are essential constituents of body fluids and tissues; they are components of enzyme systems and they are involved in normal nerve function.
- The body requires different amounts of each mineral; people have different requirements, according to their age, sex, physiological state (e.g. pregnancy) and sometimes their state of health.
- The Department of Health and Family Welfare, Govt. of India prescribes Dietary Reference Values (DRVs) for minerals for different groups of healthy people. It is generally recommended by National Institute of Nutrition, Hyderabad.
- The safest and most effective way to get adequate vitamin and mineral intake appears to be from food sources. More research is needed to fully understand the long-term effects of toxicities and supplements.
- However, people at risk of specific nutrient deficiencies do benefit from taking supplements under the supervision of a doctor. If you're interested in taking micronutrient supplements, look for products certified by a third party. Unless otherwise directed by a healthcare provider, be sure to avoid products that contain "super" or "mega" doses of any nutrient.

3.14. Terminal Questions

1. Write an account of Vitamins and its types?
2. What are Fat Soluble Vitamins? Further discuss their sources and deficiencies?
3. Discuss the importance of Vitamin C and its role in disease control
4. Define Trace Elements? Name few trace elements their importance, deficiencies and control
5. Discuss as to why mineral requirement varies with age, sex, physiological status and even the health with examples?

6. Write an essay on essential minerals with examples?

Choose the correct alternative

1. Which among the following fat soluble vitamin deficiency is responsible for Rickets in children
   a) Vitamin A
   b) Vitamin D
   c) Vitamin E
   d) Vitamin K
2. Deficiency of this mineral can give rise to Goitre in human population
   a) Iron
   b) Iodine
   c) Calcium
   d) Cadmium
3. Vitamin B3 (Niacin) is abundant in the following combinations
   a) Meat and Poultry
   b) Fruits and Vegetables
   c) Cereals and Pulses
   d) Nuts and Grams
4. Scurvy i.e. bleeding gums is caused due to deficiency of following
   a) Vitamin D
   b) Vitamin C
   c) Vitamin B
   d) Vitamin A

3.15. Further readings

1. Humphry Bowen (1966) Trace Elements in Biochemistry. Academic Press

2. Vitamin and mineral supplement fact sheets & quot;. Office of Dietary Supplements, US National

3. Principles of Biochemistry: Lehninger, Nelson and Cox. Student Edition, CBS 1439 Publishers and Distributors, Delhi.

4. General biochemistry: J.H. Weil.

5. Biochemistry: T.A. Brown, Viva book publication.

6. Bender DA (2003) Nutritional biochemistry of the vitamins. Cambridge, U.K.: Cambridge University Press.

UNIT : 4

INTRODUCTION TO PHYSIOLOGY

Structure:

4.1. Introduction

Physiology is the science of life. It is the branch of biology that aims to explore the mechanisms of living things, from the basis of cell function at the ionic and molecular levels to the integrated behavior of the whole body and the influence of the external environment. In other words it .is the study of normal functioning within living creatures. It is a sub-section of biology, covering a range of topics that include organs, anatomy, cells, biological compounds, and how they all interact to make life possible. In this unit we shall know about vital circulatory fluid i.e. Blood its composition, its basic functions and the role it carries out for oxygen transport. Blood is a circulating tissue composed of fluid plasma and cells (red blood cells, white blood cells, platelets). Blood is the means and transport system of the body used in carrying elements (e.g. nutrition, waste, heat) from one location in the body to another, by way of blood vessels.

From ancient theories to molecular laboratory techniques, physiological research has shaped our understanding of the components of our body, how they communicate, and how they keep us alive. A known scholar Merrian-Webster defines physiology as: "A branch of biology that deals with the functions and activities of life or of living matter (such as organs, tissues, or cells) and of the physical and chemical phenomena involved." Fast facts on physiology here are some key points about physiology. More detail and supporting information is in the main article.

Objectives

- Physiology can be considered a study of the functions and processes that create and sustain life.
- The study of physiology can be traced back to at least 420 BC.
- The study of physiology is split into many disciplines covering topics as different as exercise, evolution, and defense.

4.2. What is physiology?

Physiology covers a multitude of disciplines within human biology and beyond. The study of physiology is, in a sense is the study of life. It asks questions about the internal workings of organisms i.e. functions and how they interact with the world around them. Physiology tests how organs and systems within the body work, how they communicate, and how they combine their efforts to make conditions favorable for survival.

Human physiology, specifically, is often separated into subcategories; these topics cover a vast amount of information. Researchers in the field have focused on anything from microscopic organelles in cell physiology up to more wide-ranging topics, such as ecophysiology, which looks at whole organisms and how they adapt to environments.

The most relevant arm of physiological research to *Medical News Today* is applied human physiology. This field investigates biological systems at the level of the cell, organ, system, anatomy, organism, and everywhere in between. In this article, we will visit some of the subsections of physiology, developing a brief overview of this huge subject. Firstly, we will run through a short history of physiology.

4.3. History of physiology

Hippocrates is considered by many to be the "father of medicine." The study of physiology traces its roots back to ancient India and Egypt. As a medical discipline, it goes back at least as far as the time of Hippocrates, the famous "father of medicine" - around 420 BC. Hippocrates coined the theory of the four humors, stating that the body contains four distinct bodily fluids: black bile, phlegm, blood, and yellow bile. Any disturbance in their ratios, as the theory goes, causes ill or derangement in homeostasis of the physiology.

Claudius Galenus (c.130-200 AD), also known as Galen, modified Hippocrates' theory and was the first to use experimentation to derive information about the systems of the body. He is widely referred to as the founder of experimental physiology. Later it was Jean Fernel (1497-1558), a French physician, who first introduced the term "physiology," from Ancient Greek, meaning "study of nature, origins." Fernel was also the first to describe the spinal canal (the space in the spine where the spinal cord passes through). He has a crater on the moon named after him for his efforts - it is called Fernelius. Another leap forward in physiological knowledge came with the publication of William Harvey's book titled An Anatomical Dissertation Upon the Movement of the Heart and Blood in Animals as early as 1628. Harvey was the first to describe systemic circulation and blood's journey through the brain and body, propelled by the heart.

Perhaps surprisingly, much medical practice was based on the four humors until well into the 1800s (bloodletting, for instance). In 1838, a shift in thought occurred when the cell theory of Matthias Schleiden and Theodor Schwann arrived on the scene, theorizing that the body was made up of tiny individual functional cells. From here on in, the field of physiology opened up, and profound progress was made quickly:

Some contributions in chronological order are listed in short

- Joseph Lister, 1858 - initially studied coagulation and inflammation following injury, he went on to discover and utilize lifesaving antiseptics.
- Ivan Pavlov, 1891 - conditioned physiological responses in dogs.
- August Krogh, 1910 - won the Nobel Prize for discovering how blood flow is regulated in capillaries.
- Andrew Huxley and Alan Hodgkin, 1952 - discovered the ionic mechanism by which nerve impulses are transmitted.
- Andrew Huxley and Hugh Huxley, 1954 - made advances in the study of muscles with the discovery of sliding filaments in skeletal muscle.

Physiology has different branches

Defense physiology investigates nature's natural defensive reactions.

There are a great number of disciplines that use the word physiology in their title. Below are some examples:

- **Cell physiology** - studying the way cells work and interact; cell physiology mostly concentrates on membrane transport and neuron transmission.
- **System physiology** - this focuses on the computational and mathematical modeling of complex biological systems. It tries to describe the way individual cells or components of a system converge to respond as a whole. They often investigate metabolic networks and cell signaling.
- **Evolutionary physiology** - studying the way systems, or parts of systems, have adapted and changed over multiple generations. Research topics cover a lot of ground including the role of behavior in evolution, sexual selection, and physiological changes in relation to geographic variation.
- **Defense physiology** - changes that occur as a reaction to a potential threat, such as preparation for the fight-or-flight response.
- **Exercise physiology** - as the name suggests, this is the study of the physiology of physical exercise. This includes research into bioenergetics, biochemistry, cardiopulmonary function, biomechanics, hematology, skeletal muscle physiology, neuroendocrine function, and

nervous system function. The topics mentioned above are just a small selection of the available physiologies. The field of physiology is as essential as it is vast.

4.4. Biological systems

The major systems covered in the study of human physiology are as follows:

- **Circulatory system** - including the heart, the blood vessels, properties of the blood, and how circulation works in sickness and health.
- **Digestive/excretory system** - charting the movement of solids from the mouth to the anus; this includes study of the spleen, liver, and pancreas, the conversion of food into fuel and its final exit from the body.
- **Endocrine system** - the study of endocrine hormones that carry signals throughout the organism, helping it to respond in concert. The principal endocrine glands - the pituitary, thyroid, adrenals, pancreas, parathyroids, and gonads - are a major focus, but nearly all organs release endocrine hormones.
- **Immune system** - the body's natural defense system is comprised of white blood cells, the thymus, and lymph systems. A complex array of receptors and molecules combine to protect the host from attacks by pathogens. Molecules such as antibodies and cytokines feature heavily.
- **Integumentary system** - the skin, hair, nails, sweat glands, and sebaceous glands (secreting an oily or waxy substance).
- **Musculoskeletal system** - the skeleton and muscles, tendons, ligaments, and cartilage. Bone marrow - where red blood cells are made - and how bones store calcium and phosphate are included.
- **Nervous system** - the central nervous system (brain and spinal cord) and the peripheral nervous system. Study of the nervous system includes research into the senses, memory, emotion, movement, and thought.
- **Renal/urinary system** - includes the kidneys, ureters, bladder, and urethra, this system removes water from the blood, produces urine, and carries away waste.
- **Reproductive system** - consisting of the gonads and the sex organs. Study of this system also includes investigating the way a fetus is created and nurtured for 9 months.
- **Respiratory system** - consisting of the nose, nasopharynx, trachea, and lungs. This system brings in oxygen and expels carbon dioxide and water.

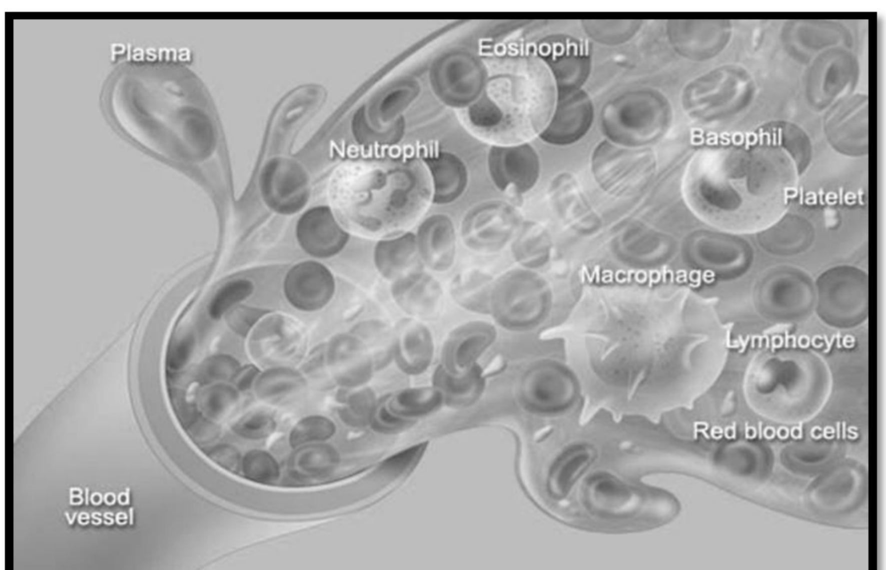
4.5. Bloods and its fundaments

Blood is a specialized body fluid. It has four main components: plasma, red blood cells, white blood cells, and platelets. Blood has many different functions, including:

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

The blood that runs through the veins, arteries, and capillaries is known as whole blood, a mixture of about 55 percent plasma and 45 percent blood cells. About 7 to 8 percent of your total body weight is blood. An average-sized man has about 12 pints of blood in his body, and an average-sized woman has about nine pints.

Blood is a body fluid in humans and other animals that delivers necessary substances such as nutrients and oxygen to the cells and transports metabolic waste products away from those same cells. In vertebrates, it is composed of blood cells suspended in blood plasma. Blood is a constantly circulating fluid providing the body with nutrition, oxygen, and waste removal. Blood is mostly liquid, with numerous cells and proteins suspended in it, making blood "thicker" than pure water on an average; a person has about 5 liters (more than a gallon) of blood in the body.



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

About half of blood volume is composed of blood cells:

- Red blood cells, which carry oxygen to the tissues
- White blood cells, which fight infections
- Platelets, smaller cells that help blood to clot

Blood is conducted through blood vessels (arteries and veins). Blood is prevented from clotting in the blood vessels by their smoothness, and the finely tuned balance of clotting factors. Your blood is made up of liquid and solids. The liquid part, called plasma, is made of water, salts, and protein. Over half of your blood is plasma. The solid part of your blood contains red blood cells, white blood cells, and platelets.

Red blood cells (RBC) deliver oxygen from your lungs to your tissues and organs. White blood cells (WBC) fight infection and are part of your immune system. Platelets help blood to clot when you have a cut or wound. Bone marrow, the spongy material inside your bones, makes new blood cells. Blood cells constantly die and your body makes new ones. Red blood cells live about 120 days, and platelets live about 6 days. Some white blood cells live less than a day, but others live much longer.

There are four blood types: A, B, AB, and O. Also, blood is either Rh-positive or Rh-negative. So if you have type A blood, it's either A positive or A negative. Which type you are is important if you need a blood transfusion. And your Rh factor could be important if you become pregnant - an incompatibility between your type and the baby's could create problems. Blood tests such as blood count tests help doctors check for certain diseases and conditions. They also help check the function of your organs and show how well treatments are working. Problems with your blood may include bleeding disorders, excessive clotting and platelet disorders. If you lose too much blood, you may need a transfusion.

Blood is a body fluid in humans and other animals that delivers necessary substances such as nutrients and oxygen to the cells and transports metabolic waste products away from those same cells.

In vertebrates, it is composed of blood cells suspended in blood plasma. Plasma, which constitutes 55% of blood fluid, is mostly water (92% by volume),[2] and contains proteins, glucose, mineral ions, hormones, carbon dioxide (plasma being the main medium for excretory product transportation), and blood cells themselves. Albumin is the main protein in plasma, and it functions to regulate the colloidal osmotic pressure of blood. The blood cells are mainly red blood cells (also called RBCs or erythrocytes), white blood cells (also called WBCs or leukocytes) and platelets (also called thrombocytes). The most abundant cells in vertebrate blood are red blood cells. These contain hemoglobin, an iron-containing protein, which facilitates oxygen transport by reversibly binding to this respiratory gas and greatly increasing its solubility in blood. In contrast, carbon dioxide is mostly transported extracellular as bicarbonate ion transported in plasma.

Vertebrate blood is bright red when its hemoglobin is oxygenated and dark red when it is deoxygenated. Some animals, such as crustaceans and mollusks, use hemocyanin to carry oxygen, instead of hemoglobin. Insects and some mollusks use a fluid called hem lymph instead of blood, the difference being that hemolymph is not contained in a closed circulatory system. In most insects, this "blood" does not contain oxygen-carrying molecules such as hemoglobin because their bodies are small enough for their tracheal system to suffice for supplying oxygen.

Jawed vertebrates have an adaptive immune system, based largely on white blood cells. White blood cells help to resist infections and parasites. Platelets are important in the clotting of blood. Arthropods, using hemolymph, have hemocytes as part of their immune system.

Blood is circulated around the body through blood vessels by the pumping action of the heart. In animals with lungs, arterial blood carries oxygen from inhaled air to the tissues of the body, and venous blood carries carbon dioxide, a waste product of metabolism produced by cells, from the tissues to the lungs to be exhaled.

Medical terms related to blood often begin with hemo- or hemato- (also spelled haemo- and haemato-) from the Greek word αἷμα(haima) for "blood". In terms of anatomy and histology, blood is considered a specialized form of connective tissue, given its origin in the bones and the presence of potential molecular fibers in the form of fibrinogen.

Blood travels in the body

With each heartbeat, the heart pumps blood throughout our body, carrying oxygen to every cell. After delivering the oxygen, the blood returns to the heart. The heart then sends the blood to the lungs to pick up more oxygen. This cycle repeats over and over again.

The circulatory system is made up of blood vessels that carry blood away from and toward the heart.

Two types of blood vessels carry blood throughout our bodies:

1. **Arteries** except pulmonary carry oxygenated blood (blood that has received oxygen from the lungs) from the heart to the rest of the body.

2. Veins carry deoxygenated blood (except pulmonary vein) back to the heart and lungs, so it gets more oxygen to send back to the body through the arteries.

As the heart beats, you can feel blood traveling through the body at pulse points — like the neck and the wrist — where large, blood-filled arteries run close to the surface of the skin.

4.6. Functions of blood

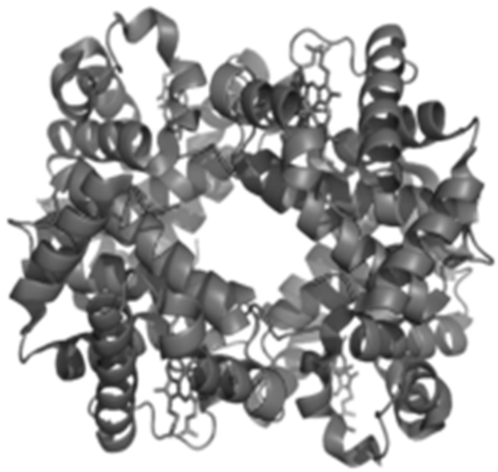


Fig. 4.1: Schematic diagram of blood

Hemoglobin, a global protein green= haem (or hem) groups red & blue= protein subunits

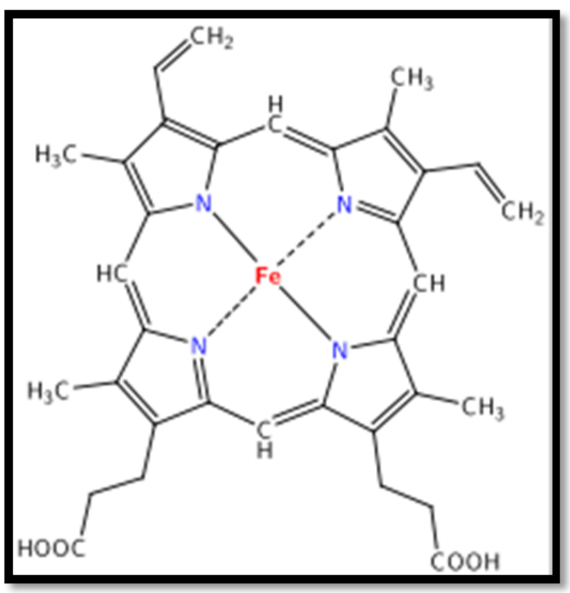


Fig. 4.2: Schematic diagram of Hemoglobin

Blood performs many important functions within the body, including:

- Supply of oxygen to tissues (bound to hemoglobin, which is carried in red cells)

- Supply of nutrients such as glucose, amino acids, and fatty acids (dissolved in the blood or bound to plasma proteins (e.g., blood lipids))
- Removal of waste such as carbon dioxide, urea, and lactic acid
- Immunological functions, including circulation of white blood cells, and detection of foreign material by antibodies
- Coagulation, the response to a broken blood vessel, the conversion of blood from a liquid to a semisolid gel to stop bleeding
- Messenger functions, including the transport of hormones and the signaling of tissue damage
- Regulation of core body temperature
- Hydraulic functions

4.7. Constituents of blood

In mammals: Blood accounts for 7% of the human body weight, with an average density around 1060 kg/m3, very close to pure water's density of 1000 kg/m3. The average adult has a blood volume of roughly 5 liters (11 US pt), which is composed of plasma and several kinds of cells. These blood cells (which are also called corpuscles or "formed elements") consist of erythrocytes (red blood cells, RBCs), leukocytes (white blood cells), and thrombocytes (platelets). By volume, the red blood cells constitute about 45% of whole blood, the plasma about 54.3%, and white cells about 0.7%.

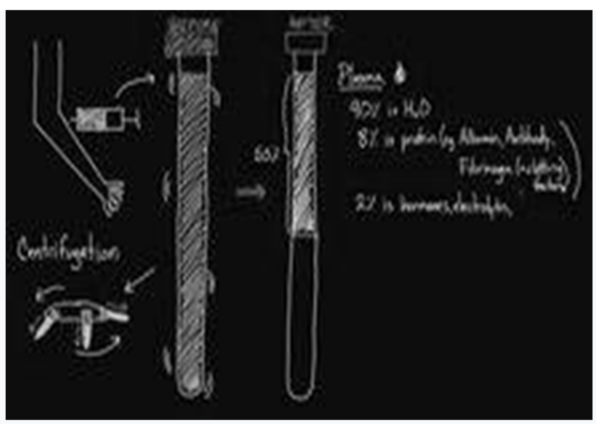


Fig. 4.3: What's Inside of Blood

Whole blood (plasma and cells) exhibits non-Newtonian fluid dynamics. If all human hemoglobin were free in the plasma rather than being contained in RBCs, the circulatory fluid would be too viscous for the cardiovascular system to function effectively. Human blood fractioned by centrifugation: Plasma (upper, yellow layer), buffy coat (middle, thin white layer) and erythrocyte layer (bottom, red layer) can be seen. Blood circulation: Red = oxygenated, blue = deoxygenated

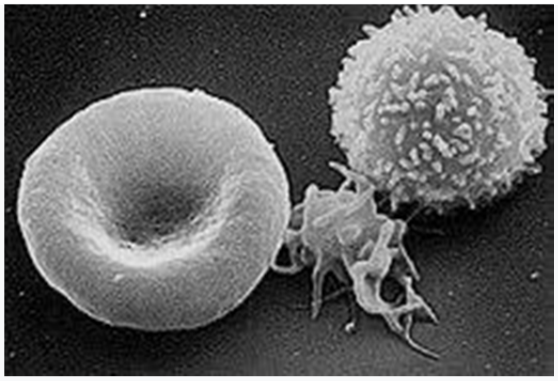


Fig. 4.4: A scanning electron microscope (SEM) image of a normal red blood cell (left), a platelet (middle), and a white blood cell (right)

One microliter of blood contains:

- 4.7 to 6.1 million (male), 4.2 to 5.4 million (female) erythrocytes: Red blood cells contain the blood's hemoglobin and distribute oxygen. Mature red blood cells lack a nucleus and organelles in mammals. The red blood cells (together with endothelial vessel cells and other cells) are also marked by glycoprotein's that define the different blood types. The proportion of blood occupied by red blood cells is referred to as the hematocrit, and is normally about 45%. The combined surface area of all red blood cells of the human body would be roughly 2,000 times as great as the body's exterior surface.
- 4,000–11,000 leukocytes: White blood cells are part of the body's immune system; they destroy and remove old or aberrant cells and cellular debris, as well as attack infectious agents (pathogens) and foreign substances. The cancer of leukocytes is called leukemia.
- 200,000–500,000 thrombocytes: Also called platelets, they take part in blood clotting (coagulation). Fibrin from the coagulation cascade creates a mesh over the platelet plug.

Constitution of normal blood	
Parameter	**Value**
Hematocrit	45 ± 7 (38–52%) for males, 42 ± 5 (37–47%) for females
pH	7.35–7.45
base excess	−3 to +3
PO_2	10–13 kPa (80–100 mm Hg)
PCO_2	4.8–5.8 kPa (35–45 mm Hg)
HCO_3^-	21–27 mM
Oxygen	Oxygenated: 98–99%
saturation	Deoxygenated: 75%

Plasma

About 55% of blood is blood plasma, a fluid that is the blood's liquid medium, which by itself is straw-yellow in color. The blood plasma volume totals of 2.7–3.0 liters (2.8–3.2 quarts) in an average human. It is essentially an aqueous solution containing 92% water, 8% blood plasma proteins, and trace amounts of other materials. Plasma circulates dissolved nutrients, such as glucose, amino acids, and fatty acids (dissolved in the blood or bound to plasma proteins), and removes waste products, such as carbon dioxide, urea, and lactic acid. Other important components include:

- Serum albumin
- Blood-clotting factors (to facilitate coagulation)
- Immunoglobulins (antibodies)
- lipoprotein particles
- Various other proteins
- Various electrolytes (mainly sodium and chloride)

The term serum refers to plasma from which the clotting proteins have been removed. Most of the proteins remaining are albumin and immunoglobulins.

pH values

Blood pH is regulated to stay within the narrow range of 7.35 to 7.45, making it slightly basic. Blood that has a pH below 7.35 is too acidic, whereas blood pH above 7.45 is too basic. Blood pH, partial pressure of oxygen (pO_2), partial pressure of carbon dioxide (pCO_2), and bicarbonate (HCO_3^-)are carefully regulated by a number of homeostatic mechanisms, which exert their influence principally through the respiratory system and the urinary system to control the acid-base balance and respiration. An arterial blood gas test measures these. Plasma also circulates hormones transmitting their messages to various tissues. The list of normal reference ranges for various blood electrolytes is extensive.

In non-mammalian vertebrates

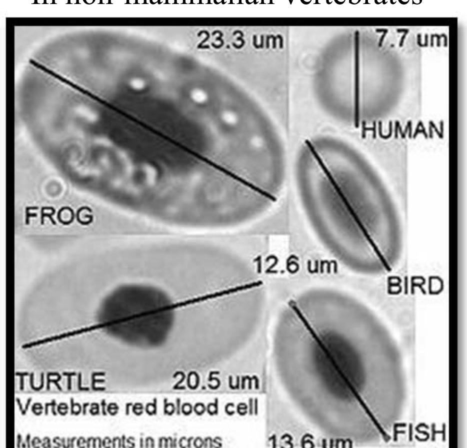


Fig. 4.5: Vertebrate red blood cell types, measurements in micrometers

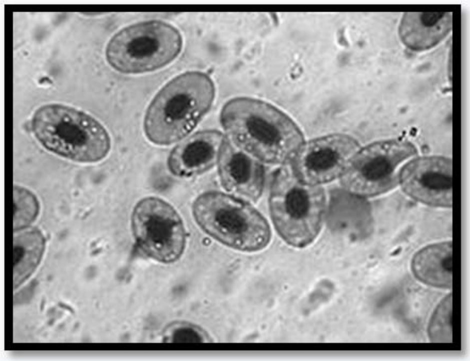


Fig. 4.6: Frog red blood cells magnified 1000 times

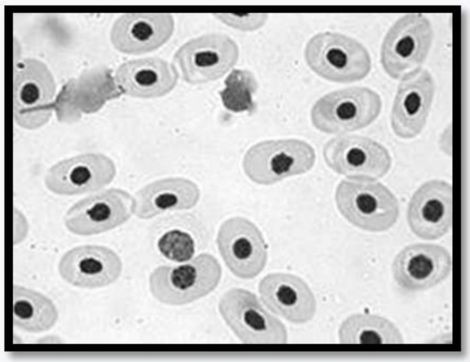


Fig. 4.7: Turtle red blood cells magnified 1000 times

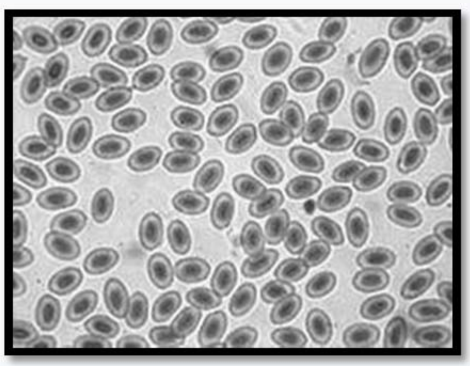


Fig. 4.8: Chicken red blood cells magnified 1000 times

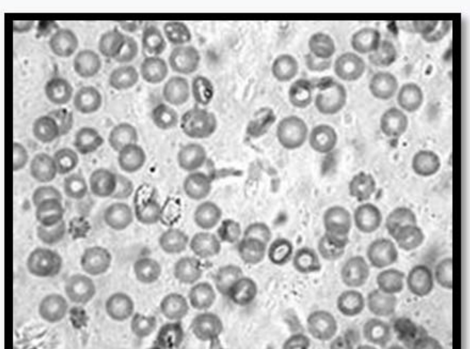


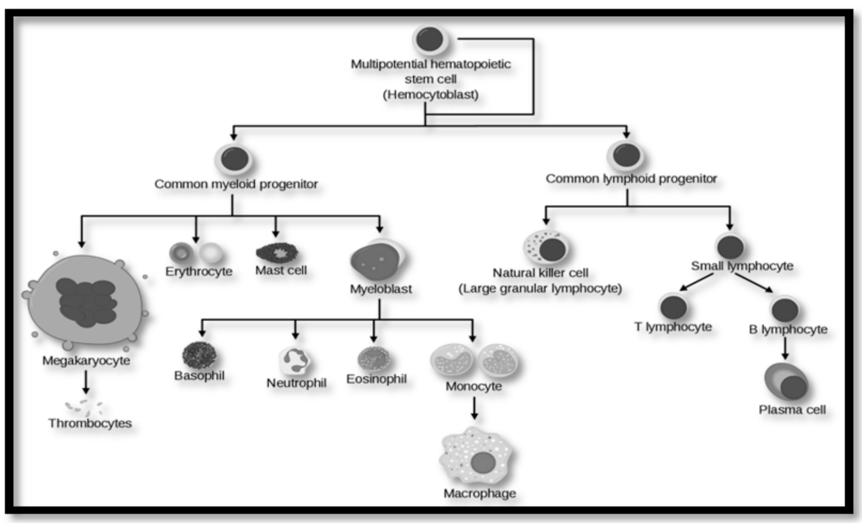
Fig. 4.9: Human red blood cells magnified 1000 times

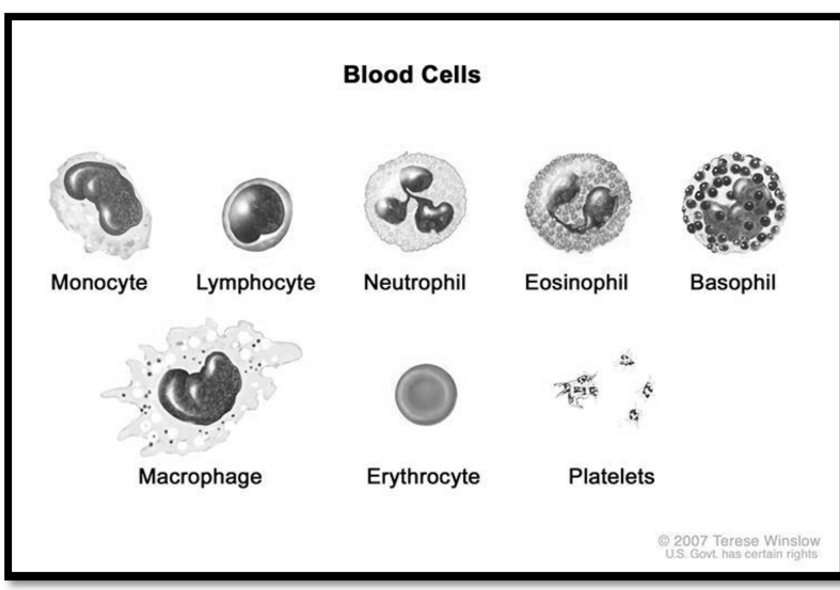
Human blood is typical of that of mammals, although the precise details concerning cell numbers, size, protein structure, and so on, vary somewhat between species. In non-mammalian vertebrates, however, there are some key differences:

- Red blood cells of non-mammalian vertebrates are flattened and ovoid in form, and retain their cell nuclei.
- There is considerable variation in the types and proportions of white blood cells; for example, acidophils are generally more common than in humans.
- Platelets are unique to mammals; in other vertebrates, small nucleated, spindle cells called thrombocytes are responsible for blood clotting instead.

4.8. Types of blood cells

There are three types of living cells in blood:





Red blood cells

Red blood cells (RBCs, also called erythrocytes; pronounced: ih-RITH-ruh-sytes) are shaped like slightly indented, flattened disks. RBCs contain hemoglobin (pronounced: HEE-muh-glow-bin), a protein that carries oxygen. Blood gets its bright red color when hemoglobin picks up oxygen in the lungs. As the blood travels through the body, the hemoglobin releases oxygen to the different body parts.

Each RBC lives for about 4 months. Each day, the body makes new RBCs to replace those that die or are lost from the body. RBCs are made in the inside part of bones called the bone marrow.

White blood cells

White blood cells (also called leukocytes; pronounced: LOO-kuh-sytes) are a key part of the immune system. The immune system helps the body defend itself against infection. Different types of white blood cells (WBCs) fight germs, such as bacteria and viruses . Some types of WBCs make antibodies, which are special proteins that recognize foreign materials and help the body get rid of them.

There are several types of WBCs, with varying their life spans from hours to years. New cells are constantly being formed some in the bone marrow and some in other parts of the body such as the spleen, thymus, and lymph nodes. Blood contains far fewer WBCs than red blood cells, although the body can increase WBC production to fight infection. The white blood cell count (the number of cells in a given amount of blood) in someone with an infection often is higher than usual because more WBCs are being made or are entering the bloodstream to battle the infection.

Platelets

Platelets (also called thrombocytes; pronounced: THROM-buh-sytes) are tiny oval-shaped cells that help in the clotting process. When a blood vessel breaks, platelets gather in the area and help seal off the leak. Platelets work with proteins called clotting factors to control bleeding inside our bodies and on our skin. Platelets survive only about 9 days in the bloodstream and are constantly being replaced by new platelets made by the bone marrow.

4.9. Whole blood

Whole blood contains red cells, white cells, and platelets (~45% of volume) suspended in blood plasma (~55% of volume).

- Color: Red
- Shelf Life: 21/35 days*
- Storage Conditions: Refrigerated
- Key Uses: Trauma, Surgery

Whole Blood is the simplest, most common type of blood for the purpose of donation. It's also the most flexible because it can be transfused in its original form, or used to help multiple people when separated into its specific components of red cells, plasma and platelets. A whole blood donation requires minimal processing before it is ready to be transfused into a patient. If not needed right away, whole blood can be refrigerated for up to 35 days, depending on the type of anticoagulant used. Whole blood is used to treat patients who need all the components of blood, such as those who have sustained significant blood loss due to trauma or surgery. Whole blood can be donated at any Red Cross blood drive or blood bank center.

Red cells

Red blood cells (RBCs), or erythrocytes, give blood its distinctive color. Produced in our bone marrow, they carry oxygen from our lungs to the rest of our bodies and take carbon dioxide back to our lungs to be exhaled. There are about one billion red blood cells in two to three drops of blood.

- Color: Red
- Shelf Life: Up to 42 days*
- Storage Conditions: Refrigerated
- Key Uses: Trauma, Surgery, Anemia, Any blood loss, Blood disorders, such as sickle cell

Red blood cells are prepared from whole blood by removing the plasma (the liquid portion of the blood). They have a shelf life of up to 42 days, depending on the type of anticoagulant used. They can also be treated and frozen for 10 years or more.

RBCs are used to treat anemia without substantially increasing the patient's blood volume. Patients who benefit most from transfusion of red blood cells include those with chronic anemia resulting from kidney failure or gastrointestinal bleeding, and those with acute blood loss resulting from trauma. They can also be used to treat blood disorders such as sickle cell disease.

Prestorage Leukocyte-Reduced Red Blood Cells

Leukocyte-reduced RBCs are prepared by removing leukocytes (white blood cells) by filtration shortly after donation. This is done before the RBCs are stored because over time the leukocytes can fragment, deteriorate, and release cytokines, which can trigger negative reactions in the patient who receives them. These reactions can occur during the initial transfusion or during any future transfusions.

Donating Red Blood Cells

The Red Cross calls RBC donations "Power Red." By donating Power Red, you double your impact by contributing two units of red cells in just one donation.

Red Blood Cells (also called erythrocytes or RBCs)

Known for their bright red color, red cells are the most abundant cell in the blood, accounting for about 40 to 45 percent of its volume. The shape of a red blood cell is a biconcave disk with a flattened center - in other words, both faces of the disc have shallow bowl-like indentations (a red blood cell looks like a donut).

Production of red blood cells is controlled by erythropoietin, a hormone produced primarily by the kidneys. Red blood cells start as immature cells in the bone marrow and after approximately seven days of maturation are released into the bloodstream. Unlike many other cells, red blood cells have no nucleus and can easily change shape, helping them fit through the various blood vessels in your body. However, while the lack of a nucleus makes a red blood cell more flexible, it also limits the life of the cell as it travels through the smallest blood vessels, damaging the cell's membranes and depleting its energy supplies. The red blood cell survives on average for120 days.

Red cells contain a special protein called hemoglobin, which helps carry oxygen from the lungs to the rest of the body and then returns carbon dioxide from the body to the lungs so it can be exhaled. Blood appears red because of the large number of red blood cells, which get their color from the hemoglobin. The percentage of whole blood volume that is made up of red blood cells is called the hematocrit and is a common measure of red blood cell levels.

Platelets or thrombocytes

Platelets also called thrombocytes. Unlike red and white blood cells, platelets are not actually cells but rather small fragments of cells. Platelets help the blood clotting process (or coagulation) by gathering at the site of an injury, sticking to the lining of the injured blood vessel, and forming a platform on which blood coagulation can occur. This results in the formation of a fibrin clot, which covers the wound and prevents blood from leaking out. Fibrin also forms the initial scaffolding upon which new tissue forms, thus promoting healing.

A higher than normal number of platelets can cause unnecessary clotting, which can lead to strokes and heart attacks; however, thanks to advances made in antiplatelet therapies, there are treatments available to help prevent these potentially fatal events. Conversely, lower than normal counts can lead to extensive bleeding.

Platelets, or thrombocytes, are small, colorless cell fragments in our blood whose main function is to stick to the lining of blood vessels and help stop or prevent bleeding. Platelets are made in our bone marrow.

- Color: Colorless

- Shelf Life: 5 days
- Storage Conditions: Room temperature with constant agitation to prevent clumping
- Key Uses: Cancer treatments, Organ transplants, Surgery

Platelets can be prepared by using a centrifuge device to separate the platelet-rich plasma from donated whole blood. Platelets from several different donors are then combined to make one tranfusable unit. Alternately, platelets can be obtained using an apheresis machine which draws blood from the donor’s arm, separates the blood into its components, retains some of the platelets, and returns the remainder of the blood to the donor. Using this process, one donor can contribute about four to six times as many platelets as a unit of platelets obtained from a whole blood donation.

Platelets are stored at room temperature for up to 5 days. They must receive constant gentle agitation to prevent them from clumping.

Platelets are most often used during cancer treatment as well as surgical procedures such as organ transplant, in order to treat a condition called thrombocytopenia, in which there is a shortage of platelets. They are also used to treat platelet function abnormalities.

Donating Platelets

Since platelets must be used within 5 days of donation, there is a constant need for platelet donors.

Plasma

The liquid component of blood is called plasma, a mixture of water, sugar, fat, protein, and salts. The main job of the plasma is to transport blood cells throughout your body along with nutrients, waste products, antibodies, clotting proteins, chemical messengers such as hormones, and proteins that help maintain the body's fluid balance.

Plasma is the liquid portion of blood; our red and white blood cells and platelets are suspended in plasma as they move throughout our bodies.

- Color: Yellowish
- Shelf Life: 1 year
- Storage Conditions: Frozen
- Key Uses: Burn patients, Shock, Bleeding disorders

Blood plasma serves several important functions in our bodies, despite being about 92% water. (Plasma also contains 7% vital proteins such as albumin, gamma globulin and anti-hemophilic factor, and 1% mineral salts, sugars, fats, hormones and vitamins.) It helps us maintain a satisfactory blood pressure and volume, and supplies critical proteins for blood clotting and immunity. It also carries electrolytes such as sodium and potassium to our muscles and helps to maintain a proper pH (acid-base) balance in the body, which is critical to cell function.

Plasma is obtained by separating the liquid portion of blood from the cells. Plasma is frozen within 24 hours of being donated in order to preserve the valuable clotting factors. It is then stored for up to one year, and thawed when needed. Plasma is commonly transfused to trauma, burn and shock patients, as well as people with severe liver disease or multiple clotting factor deficiencies.

Plasma Derivatives

In some cases, patients need only plasma derivatives instead. These are concentrates of specific plasma proteins obtained through a process known as fractionation. The derivatives are treated with heat and/or solvent detergent to kill certain viruses like those that cause HIV, hepatitis B, and hepatitis C. Plasma derivatives include:

- Factor VIII Concentrate
- Factor IX Concentrate
- Anti-Inhibitor Coagulation Complex (AICC)
- Albumin
- Immune Globulins, including Rh Immune Globulin
- Anti-Thrombin III Concentrate
- Alpha 1-Proteinase Inhibitor Concentrate

Donating AB Plasma

When collecting specifically plasma, the Red Cross is seeking AB-type donors. AB plasma is collected at select Red Cross Donation Centers only.

Cryoprecipitate Antihemophilic Factor (CRYO)

Cryoprecipitated Antihemophilic Factor (Cryo) is a portion of plasma rich in clotting factors, including Factor VIII and fibrinogen. These clotting factors reduce blood loss by helping to slow or stop bleeding due to illness or injury.

- Color: White
- Shelf Life: 1 year
- Storage Conditions: Frozen
- Key Uses: Hemophilia, Von Willebrand disease (most common hereditary coagulation abnormality), Rich source of Fibrinogen

Cryo is prepared by freezing and then slowly thawing frozen plasma. The precipitate is collected and then pooled with contributions from other donors to reach a sufficient volume for transfusion. It can be stored, frozen, for up to a year.

Cryo is used to prevent or control bleeding in people whose own blood does not clot properly. This includes patients with hereditary conditions such as hemophilia and von Willebrands disease. Cryo is also a source of fibrinogen for patients who cannot produce the necessary amount of this important clotting protein on their own. Donating Cryoprecipitated AHF. Cryo is prepared from donated plasma.

White cells & granulocytes

White Blood Cells (also called leukocytes) White blood cells protect the body from infection. They are much fewer in number than red blood cells, accounting for about 1 percent of your blood. The most common type of white blood cell is the neutrophil, which is the "immediate response" cell and accounts for 55 to 70 percent of the total white blood cell count. Each neutrophil lives less than a day, so your bone marrow must constantly make new neutrophils to maintain protection against infection. Transfusion of neutrophils is generally not effective since they do not remain in the body for very long. The other major type of white blood cell is a lymphocyte. There are two main populations of these cells. T lymphocytes help regulate the function of other immune cells and directly attack various infected cells and tumors. B lymphocytes make antibodies, which are proteins that specifically target bacteria, viruses, and other foreign materials.

White blood cells, or leukocytes, are one of the body's defenses against disease: some destroy bacteria and others create antibodies against bacteria and viruses or fight malignant disease. But while our own white cells help us stay healthy, they can be dangerous to someone who receives donated blood. That's because leukocytes may carry viruses that cause immune suppression and release toxic substances in the recipient. To avoid these negative reactions, leukocytes are often removed from transfusable blood components, a process called leuko-reduction.

It doesn't necessarily mean your white cells can't be used to help patients in need! Granulocytes are a type of white cell that protects against infection by surrounding and destroying invading bacteria and viruses. They can be used to treat infections that don't respond to antibiotics. Granulocytes are collected by an automated process called apheresis and must be transfused into the patient within 24 hours of being donated.

4.10. Complete Blood Count (CBC)

A complete blood count (CBC) test gives your doctor important information about the types and numbers of cells in your blood, especially the red blood cells and their percentage (hematocrit) or protein content (hemoglobin), white blood cells, and platelets. The results of a CBC may diagnose conditions like anemia, infection, and other disorders. These investigation help physicians in reaching correct diagnosis and treatment plan. The platelet count and plasma clotting tests (prothombin time, partial thromboplastin time, and thrombin time) may be used to evaluate bleeding and clotting disorders.

If someone has low numbers of blood cells

Sometimes medicine can be given to help a person make more blood cells. And sometimes blood cells and some of the special proteins blood contains can be replaced by giving a person blood from someone else. This is called a blood transfusion (pronounced: trans-FEW-zyun).

People can get transfusions of the part of blood they needed, such as platelets, RBCs, or a clotting factor. When someone donates blood, the whole blood can be separated into its different parts to be used in these ways

Blood conditions

- Hemorrhage (bleeding): Blood leaking out of blood vessels may be obvious, as from a wound penetrating the skin. Internal bleeding (such as into the intestines or after a car accident) may not be immediately apparent.
- Hematoma: A collection of blood inside the body tissues. Internal bleeding often causes a hematoma.
- Leukemia: A form of blood cancer, in which white blood cells multiply abnormally and circulate through the blood. The abnormal white blood cells make getting sick from infections easier than normal.
- Multiple myeloma: A form of blood cancer of plasma cells similar to leukemia. Anemia, kidney failure and high blood calcium levels are common in multiple myeloma.
- Lymphoma: A form of blood cancer, in which white blood cells multiply abnormally inside lymph nodes and other tissues. The enlarging tissues, and disruption of blood's functions, can eventually cause organ failure.
- Anemia: An abnormally low number of red blood cells in the blood. Fatigue and breathlessness can result, although anemia often causes no noticeable symptoms.
- Hemolytic anemia: Anemia caused by rapid bursting of large numbers of red blood cells (hemolysis). An immune system malfunction is one cause.
- Hemochromatosis: A disorder causing excessive levels of iron in the blood. The iron deposits in the liver, pancreas and other organs, causing liver problems and diabetes.
- Sickle cell disease: A genetic condition in which red blood cells periodically lose their proper shape (appearing like sickles, rather

than discs). The deformed blood cells deposit in tissues, causing pain and organ damage.

- Bacteremia: Bacterial infection of the blood. Blood infections are serious, and often require hospitalization and continuous antibiotic infusion into the veins.
- Malaria: Infection of red blood cells by Plasmodium, a parasite transmitted by mosquitos. Malaria causes episodic fevers, chills, and potentially organ damage.
- Thrombocytopenia: Abnormally low numbers of platelets in the blood. Severe thrombocytopenia may lead to bleeding.
- Leukopenia: Abnormally low numbers of white blood cells in the blood. Leukopenia can result in difficulty fighting infections.
- Disseminated intravascular coagulation (DIC): An uncontrolled process of simultaneous bleeding and clotting in very small blood vessels. DIC usually results from severe infections or cancer.
- Hemophilia: An inherited (genetic) deficiency of certain blood clotting proteins. Frequent or uncontrolled bleeding can result from hemophilia.
- Hypercoaguable state: Numerous conditions can result in the blood being prone to clotting. A heart attack, stroke, or blood clots in the legs or lungs can result.
- Polycythemia: Abnormally high numbers of red blood cells in the blood. Polycythemia can result from low blood oxygen levels, or may occur as a cancer-like condition.
- Deep venous thrombosis (DVT): It is blood clot in a deep vein, usually in the leg. DVTs are dangerous because they may become dislodged and travel to the lungs, causing a pulmonary embolism (PE).
- Myocardial infarction (MI): Commonly called as heart attack, a myocardial infarction occurs when a sudden blood clot develops in one of the coronary arteries, which supplies blood to the heart.

Blood tests

- **Complete blood count**: An analysis of the concentration of red blood cells, white blood cells, and platelets in the blood. Automated cell counters perform this test. http://www.webmd.com/a-to-z-guides/complete-blood-count-cbc
- **Blood smear:** Drops of blood are smeared across a microscope slide, to be examined by an expert in a lab. Leukemia, anemia, malaria, and numerous other blood conditions can be identified with a blood smear.

- **Blood type:** A test for compatibility before receiving a blood transfusion. The major blood types (A, B, AB, and O) are determined by the protein markers (antigens) present on the surface of red blood cells.
- **Coombs test:** A blood test looking for antibodies that could bind to and destroy red blood cells. Pregnant women and people with anemia may undergo Coombs testing.
- **Blood culture:** A blood test looking for infection present in the bloodstream. If bacteria or other organisms are present, they may multiply in the tested blood, allowing their identification.
- **Mixing study:** A blood test to identify the reason for blood being "too thin" (abnormally resistant to clotting). The patient's blood is mixed in a tube with normal blood, and the mixed blood's properties may provide a diagnosis.
- **Bone marrow biopsy:** A thick needle is inserted into a large bone (usually in the hip), and bone marrow is drawn out for tests. Bone marrow biopsy can identify blood conditions that simple blood tests cannot.

4.11. Types of blood

Blood typing is a method to tell what type of blood you have. Blood typing is done so you can safely donate your blood or receive a blood transfusion. It is also done to see if you have a substance called Rh factor on the surface of your red blood cells. Your blood type is based on whether or not certain proteins are on your red blood cells. These proteins are called antigens. Your blood type (or blood group) depends on what types your parents passed down to you. Blood is often grouped according to the ABO blood typing system. The 4 major blood types are:

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

- The human body contains around 8 to 10 pints of blood depending on the size of the individual. However, the composition of the blood is not the same in each person. This is what makes the person's blood type.
- An individual's blood type depends on which genes were passed on by their mother or father.
- The best-known way of grouping of blood types is the ABO system, although there are other groups.
- Within the ABO group, four major categories are divided into eight common blood types: A, B, O, and AB.

- Over 9.5 million people in the United States (U.S.) are blood donors, and around 5 million patients receive blood each year, according to the Centers for Disease Control and Prevention (CDC).
- It is crucial to give a patient the right compatible blood type in a transfusion. The wrong type can trigger an adverse and potentially fatal reaction.

ABO and the most common blood types

The ABO blood group system is used to determine the different types of antigens in the red blood cells and antibodies in the plasma. This system and RhD antigen status determine which blood type or types will match for a safe red blood cell transfusion. There are four ABO groups:

Group A : The surface of the red blood cells contains A antigen, and the plasma has anti-B antibody that would attack any foreign B antigen containing red blood cells.

Group B : The surface of the red blood cells contains B antigen, and the plasma has anti-A antibody that would attack any foreign A antigen containing red blood cells.

Group AB: The red blood cells have both A and B antigens, but the plasma does not contain anti-A/anti-B antibodies. Individuals with type AB can receive any ABO blood type.

Group O: The plasma contains both types of anti-A/anti-B antibodies, but the surface of the red blood cells does not contain any A/B antigens. Having none of these A/B antigens means that they can be donated to a person with any ABO blood type.

Some red blood cells have the Rh factor, which is also called RhD antigen. Rhesus grouping adds another dimension. If the red blood cells contain the RhD antigen, they are RhD positive. If they do not, they are RhD negative. This means that there are eight main blood types in the ABO/RhD blood group system. Some of these are more common than others.

The eight main blood types are A, B, O, or AB, and each type can be positive or negative.

- A-positive (A+) occurs in 30 percent of people in the U.S.
- A-negative (A-) occurs in 6 percent of people
- B-positive (B+) occurs in 9 percent of people
- B-negative (B-) occurs in 2 percent of people
- AB-positive (AB+) occurs in 4 percent of people
- AB-negative (AB-) occurs in 1 percent of people
- O-positive (O+) occurs in 39 percent of people
- O-negative (O-) occurs in 9 percent of people

Around 82 percent of the population in the U.S. has RhD-positive blood. The rarest blood type is AB negative.

Universal donor and universal recipient

O negative blood contains no A or B or RhD antigens. These red blood cells can be transfused to nearly all patients of any blood type. Group O negative is known as the "universal donor" type.

AB positive blood, on the other hand, contains no anti-A/anti-B/RhD antibodies, so patients with this blood type can, therefore, receive nearly any type of red blood cell transfusion. This type is, therefore, referred to as the "universal recipient" type.

When is blood group important?

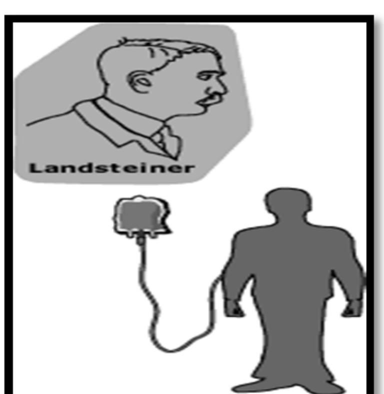
It is important to confirm a person's blood type when they are donating blood or receiving a transfusion. If someone with group B antigen receives red blood cells from someone with group A antigen, their body will reject the transfusion. This is because patients with B antigen on their red blood cells have anti-A antibody in their plasma. The anti-A antibody in the plasma then attacks and destroys the A antigen donor red blood cells. This can be fatal.

4.12. The discovery of blood groups

Experiments with blood transfusions, the transfer of blood or blood components into a person's blood stream, have been carried out for hundreds of years. Many patients have died and it was not until 1901, when the Austrian Karl Landsteiner discovered human blood groups, that blood transfusions became safer.

Mixing blood from two individuals can lead to blood clumping or agglutination. The clumped red cells can crack and cause toxic reactions. This can have fatal consequences. Karl Landsteiner discovered that blood clumping was an immunological reaction which occurs when the receiver of a blood transfusion has antibodies against the donor blood cells.

Karl Landsteiner's work made it possible to determine blood groups and thus paved the way for blood transfusions to be carried out safely. For this discovery he was awarded the Nobel Prize in Physiology or Medicine in 1930.



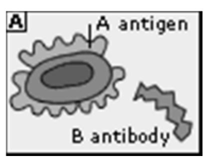
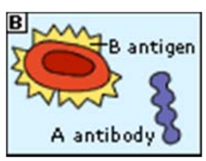
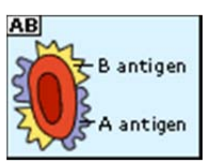
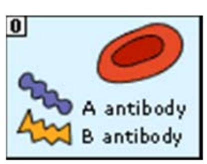
The differences in human blood are due to the presence or absence of certain protein molecules called antigens and antibodies. The antigens are located on the surface of the red blood cells and the antibodies are in the blood plasma. Individuals have different types and combinations of these molecules. The blood group you belong to depends on what you have inherited from your parents.

There are more than 20 genetically determined blood group systems known today, but the AB0 and Rh systems are the most important ones used for blood transfusions. Not all blood groups are compatible with each other. Mixing incompatible blood groups leads to blood clumping or agglutination, which is dangerous for individuals.

Nobel Laureate Karl Landsteiner was involved in the discovery of both the AB0 blood group (in 1901) and Rh blood group (in 1937).

4.13. ABO blood grouping system

According to the AB0 blood group system there are four different kinds of blood groups: A, B, AB or 0 (null).

	**Blood group A** If you belong to the blood group A, you have A antigens on the surface of your red blood cells and B antibodies in your blood plasma.
	**Blood group B** If you belong to the blood group B, you have B antigens on the surface of your red blood cells and A antibodies in your blood plasma.
	**Blood group AB** If you belong to the blood group AB, you have both A and B antigens on the surface of your red blood cells and no A or B antibodies at all in your blood plasma.
	**Blood group 0** If you belong to the blood group 0 (null), you have neither A or B antigens on the surface of your red blood cells but you have both A and B antibodies in your blood plasma.

4.14. How the blood test is performed

Testing for blood type

A blood test can determine an individual's blood type.

Blood testing is essential for patient safety.

A technician mixes the individual's blood with a variety of serum samples. The blood type of each serum sample is already known. Each sample consists of a different blood type, with the clotting agent removed. This is serum. The technician will monitor how the person's blood reacts with each serum. The antibodies in the serum will cause a different reaction in each one. In this way, the blood type can be identified.

For example, if a reaction occurs when the individual's blood is mixed with serum consisting of blood type A, which contains anti-B antibody, the unknown blood type, which is the individual's, must be type B. Blood typing must be tested in this way before carrying out a red blood cell transfusion. This is important because, apart from the eight main groups, are there many lesser-known blood types. It is rarer for these other antigens to cause transfusion reactions, but it can happen, so precautions are essential.

A blood sample is needed. The test to determine your blood group is called ABO typing. Your blood sample is mixed with antibodies against type A and B blood. Then, the sample is checked to see whether or not the blood cells stick together. If blood cells stick together, it means the blood reacted with one of the antibodies.

The second step is called back typing. The liquid part of your blood without cells (serum) is mixed with blood that is known to be type A and type B. People with type A blood have anti-B antibodies. People with type B blood have anti-A antibodies. Type O blood contains both types of antibodies.

The 2 steps above can accurately determine your blood type.

Rh typing uses a method similar to ABO typing. When blood typing is done to see if you have Rh factor on the surface of your red blood cells, the results will be one of these:

- Rh+ (positive), if you have this cell surface protein
- Rh- (negative), if you do not have this cell surface protein

4.15. Blood transfusion

Blood transfusions in humans were risky procedures until the discovery of the major human blood groups by Karl Landsteiner, an Austrian biologist and physician, in 1900. Until that point, physicians did not understand that death sometimes followed blood transfusions, when the type of donor blood infused into the patient was incompatible with the patient's own blood. Blood groups are determined by the presence or absence of specific marker molecules on the plasma membranes of erythrocytes. With their discovery, it became possible for the first time to match patient-donor blood types and prevent transfusion reactions and deaths.

Antigens, Antibodies, and Transfusion Reactions

Antigens are substances that the body does not recognize as belonging to the "self" and that therefore trigger a defensive response from the leukocytes of the immune system. (Seek more content for additional information on immunity.) Here, we will focus on the role of immunity in blood transfusion reactions. With RBCs in particular, you may see the antigens referred to as isoantigens or agglutinogens (surface antigens) and the antibodies referred to as isoantibodies or agglutinins. In this chapter, we will use the more common terms antigens and antibodies.

Antigens are generally large proteins, but may include other classes of organic molecules, including carbohydrates, lipids, and nucleic acids. Following an infusion of incompatible blood, erythrocytes with foreign antigens appear in the bloodstream and trigger an immune response. Proteins called antibodies (immunoglobulins), which are produced by certain B lymphocytes called plasma cells, attach to the antigens on the plasma membranes of the infused erythrocytes and cause them to adhere to one another.

- Because the arms of the Y-shaped antibodies attach randomly to more than one nonself erythrocyte surface, they form clumps of erythrocytes. This process is called agglutination.
- The clumps of erythrocytes block small blood vessels throughout the body, depriving tissues of oxygen and nutrients.
- As the erythrocyte clumps are degraded, in a process called hemolytic, their hemoglobin is released into the bloodstream. This hemoglobin travels to the kidneys, which are responsible for filtration of the blood. However, the load of hemoglobin released can easily overwhelm the kidney's capacity to clear it, and the patient can quickly develop kidney failure.

More than 50 antigens have been identified on erythrocyte membranes, but the most significant in terms of their potential harm to patients are classified in two groups: the ABO blood group and the Rh blood group.

The ABO Blood Group

Although the ABO blood group name consists of three letters, ABO blood typing designates the presence or absence of just two antigens, A and B. Both are glycoproteins. People whose erythrocytes have A antigens on their erythrocyte membrane surfaces are designated blood type A, and those whose erythrocytes have B antigens are blood type B. People can also have both A and B antigens on their erythrocytes, in which case they are blood type AB. People with neither A nor B antigens are designated blood type O. ABO blood types are genetically determined.

Normally the body must be exposed to a foreign antigen before an antibody can be produced. This is not the case for the ABO blood group. Individuals with type A blood—without any prior exposure to incompatible blood—have preformed antibodies to the B antigen circulating in their blood plasma. These antibodies, referred to as anti-B antibodies, will cause agglutination and hemolysis if they ever encounter erythrocytes with B antigens. Similarly, an individual with type B blood has pre-formed anti-A antibodies. Individuals with type AB blood, which has both antigens, do not have preformed antibodies to either of these. People with type O blood lack antigens A and B on their erythrocytes, but both anti-A and anti-B antibodies circulate in their blood plasma.

Rh Blood Groups

The **Rh blood group** is classified according to the presence or absence of a second erythrocyte antigen identified as Rh. (It was first discovered in a type of primate known as a rhesus macaque, which is often used in research, because its blood is similar to that of humans.) Although dozens of Rh antigens have been identified, only one, designated D, is clinically important. Those who have the Rh D antigen present on their erythrocytes—about 85 percent of Americans—are described as Rh positive (Rh^+) and those who lack it are Rh negative (Rh^-). Note that the Rh group is distinct from the ABO group, so any individual, no matter their ABO blood type, may have or lack this Rh antigen. When identifying a patient's blood type, the Rh group is designated by adding the word positive or negative to the ABO type. For example, A positive (A^+) means ABO group A blood with the Rh antigen present, and AB negative (AB^-) means ABO group AB blood without the Rh antigen.

Determining ABO Blood Types

Clinicians are able to determine a patient's blood type quickly and easily using commercially prepared antibodies. An unknown blood sample is allocated into separate wells. Into one well a small amount of anti-A antibody is added, and to another a small amount of anti-B antibody. If the antigen is present, the antibodies will cause visible agglutination of the cells (Figure 2). The blood should also be tested for Rh antibodies.

. Cross Matching Blood Types. This sample of a commercially produced "bedside" card enables quick typing of both a recipient's and donor's blood before transfusion. The card contains three reaction sites or wells. One is coated with an anti-A antibody, one with an anti-B antibody, and one with an anti-D antibody (tests for the presence of Rh factor D). Mixing a drop of blood and saline into each well enables the blood to interact with a preparation of type-specific antibodies, also called anti-seras. Agglutination of RBCs in a given site indicates a positive identification of the blood antigens, in this case A and Rh antigens for blood type A+. For the purpose of transfusion, the donor's and recipient's blood types must match.

ABO Transfusion Protocols

To avoid transfusion reactions, it is best to transfuse only matching blood types; that is, a type B^+ recipient should ideally receive blood only from a type B^+ donor and so on. That said, in emergency situations, when acute hemorrhage threatens the patient's life, there may not be time for cross matching to identify blood type. In these cases, blood from a **universal donor**—an individual with type O^- blood—may be transfused. Recall that type O erythrocytes do not display A or B antigens. Thus, anti-A or anti-B antibodies that might be circulating in the patient's blood plasma will not encounter any erythrocyte surface antigens on the donated blood and therefore will not be provoked into a response. One problem with this designation of universal donor is if the O^- individual had prior exposure to Rh antigen, Rh antibodies may be present in the donated blood. Also, introducing type O blood into an individual with type A, B, or AB blood will nevertheless introduce antibodies against both A and B antigens, as these are always circulating in the type O blood plasma. This may cause problems for the recipient, but because the volume of blood transfused is much lower than the volume of the patient's own blood, the adverse effects of the relatively few infused plasma antibodies are typically limited. Rh factor also plays a role. If Rh^- individuals receiving blood have had prior exposure to Rh antigen, antibodies for this antigen may be present in the blood and trigger agglutination to some degree. Although it is always preferable to cross match a patient's blood before transfusing, in a true life-threatening emergency situation, this is not always possible, and these procedures may be implemented.

A patient with blood type AB^+ is known as the **universal recipient**. This patient can theoretically receive any type of blood, because the patient's own blood—having both A and B antigens on the erythrocyte surface—does not produce anti-A or anti-B antibodies. In addition, an Rh^+ patient can receive both Rh^+ and Rh^- blood. However, keep in mind that the donor's blood will contain circulating antibodies, again with possible negative implications. Figure 3summarizes the blood types and compatibilities.

At the scene of multiple-vehicle accidents, military engagements, and natural or human-caused disasters, many victims may suffer simultaneously from acute hemorrhage, yet type O blood may not be immediately available. In these circumstances, medics may at least try to replace some of the volume of blood that has been lost. This is done by intravenous administration of a saline solution that provides fluids and electrolytes in proportions equivalent to those of normal blood plasma. Research is ongoing to develop a safe and effective artificial blood that would carry out the oxygen-carrying function of blood without the RBCs, enabling transfusions in the field without concern for incompatibility. These blood substitutes normally contain hemoglobin- as well as perfluorocarbon-based oxygen carriers.

Antigens are nonself molecules, usually large proteins, which provoke an immune response. In transfusion reactions, antibodies attach to antigens on the surfaces of erythrocytes and cause agglutination and hemolysis. ABO blood group antigens are designated A and B. People with type A blood have A antigens on their erythrocytes, whereas those with type B blood have B antigens. Those with AB blood have both A and B antigens, and those with type O blood have neither A nor B antigens. The blood plasma contains preformed antibodies against the antigens not present on a person's erythrocytes.

A second group of blood antigens is the Rh group, the most important of which is Rh D. People with Rh^- blood do not have this antigen on their erythrocytes, whereas those who are Rh^+ do. About 85 percent of Americans are Rh^+. When a woman who is Rh^- becomes pregnant with an Rh^+ fetus, her body may begin to produce anti-Rh antibodies. If she subsequently becomes pregnant with a second Rh^+ fetus and is not treated preventively with Rho GAM, the foetus will be at risk for an antigen-antibody reaction, including agglutination and hemolysis. This is known as hemolytic disease of the newborn.

Cross matching to determine blood type is necessary before transfusing blood, unless the patient is experiencing hemorrhage that is an immediate threat to life, in which case type O^- blood may be transfused.

4.16. Summary

After reading this unit you will be able understand

Physiology is the study of normal functioning of body system within living creatures. It is a sub-section of biology, covering a range of topics that include organs, anatomy, cells, biological compounds, and how they all interact to make life possible. Blood is a specialized body fluid. It has four main components: plasma, red blood cells, white blood cells, and platelets. Blood has many different functions, including: transporting oxygen and nutrients to the lungs and tissues. Supplying oxygen to cells and tissues. Blood is circulated around the body through blood vessels by the pumping action of the heart. Blood is often grouped according to the ABO blood typing system. The 4 major blood types are A, B, AB and O. Providing essential nutrients to cells, such as amino acids, fatty acids, and glucose. Removing waste materials, such as carbon dioxide, urea, and lactic acid. Platelets protecting the body from infection and foreign bodies through the white blood cells Functions of blood. About 55% of blood is blood plasma, a fluid that is the blood's liquid medium, which by itself is straw-yellow in color. Blood gets its bright red color when hemoglobin picks up oxygen in the lungs. Platelets are tiny oval-shaped cells that help in the clotting process. Whole blood contains red cells, white cells, and platelets (~45% of volume) suspended in blood plasma (~55% of volume). A complete blood count (CBC) test gives your doctor important information about the types and numbers of cells in your blood. Blood leaking out of blood vessels may be obvious, as from a wound penetrating the skin.

4.17. Terminal questions

Q.1. Define the term physiology, further elaborate on its branches?

Answer:---

Q.2. What is blood? Briefly define the types of blood cells.

Answer:---

Q.3. Briefly define constituents of blood.

Answer:---

Q.4. Discus the role of Blood in human body

Answer:---

Q.5. What is plasma? Discuss the role of plasma in blood cells.

Answer:---

Q.6. Discuss about blood tests.

Answer:---

4.18. Further readings

1. Human Anatomy and Physiology I for B. PHARMACY PCI 17 (I - BP101T) by, wati V. Joggdand Prashant Sarda Dr. Naitik D. Trivedi
2. Introduction to Physiology for Paramedical Students, R. K. Ruprai
3. Introduction to Human Anatomy and Physiology by Solomon PhD, Eldra Pearl
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5. Speed Learning for Anatomy Systems and Functions of the Human Body Quick and Easy by Bachsteiner.

Uttar Pradesh Rajarshi Tandon
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PGBCH-105

Nutrition and Physiology

BLOCK

3

DIGESTIVE SYSTEM AND RESPIRATION

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Introduction

This block of nutrition and physiology consists the following two units as following.

Unit-5: Digestion is the way that an organism changes a substance into nutrients. This takes place in the gastrointestinal system. In fact human beings start digesting food in the mouth. Mechanical digestion is physical breakdown of large pieces of food into smaller smaller pieces which can be got further broken at by digestive enzymes. In chemical digestion, enzymes break down food into the small molecules the body can use. The mixture passes into the small intestine, where tiny bits of food pass into the bloodstream. The digestive process starts in your mouth when you chew. The salivary glands produce saliva, a digestive juice, which moistens food so it moves more easily through your esophagus into your stomach. Saliva also has an enzyme that begins to break down starches in your food. Human digestive system, the system used in the human body for the process of digestion would be explained in this unit.

Unit-6: Respiration is one of the most vital physiological processes in life of all the living beings. It is interchange or exchange of gases between an organism and the medium in which it lives. Generally in human body, we further classify respiration by external and internal processes i.e., inhalation and exhalation. The external process of respiration involves the transfer of oxygen (O_2) and carbon dioxide (CO_2) that occurs in the lungs between the atmosphere and the pulmonary circulation. The internal process of respiration is the similar process that occurs at the cellular level. While both aspects of respiration are essential to life, this unit covered types of respiration and its three primary components: ventilation, perfusion and diffusion. A thorough understanding of each of these components and their potential impairments provides further understanding on the topic in a functional manner. Physiologically the main function of the respiratory system as above is gaseous exchange. This gaseous exchange consists of obtaining O_2 from the atmosphere and removing CO_2 from the blood. It is important to consider that O_2 is necessary for normal metabolism and CO_2 is a waste product of this metabolism. CO_2 is only inhaled in negligible quantity and thus the CO_2 we exhale is created within the body. While CO_2 plays a role in acid-base balance, therefore it must be cleared from the body in appropriate levels through ventilation.

UNIT : 5

DIGESTIVE SYSTEM

Structure:

5.1. Introduction

Human digestive system, the system used in the human body for the process of digestion. Digestion is the way that an organism changes a substance into nutrients. This happens in the gastrointestinal system. Humans start digesting food in the mouth. Mechanical digestion is the physical breakdown of large pieces of food into smaller pieces which can be got at by digestive enzymes. In chemical digestion, enzymes break down food into the small molecules the body can use. The mixture passes into the small intestine, where tiny bits of food pass into the bloodstream. The digestive process starts in your mouth when you chew. Your salivary glands make saliva, a digestive juice, which moistens food so it moves more easily through your esophagus into your stomach. Saliva also has an enzyme that begins to break down starches in your food. Human digestive system, the system used in the human body for the process of digestion. The human digestive system consists primarily of the digestive tract, or the series of structures and organs through which food and liquids pass during their processing into forms absorbable into the bloodstream. The system also consists of the structures through which wastes pass in the process of elimination and other organs that contribute juices necessary for the digestive process.

Objectives

- To get acquainted with the physiology of digestion, its mechanism and types with examples.
- Further the unit elaborates on the structures of gastrointestinal tract in relation to its function.
- To discuss the abnormalities and issues pertaining to impairment of digestive function with some salient examples

5.2. Digestive System

The digestive tract begins at the lips and ends at the anus. It consists of the mouth, or oral cavity, with its teeth, for grinding the food, and its tongue, which serves to knead food and mix it with saliva; the throat, or pharynx; the esophagus; the stomach; the small intestine, consisting of the duodenum, the jejunum, and the ileum; and the large intestine, consisting of the cecum, a closed-end sac connecting with the ileum, the ascending colon, the transverse colon, the descending colon, and the sigmoid colon, which terminates in the rectum. Glands contributing digestive juices include the salivary glands, the gastric glands in the stomach lining, the pancreas, and the liver and its adjuncts the gallbladder and bile ducts. All of these organs and glands contribute to the physical and chemical breaking down of ingested food and to the eventual elimination of no digestible wastes. Their structures and functions are described step by step in this section. The abdominal organs are supported and protected by the bones of the pelvis and ribcage and are covered by the greater momentum, a fold of peritoneum that consists mainly of fat.

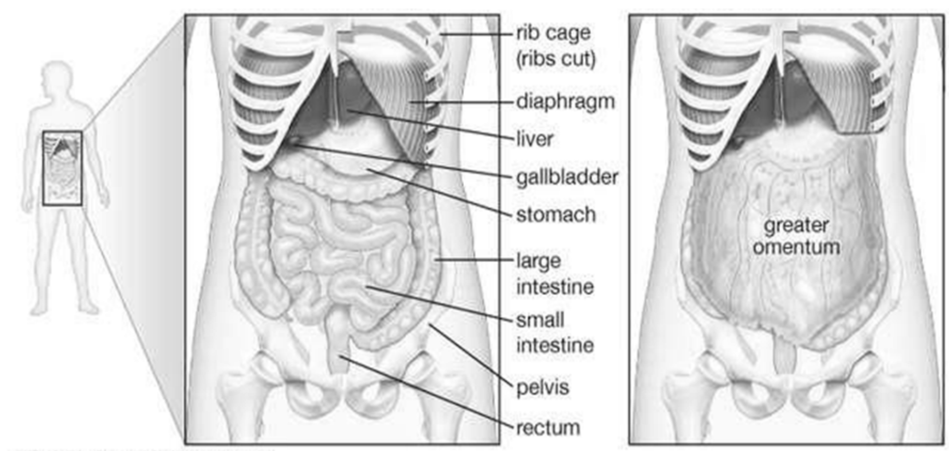


Fig.5.1: Schematic representation of abdominal organs in in situ with omentum

Source: *Encyclopædia Britannica, Inc.*

5.3. Mouth and oral structures

Little digestion of food actually takes place in the mouth. However, through the process of mastication, or chewing, food is prepared in the mouth for transport through the upper digestive tract into the stomach and small intestine, where the principal digestive processes take place. Chewing is the first mechanical process to which food is subjected. Movements of the lower jaw in chewing are brought about by the muscles of mastication (the masseter, the temporal, the medial and lateral pterygoids, and the buccinator). The sensitivity of the periodontal membrane that surrounds and supports the teeth, rather than the power of the muscles of mastication, determines the force of the bite.

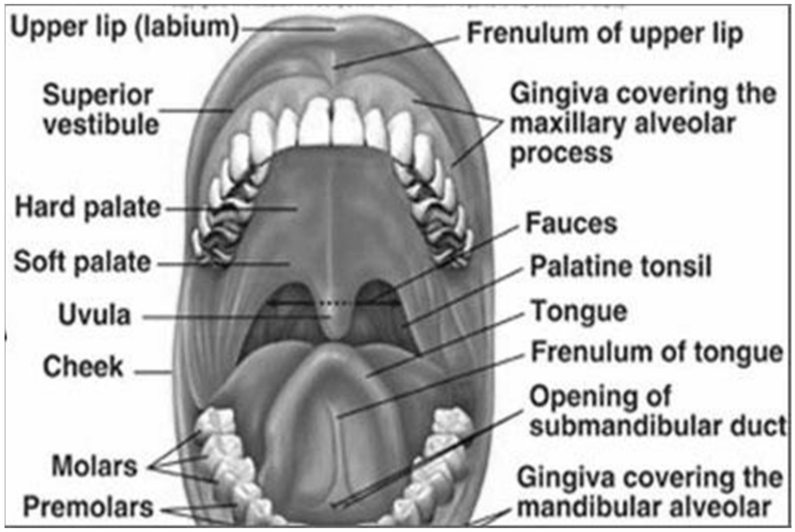


Fig.5.2: Anterior view of the oral cavity**.**

Source: http://www.health.am/

Mastication alone is not enough for adequate digestion. Chewing does aid digestion, however, by reducing food to small particles and mixing it with the saliva secreted by the salivary glands. The saliva lubricates and moistens dry food, while chewing distributes the saliva throughout the food mass. The movement of the tongue against the hard palate and the cheeks helps to form a rounded mass, or bolus, of food.

The lips and cheeks

The lips, two fleshy folds that surround the mouth, are composed externally of skin and internally of mucous membrane, or mucosa. The mucosa is rich in mucus-secreting glands, which together with saliva ensure adequate lubrication for the purposes of speech and mastication.

The cheeks, the sides of the mouth, are attached in continuation with lips and have a similar structure. A distinct fat pad is found in the subcutaneous tissue (the tissue beneath the skin) of the cheek; this pad is especially large in infants and is known as the sucking pad. On the inner surface of each cheek, opposite the second upper molar tooth, is a slight elevation that marks the opening of the parotid duct, leading from the parotid salivary gland, which is located in front of the ear. Just behind this gland are four to five mucus-secreting glands, the ducts of which open opposite the last molar tooth.

The roof of the mouth

The roof of the mouth is concave and is formed by the hard and soft palate. The hard palate is formed by the horizontal portions of the two palatine bones and the palatine portions of the maxillae, or upper jaws. The hard palate is covered by a thick, somewhat pale mucous membrane that is continuous with that of the gums and is bound to the upper jaw and palate bones by firm fibrous tissue. The soft palate is continuous with the hard palate in front. Posteriorly it is continuous with the mucous membrane covering the floor of the nasal cavity. The soft palate is composed of a strong, thin, fibrous sheet, the palatine aponeurosis, and the glossopalatine and pharyngopalatine muscles. A small projection called the uvula hangs free from the posterior of the soft palate.

The floor of the mouth

The floor of the mouth can be seen only when the tongue is raised. In the midline is a prominent, elevated fold of mucous membrane (frenulum linguae) that binds each lip to the gums, and on each side of this is a slight fold called a sublingual papilla, from which the ducts of the submandibular salivary glands open. Running outward and backward from each sublingual papilla is a ridge (the plica sublingualis) that marks the upper edge of the sublingual (under the tongue) salivary gland and onto which most of the ducts of that gland open.

The gums

The gums consist of mucous membranes connected by thick fibrous tissue to the membrane surrounding the bones of the jaw. The gum membrane rises to form a collar around the base of the crown (exposed portion) of each tooth. Rich in blood vessels, the gum tissues receive branches from the alveolar arteries; these vessels, called alveolar because of their relationship to the alveoli dentales, or tooth sockets, also supply the teeth and the spongy bone of the upper and lower jaws, in which the teeth are lodged.

5.4. Human digestive system

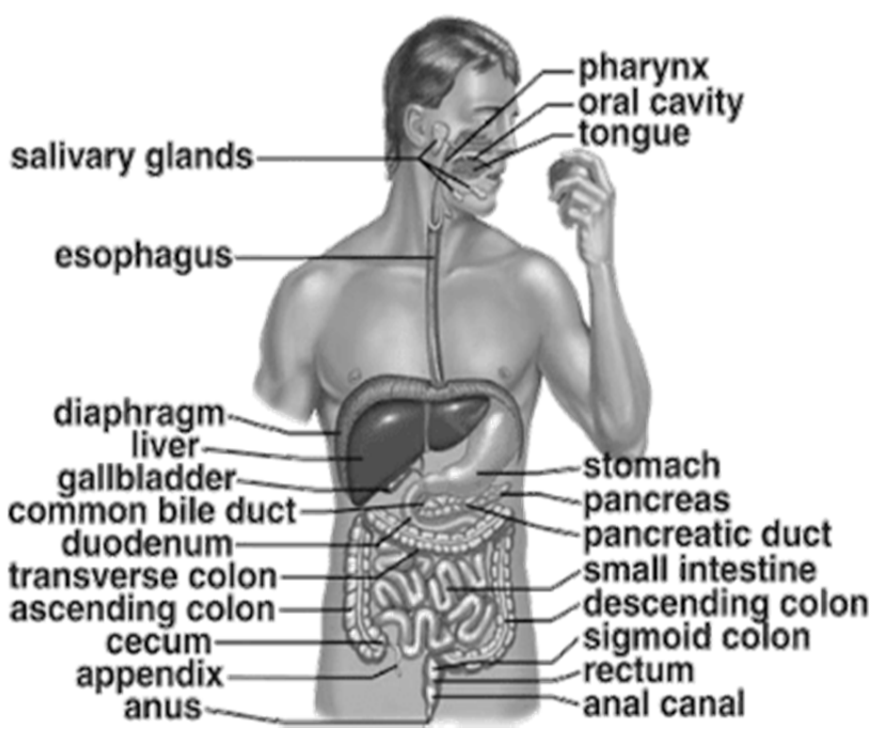


Fig. 5.3: Schematic representation of human digestive system

Souce:https://apniduniyas.blogspot.com/2018/01/digestive-system

5.5. The teeth

The teeth are hard, white structures found in the mouth. Usually used for mastication, the teeth of different vertebrate species are sometimes specialized. The teeth of snakes, for example, are very thin and sharp and usually curve backward; they function in capturing prey but not in chewing, because snakes swallow their food whole. The teeth of carnivorous mammals, such as cats and dogs, are more pointed than those of primates, including humans; the canines are long, and the premolars lack flat grinding surfaces, being more adapted to cutting and shearing (often the more posterior molars are lost). On the other hand, herbivores such as cows and horses have very large, flat premolars and molars with complex ridges and cusps; the canines are often totally absent. Sharp pointed teeth, poorly adapted for chewing, generally characterize meat eaters such as snakes, dogs, and cats; and broad, flat teeth, well adapted for chewing, characterize herbivores. The differences in the shapes of teeth are functional adaptations. Few animals can digest cellulose, yet the plant cells used as food by herbivores are enclosed in cellulose cell walls that must be broken down before the cell contents can be exposed to the action of digestive enzymes. By contrast, the animal cells in meat are not encased in undigestible matter and can be acted upon directly by digestive enzymes. Consequently, chewing is not so essential for carnivores as it is for herbivores. Humans, who are omnivores (eaters of plants and animal tissue), have teeth that belong, functionally and structurally, somewhere between the extremes of specialization attained by the teeth of carnivores and herbivores.

Each tooth consists of a crown and one or more roots. The crown is the functional part of the tooth that is visible above the gum. The root is the unseen portion that supports and fastens the tooth in the jawbone. The shapes of the crowns and the roots vary in different parts of the mouth and from one animal to another. The teeth on one side of the jaw are essentially a mirror image of those located on the opposite side. The upper teeth differ from the lower and are complementary to them. Humans normally have two sets of teeth during their lifetime. The first set, known as the deciduous, milk, or primary dentition, is acquired gradually between the ages of six months and two years. As the jaws grow and expand, these teeth are replaced one by one by the teeth of the secondary set. There are five deciduous teeth and eight permanent teeth in each quarter of the mouth, resulting in a total of 32 permanent teeth to succeed the 20 deciduous ones.

The tongue

The tongue, a muscular organ located on the floor of the mouth, is an extremely mobile structure and is an important accessory organ in such motor functions as speech, chewing, and swallowing. In conjunction with the cheeks, it is able to guide and maintain food between the upper and lower teeth until mastication is complete. The motility of the tongue aids in creating a negative pressure within the oral cavity and thus enables infants to suckle. Especially important as a peripheral sense organ, the tongue contains groups of specialized epithelial cells, known as taste buds, that carry stimuli from the oral cavity to the central nervous system. Furthermore, the tongue's glands produce some of the saliva necessary for swallowing.

The tongue consists of a mass of interwoven striated (striped) muscles interspersed with fat. The mucous membrane that covers the tongue varies in different regions. The tongue is attached to the lower jaw, the hyoid bone (a U-shaped bone between the lower jaw and the larynx), the skull, the soft palate, and the pharynx by its extrinsic muscles. It is bound to the floor of the mouth and to the epiglottis (a plate of cartilage that serves as a lid for the larynx) by folds of mucous membrane.

5.6. Salivary glands

Food is tasted and well mixed with saliva that is secreted by several sets of glands. Besides the many minute glands that secrete saliva, there are three major pairs of salivary glands: the parotid, the submandibular, and the sublingual glands. The parotid glands, the largest of the pairs, are located at the side of the face, below and in front of each ear. The parotid glands are enclosed in sheaths that limit the extent of their swelling when inflamed, as in mumps. The submandibular glands, which are rounded in shape, lie near the inner side of the lower jawbone, in front of the sternomastoid muscle (the prominent muscle of the jaw). The sublingual glands lie directly under the mucous membrane covering the floor of the mouth beneath the tongue.

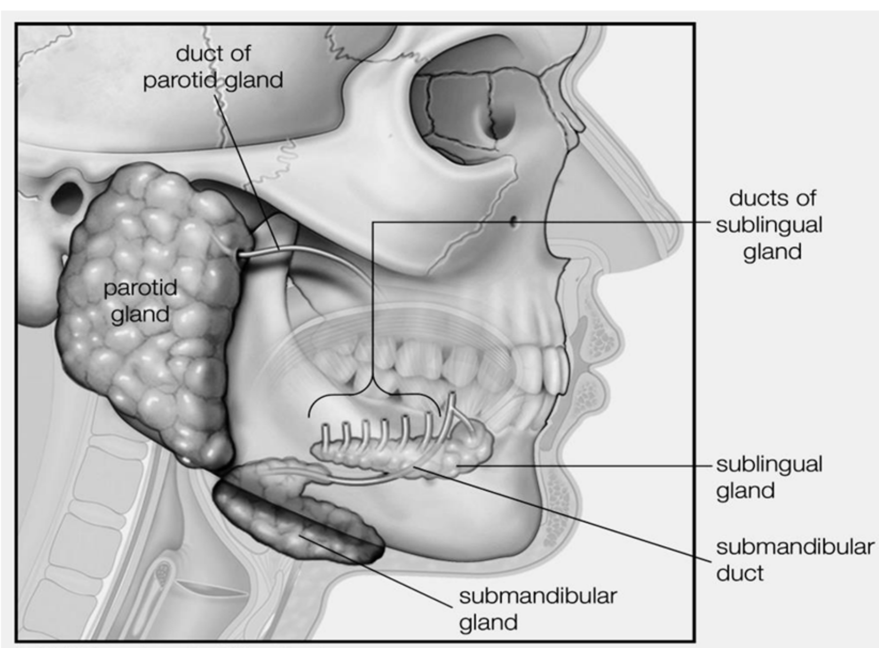


Fig.5.4: The three major pairs of salivary glands.

Source: https://www.verywellhealth.com/everything-you-need-to-know-about-sialolithiasis-1192027

The salivary glands are of the type called racemose, from the Latin *racemosus* ("full of clusters"), because of the clusterlike arrangement of their secreting cells in rounded sacs, called acini, attached to freely branching systems of ducts. The walls of the acini surround a small central cavity known as an alveolus. In the walls of the acini are pyramidal secreting cells and some flat, star-shaped contractile cells called myoepithelial, or basket, cells. The latter cells are thought to contract, like the similar myoepithelial cells of the breast, which by their contraction expel milk from the milk ducts.

The secreting cells may be of the serous or the mucous type. The latter type secretes mucin, the chief constituent of mucus; the former, a watery fluid containing the enzyme amylase. The secreting cells of the parotid glands are of the serous type; those of the submandibular glands, of both serous and mucous types, with the serous cells outnumbering the mucous cells by four to one. The acini of the sublingual glands are composed primarily of mucous cells.

The salivary glands are controlled by the two divisions of the autonomic nervous system, the sympathetic and the parasympathetic. The parasympathetic nerve supply regulates secretion by the acinar cells and causes the blood vessels to dilate. Functions regulated by the sympathetic nerves include secretion by the acinar cells, constriction of blood vessels, and, presumably, contraction of the myoepithelial cells. Normally secretion of saliva is constant, regardless of the presence of food in the mouth. The amount of saliva secreted in 24 hours usually amounts to 1–1.5 litres. When something touches the gums, the tongue, or some region of the mouth lining, or when chewing occurs, the amount of saliva secreted increases. The stimulating substance need not be food—dry sand in the mouth or even moving the jaws and tongue when the mouth is empty increases the salivary flow. This coupling of direct stimulation to the oral mucosa with increased salivation is known as the unconditioned salivary reflex. When an individual learns that a particular sight, sound, smell, or other stimulus is regularly associated with food, that stimulus alone may suffice to stimulate increased salivary flow. This response is known as the conditioned salivary reflex.

Saliva

Saliva dissolves some of the chewed food and acts as a lubricant, facilitating passage through the subsequent portions of the digestive tract. Saliva also contains a starch-digesting enzyme called amylase (ptyalin), which initiates the process of enzymatic hydrolysis; it splits starch (a polysaccharide containing many sugar molecules bound in a continuous chain) into molecules of the double sugar maltose. Many carnivores, such as dogs and cats, have no amylase in their saliva; therefore, their natural diet contains very little starch. Substances must be in solution for the taste buds to be stimulated; saliva provides the solvent for food materials.

The composition of saliva varies, but its principal components are water, inorganic ions similar to those commonly found in blood plasma, and a number of organic constituents, including salivary proteins, free amino acids, and the enzymes lysozyme and amylase. Although saliva is slightly acidic, the bicarbonates and phosphates contained within it serve as buffers and maintain the pH, or hydrogen ion concentration, of saliva relatively constant under ordinary conditions.

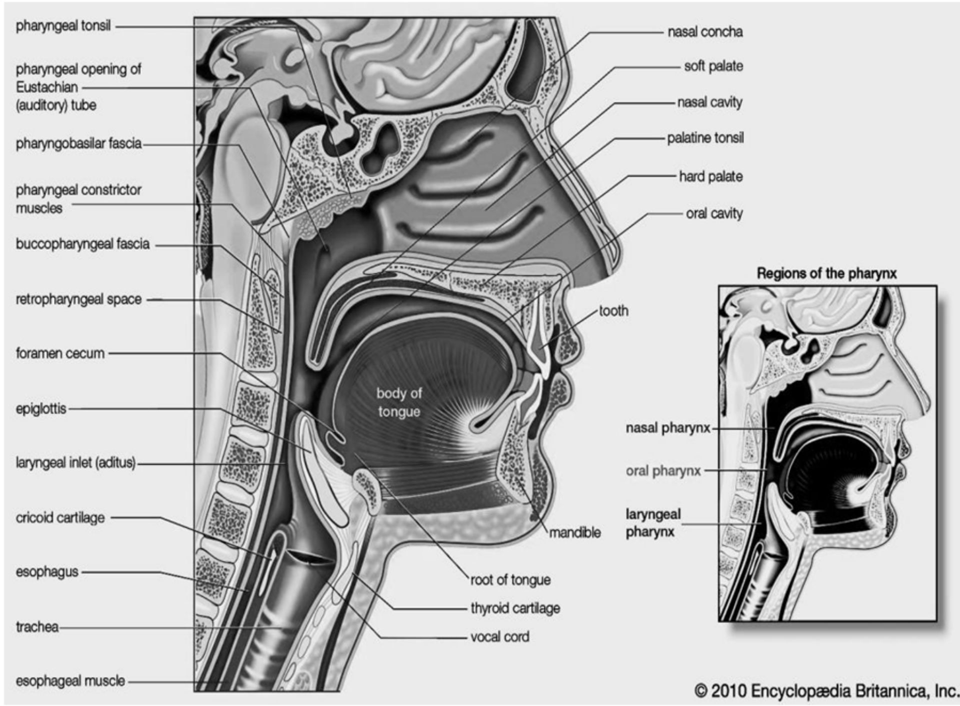
The concentrations of bicarbonate, chloride, potassium, and sodium in saliva are directly related to the rate of their flow. There is also a direct relation between bicarbonate concentration and the partial pressure of carbon dioxide in the blood. The concentration of chloride in the blood varies from 5 millimoles per litre at low flow rates to 70 millimoles per litre when the flow rate is high. The sodium concentrations in similar circumstances vary from 5 millimoles per litre to 100 millimoles per litre. The concentration of potassium in the blood is often higher than that in the blood plasma, up to 20 millimoles per litre, which accounts for the sharp and metallic taste of saliva when flow is brisk.

The constant flow of saliva keeps the oral cavity and teeth moist and comparatively free from food residues, sloughed epithelial cells, and foreign particles as well. By removing material that may serve as culture media, saliva inhibits the growth of bacteria. Saliva serves a protective function, for the enzyme lysozyme has the ability to lyse, or dissolve, certain bacteria. The secretion of saliva also provides a mechanism whereby certain organic and inorganic substances can be excreted from the body, including mercury, lead, potassium iodide, bromide, morphine, ethyl alcohol, and certain antibiotics such as penicillin, streptomycin, and chlortetracycline.

Although saliva is not essential to life but, its absence a deficiency results in a number of inconveniences, including dryness of the oral mucous membrane, poor oral hygiene because of bacterial overgrowth, a greatly diminished sense of taste, and difficulties with speech.

Pharynx

The pharynx, or throat, is the passageway leading from the mouth and nose to the esophagus and larynx. The pharynx permits the passage of swallowed solids and liquids into the esophagus, or gullet, and conducts air to and from the trachea, or windpipe, during respiration. The pharynx also connects on either side with the cavity of the middle ear by way of the Eustachian tube and provides for equalization of air pressure on the eardrum membrane, which separates the cavity of the middle ear from the external ear canal. The pharynx has roughly the form of a flattened funnel. It is attached to the surrounding structures but is loose enough to permit gliding of the pharyngeal wall against them in the movements of swallowing. The principal muscles of the pharynx, involved in the mechanics of swallowing, are the three pharyngeal constrictors, which overlap each other slightly and form the primary musculature of the side and rear pharyngeal walls.



Source: *Encyclopædia Britannica, Inc.*

Fig.5.5: Sagittal section of the pharynx.

There are three main divisions of the pharynx: the oral pharynx, the nasal pharynx, and the laryngeal pharynx. The latter two are airways, whereas the oral pharynx is shared by both the respiratory and digestive tracts. On either side of the opening between the mouth cavity and the oral pharynx is a palatine tonsil, so called because of its proximity to the palate. Each palatine tonsil is located between two vertical folds of mucous membrane called the glossopalatine arches. The nasal pharynx, above, is separated from the oral pharynx by the soft palate. Another pair of tonsils are located on the roof of the nasal pharynx. The pharyngeal tonsils, also known as the adenoids, are part of the body's immune system. When the pharyngeal tonsils become grossly swollen (which occurs often during childhood) they occlude the airway. The laryngeal pharynx and the lower part of the oral pharynx are hidden by the root of the tongue.

The first stage of deglutition, or swallowing, consists of passage of the bolus into the pharynx and it is initiated voluntarily. The front part of the tongue is retracted and depressed, mastication ceases, respiration is inhibited, and the back portion of the tongue is elevated and retracted against the hard palate. This action, produced by the strong muscles of the tongue, forces the bolus from the mouth into the pharynx. Entry of the bolus into the nasal pharynx is prevented by the elevation of the soft palate against the posterior pharyngeal wall. As the bolus is forced into the pharynx, the larynx moves upward and forward under the base of the tongue. The superior pharyngeal constrictor muscles contract, initiating a rapid pharyngeal peristaltic, or squeezing, contraction that moves down the pharynx, propelling the bolus in front of it. The walls and structures of the lower pharynx are elevated to engulf the oncoming mass of food. The epiglottis, a lidlike covering that protects the entrance to the larynx, diverts the bolus to the pharynx. The cricopharyngeal muscle, or upper esophageal sphincter, which has kept the esophagus closed until this point, relaxes as the bolus approaches and allows it to enter the upper esophagus. The pharyngeal peristaltic contraction continues into the esophagus and becomes the primary esophageal peristaltic contraction.

Oesophagus

The esophagus, which passes food from the pharynx to the stomach, is about 25 cm (10 inches) in length; the width varies from 1.5 to 2 cm (about 1 inch). The esophagus lies behind the trachea and heart and in front of the spinal column; it passes through the diaphragm before entering the stomach.

The esophagus contains four layers—the mucosa, submucosa, muscularis, and tunica adventitia. The mucosa is made up of stratified squamous epithelium containing numerous mucous glands. The submucosa is a thick, loose fibrous layer connecting the mucosa to the muscularis. Together the mucosa and submucosa form long longitudinal folds, so that a cross section of the esophagus opening would be star-shaped. The muscularis is composed of an inner layer, in which the fibres are circular, and an outer layer of longitudinal fibres. Both muscle groups are wound around and along the alimentary tract, but the inner one has a very tight spiral, so that the windings are virtually circular, whereas the outer one has a very slowly unwinding spiral that is virtually longitudinal. The outer layer of the esophagus, the tunica adventitia, is composed of loose fibrous tissue that connects the esophagus with neighbouring structures. Except during the act of swallowing, the esophagus is normally empty, and its lumen, or channel, is essentially closed by the longitudinal folds of the mucosal and submucosal layers.

The upper third of the esophagus is composed of striated (voluntary) muscle. The middle third is a mixture of striated and smooth (involuntary) muscle, and the lower third consists only of smooth muscle. The esophagus has two sphincters, circular muscles that act like drawstrings in closing channels. Both sphincters normally remain closed except during the act of swallowing. The upper esophageal sphincter is located at the level of the cricoid cartilage (a single ringlike cartilage forming the lower part of the larynx wall). This sphincter is called the cricopharyngeus muscle. The lower esophageal sphincter encircles the 3 to 4 cm of the esophagus that pass through an opening in the diaphragm called the diaphragmatic hiatus. The lower esophageal sphincter is maintained in tension at all times, except in response to a descending contraction wave, at which point it relaxes momentarily to allow the release of gas (belching) or vomiting. The lower esophageal sphincter has an important role, therefore, in protecting the esophagus from the reflux of gastric contents with changes in body position or with alterations of intragastric pressure.

Transportation of food through the esophagus is accomplished by the primary esophageal peristaltic contractions, which, as noted above, originate in the pharynx. These contractions are produced by an advancing peristaltic wave that creates a pressure gradient and sweeps the bolus ahead of it. Transport of material through the esophagus takes approximately 10 seconds. When the bolus arrives at the junction with the stomach, the lower esophageal sphincter relaxes and the bolus enters the stomach. If the bolus is too large, or if the peristaltic contraction is too weak, the bolus may become arrested in the middle or lower esophagus. When this occurs, secondary peristaltic contractions originate around the bolus in response to the local distension of the esophageal wall and propel the bolus into the stomach.

When a liquid is swallowed, its transport through the esophagus depends somewhat on the position of the body and the effects of gravity. When swallowed in a horizontal or head-down position, liquids are handled in the same manner as solids, with the liquid moving immediately ahead of the advancing peristaltic contraction. (The high pressures and strong contractions of the esophageal peristaltic wave make it possible for animals with very long necks, such as the giraffe, to transport liquids through the esophagus for many feet.) When the body is in the upright position, however, liquids enter the esophagus and fall by gravity to the lower end; there they await the arrival of the peristaltic contraction and the opening of the lower esophageal sphincter (8 to 10 seconds) before being emptied into the stomach.

5.7. Stomach

5.7.1. Anatomy

The stomach receives ingested food and liquids from the esophagus and retains them for grinding and mixing with gastric juice so that food particles are smaller and more soluble. The main functions of the stomach is to commence the digestion of carbohydrates and proteins, to convert the meal into chyme, and to discharge the chyme into the small intestine periodically as the physical and chemical condition of the mixture is rendered suitable for the next phase of digestion. The stomach is located in the left upper part of the abdomen immediately below the diaphragm. In front of the stomach are the liver, part of the diaphragm, and the anterior abdominal wall. Behind it are the pancreas, the left kidney, the left adrenal gland, the spleen, and the colon. The stomach is more or less concave on its right side, convex on its left. The concave border is called the lesser curvature; the convex border, the greater curvature. When the stomach is empty, its mucosal lining is thrown into numerous longitudinal folds, known as rugae; these tend to disappear when the stomach is distended.

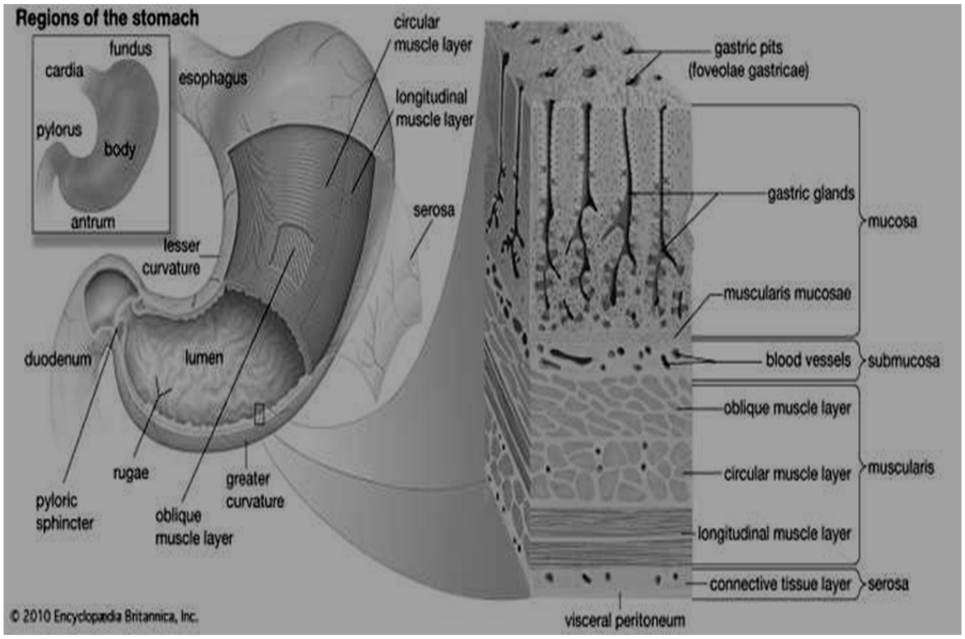


Fig.5.6: Structures of the human stomach

Source: https://www.britannica.com/science/stomach

The stomach has three layers of muscle: an outer longitudinal layer, a middle circular layer, and an inner oblique layer. The inner lining consists of four layers: the serosa, the muscularis, the submucosa, and the mucosa. The mucosa is densely packed with gastric glands, which contain cells that produce digestive enzymes, hydrochloric acid, and mucus.

The cardia is the opening of the esophagus into the stomach. The uppermost part of the stomach, located above the entrance of the esophagus, is the fundus. The fundus adapts to the varying volume of ingested food by relaxing its muscular wall; it frequently contains a gas bubble, especially after a meal. The largest part of the stomach is known simply as the body; it serves primarily as a reservoir for ingested food and liquids. The antrum, the lowermost part of the stomach, is somewhat funnel-shaped, with its wide end joining the lower part of the body and its narrow end connecting with the pyloric canal, which empties into the duodenum (the upper division of the small intestine). The pyloric portion of the stomach (antrum plus pyloric canal) tends to curve to the right and slightly upward and backward and thus gives the stomach its J-shaped appearance. The pylorus, the narrowest portion of the stomach, is the outlet from the stomach into the duodenum. It is approximately 2 cm (almost 1 inch) in diameter and is surrounded by thick loops of smooth muscle.

The muscles of the stomach wall are arranged in three layers, or coats. The external coat, called the longitudinal muscle layer, is continuous with the longitudinal muscle coat of the esophagus. Longitudinal muscle fibres are divided at the cardia into two broad strips.

The one on the right, the stronger, spreads out to cover the lesser curvature and the adjacent posterior and anterior walls of the stomach. Longitudinal fibres on the left radiate from the esophagus over the dome of the fundus to cover the greater curvature and continue on to the pylorus, where they join the longitudinal fibres coming down over the lesser curvature. The longitudinal layer continues on into the duodenum, forming the longitudinal muscle of the small intestine.

The middle, or circular muscular layer, the strongest of the three muscular layers, completely covers the stomach. The circular fibres of this coat are best developed in the lower portion of the stomach, particularly over the antrum and pylorus. At the pyloric end of the stomach, the circular muscle layer becomes greatly thickened to form the pyloric sphincter. This muscular ring is slightly separated from the circular muscle of the duodenum by connective tissue.

The innermost layer of smooth muscle, called the oblique muscular layer, is strongest in the region of the fundus and progressively weaker as it approaches the pylorus.

The stomach is capable of dilating to accommodate more than one litre (about one quart) of food or liquids without increasing pressure on the stomach. This receptive relaxation of the upper part of the stomach to accommodate a meal is partly due to a neural reflex that is triggered when hydrochloric acid comes into contact with the mucosa of the antrum, possibly through the release of the hormone known as vasoactive intestinal peptide. The distension of the body of the stomach by food activates a neural reflex that initiates the muscle activity of the antrum.

5.7.2. Blood and nerve supply

Many branches of the celiac trunk bring arterial blood to the stomach. The celiac trunk is a short, wide artery that branches from the abdominal portion of the aorta, the main vessel conveying arterial blood from the heart to the systemic circulation. Blood from the stomach is returned to the venous system through the portal vein, which carries the blood to the liver.

The nerve supply to the stomach is provided by both the parasympathetic and sympathetic divisions of the autonomic nervous system. The parasympathetic nerve fibres are carried in the vagus, or 10th cranial, nerve. As the vagus nerve passes through the opening in the diaphragm together with the esophagus, branches of the right vagus nerve spread over the posterior part of the stomach, while the left vagus nerve supplies the anterior part. Sympathetic branches from a nerve network called the celiac, or solar, plexus accompany the arteries of the stomach into the muscular wall.

5.7.3. Stomach contractions

Three types of motor activity of the stomach have been observed. The first is a small contraction wave of the stomach wall that originates in the upper part of the stomach and slowly moves down over the organ toward the pyloric sphincter. This type of contraction produces a slight indentation of the stomach wall. Retrograde waves frequently sweep from the pyloric sphincter to the antrum and up to its junction with the body of the stomach, which results in a back-and-forth movement of the gastric contents that has a mixing and crushing effect. The second type of motor activity is also a contracting wave, but it is peristaltic in nature. The contraction originates in the upper part of the stomach as well and is slowly propagated over the organ toward the pyloric sphincter. This type of gastric contraction produces a deep indentation in the wall of the stomach. As the peristaltic wave approaches the antrum, the indentation completely obstructs the stomach lumen, or cavity, and thus compartmentalizes it. The contracting wave then moves over the antrum, propelling the material ahead of it through the pyloric sphincter into the duodenum. This type of contraction serves as a pumping mechanism for emptying the contents of the gastric antrum through the pyloric sphincter. Both the mixing and the peristaltic contractions of the stomach occur at a constant rate of three contractions per minute when recorded from the gastric antrum. A wave of peristalsis sweeps along the lower half of the stomach and along the entire intestine to the proximal colon at two-hour intervals after meals. These peristaltic waves can be halted by eating and can be induced by the hormone motilin.

The third type of gastric motor activity is best described as a tonic, or sustained, contraction of all the stomach muscles. The tonic contraction decreases the size of the stomach lumen, as all parts of the gastric wall seem to contract simultaneously. This activity accounts for the stomach’s ability to accommodate itself to varying volumes of gastric content. The tonic contraction is independent of the other two types of contractions; however, mixing contractions and peristaltic contractions normally occur simultaneously with the tonic contraction. As food is broken down, smaller particles flow through the pyloric sphincter, which opens momentarily as a peristaltic wave descends through the antrum toward it. This permits “sampling” of the gastric contents by the duodenum.

5.7.4. Gastric mucosa

The inner surface of the stomach is lined by a mucous membrane known as the gastric mucosa. The mucosa is always covered by a layer of thick mucus that is secreted by tall columnar epithelial cells. Gastric mucus is a glycoprotein that serves two purposes: the lubrication of food masses in order to facilitate movement within the stomach and the formation of a protective layer over the lining epithelium of the stomach cavity. This protective layer is a defense mechanism the stomach has against being digested by its own protein-lyzing enzymes, and it is facilitated by the secretion of bicarbonate into the surface layer from the underlying mucosa. The acidity, or hydrogen ion concentration, of the mucous layer measures pH7 (neutral) at the area immediately adjacent to the epithelium and becomes more acidic (pH2) at the luminal level. When the gastric mucus is removed from the surface epithelium, small pits, called foveolae gastricae, may be observed with a magnifying glass. There are approximately 90 to 100 gastric pits per square millimetre (58,000 to 65,000 per square inch) of surface epithelium. Three to seven individual gastric glands empty their secretions into each gastric pit. Beneath the gastric mucosa is a thin layer of smooth muscle called the muscularis mucosae, and below this, in turn, is loose connective tissue, the submucosa, which attaches the gastric mucosa to the muscles in the walls of the stomach.

The gastric mucosa contains six different types of cells. In addition to the tall columnar surface epithelial cells mentioned above, there are five common cell types found in the various gastric glands.

1. Mucoid cells secrete gastric mucus and are common to all types of gastric glands. Mucoid cells are the main cell type found in the gastric glands in the cardiac and pyloric areas of the stomach. The necks of the glands in the body and fundic parts of the stomach are lined with mucoid cells.

2. Zymogenic, or chief, cells are located predominantly in gastric glands in the body and fundic portions of the stomach. These cells secrete pepsinogen, from which the proteolytic (protein-digesting) enzyme pepsin is formed. There are two varieties of pepsinogen, known as pepsinogen I and pepsinogen II. Both are produced in the mucous and zymogenic cells in the glands of the body of the stomach, but the mucous glands located elsewhere in the stomach produce only pepsinogen II. Those stimuli that cause gastric acid secretion—in particular, vagal nerve stimulation—also promote the secretion of the pepsinogens.

3. Gastrin cells, also called G cells, are located throughout the antrum. These endocrine cells secrete the acid-stimulating hormone gastrin as a response to lowered acidity of the gastric contents when food enters the stomach and gastric distention. Gastrin then enters the bloodstream and is carried in the circulation to the mucosa of the body of the stomach, where it binds to receptor sites on the outer membrane of the parietal cells (described below). The gastrin-receptor complex that is formed triggers an energy-consuming reaction moderated by the presence of the enzyme ATPase, bound to the membrane that leads to the production and secretion of hydrogen ions in the parietal cells.

4. Parietal, or oxyntic, cells, found in the glands of the body and fundic portions of the stomach, secrete hydrogen ions that combine with chloride ions to form hydrochloric acid (HCl). The acid that is produced drains into the lumen of the gland and then passes through to the stomach. This process occurs only when one or more types of receptors on the outer membrane of the parietal cell are bound to histamine, gastrin, or acetylcholine. Prostaglandins, hormonelike substances that are present in virtually all tissues and body fluids, inhibit the secretion of hydrochloric acid. The drugs omeprazole (Losec™ or Prilosec™) and lansoprazole (Prevacid™) also inhibit acid secretion by the parietal cells and are used as treatments for peptic ulcer. Parietal cells produce most of the water found in gastric juice; they also produce glycoproteins called intrinsic factor, which are essential to the maturation of red blood cells, vitamin B_{12} absorption, and the health of certain cells in the central and peripheral nervous systems.

5. Endocrine cells are also called enterochromaffin-like cells because of their staining characteristics are scattered throughout the body of the stomach. Enterochromaffin-like cells secrete several substances, including the hormone serotonin.

5.8. Gastric secretion

The gastric mucosa secretes 1.2 to 1.5 litres of gastric juice per day. Gastric juice renders food particles soluble, initiates digestion (particularly of proteins), and converts the gastric contents to a semiliquid mass called chyme, thus preparing it for further digestion in the small intestine. Gastric juice is a variable mixture of water, hydrochloric acid, electrolytes (sodium, potassium, calcium, phosphate, sulfate, and bicarbonate), and organic substances (mucus, pepsins, and protein). This juice is highly acidic because of its hydrochloric acid content, and it is rich in enzymes. As noted above, the stomach walls are protected from digestive juices by the membrane on the surface of the epithelial cells bordering the lumen of the stomach; this membrane is rich in lipoproteins, which are resistant to attack by acid. The gastric juice of some mammals (e.g., calves) contains the enzyme rennin, which clumps milk proteins and thus takes them out of solution and makes them more susceptible to the action of a proteolytic enzyme.

The process of gastric secretion can be divided into three phases (cephalic, gastric, and intestinal) that depend upon the primary mechanisms that cause the gastric mucosa to secrete gastric juice. The phases of gastric secretion overlap, and there is an interrelation and some interdependence between the neural and humoral pathways.

The cephalic phase of gastric secretion occurs in response to stimuli received by the senses that is, taste, smell, sight, and sound. This phase of gastric secretion is entirely reflex in origin and is mediated by the vagus (10th cranial) nerve. Gastric juice is secreted in response to vagal stimulation, either directly by electrical impulses or indirectly by stimuli received through the senses. Ivan Petrovich Pavlov, the Russian physiologist, originally demonstrated this method of gastric secretion in a now-famous experiment with dogs.

The gastric phase is mediated by the vagus nerve and by the release of gastrin. The acidity of the gastric contents after a meal is buffered by proteins so that overall it remains around pH3 (acidic) for approximately 90 minutes. Acid continues to be secreted during the gastric phase in response to distension and to the peptides and amino acids that are liberated from protein as digestion proceeds. The chemical action of free amino acids and peptides excites the liberation of gastrin from the antrum into the circulation. Thus, there are mechanical, chemical, and hormonal factors contributing to the gastric secretory response to eating. This phase continues until the food has left the stomach.

The intestinal phase is not fully understood, because of a complex stimulatory and inhibitory process. Amino acids and small peptides that promote gastric acid secretion are infused into the circulation, however, at the same time chyme inhibits acid secretion. The secretion of gastric acid is an important inhibitor of gastrin release. If the pH of the antral contents falls below 2.5, gastrin is not released. Some of the hormones that are released from the small intestine by products of digestion (especially fat), in particular glucagon and secretin, also suppress acid secretion.

Absorption and emptying

Although the stomach absorbs few of the products of digestion, it can absorb many other substances, including glucose and other simple sugars, amino acids, and some fat-soluble substances. The pH of the gastric contents determines whether some substances are absorbed. At a low pH, for example, the environment is acidic and aspirin is absorbed from the stomach almost as rapidly as water, but, as the pH of the stomach rises and the environment becomes more basic, aspirin is absorbed more slowly. Water moves freely from the gastric contents across the gastric mucosa into the blood. The net absorption of water from the stomach is small, however, because water moves just as easily from the blood across the gastric mucosa to the lumen of the stomach. The absorption of water and alcohol can be slowed if the stomach contains foodstuffs and especially fats, probably because gastric emptying is delayed by fats, and most water in any situation is absorbed from the small intestine.

The rate of emptying of the stomach depends upon the physical and chemical composition of the meal. Fluids empty more rapidly than solids, carbohydrates more rapidly than proteins, and proteins more rapidly than fats. When food particles are sufficiently reduced in size and are nearly soluble and when receptors in the duodenal bulb (the area of attachment between the duodenum and the stomach) have a fluidity and a hydrogen ion concentration of a certain level, the duodenal bulb and the second part of the duodenum relax, allowing emptying of the stomach to start. During a duodenal contraction, the pressure in the duodenal bulb rises higher than that in the antrum. The pylorus prevents reflux into the stomach by shutting. The vagus nerve has an important role in the control of emptying, but there is some indication that the sympathetic division of the autonomic nervous system is also involved. Several of the peptide hormones of the digestive tract also have an effect on intragastric pressure and gastric movements, but their role in physiological circumstances is unclear.

5.9. Small intestine

The small intestine is the principal organ of the digestive tract. The primary functions of the small intestine are mixing and transporting of intraluminal contents, production of enzymes and other constituents essential for digestion, and absorption of nutrients. Most of the processes that solubilize carbohydrates, proteins, and fats and reduce them to relatively simple organic compounds occur in the small intestine.

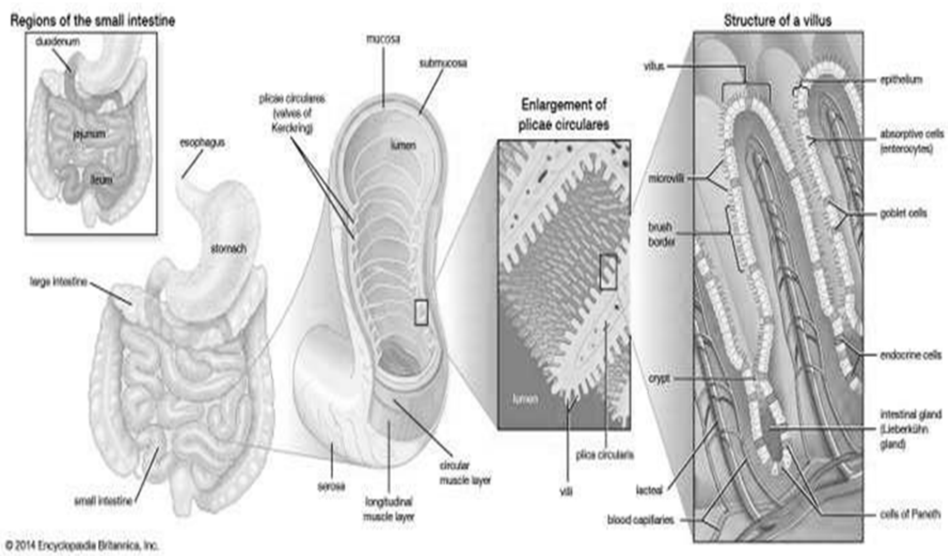


Fig.5.7: Schematic representation of small intestine

Source: *QA International. www.qa-international.com*

Most of the digestive process occurs in the small intestine, which channels water to the lymphatic system and nutrients to the circulatory system. The large intestine absorbs any remaining water. Structures of the small intestine. The inner wall of the small intestine is covered by numerous folds of mucous membrane called plicae circulares. The surface of these folds contains tiny projections called villi and microvilli, which further increase the total area for absorption. Absorbed nutrients are moved into circulation by blood capillaries and lacteals, or lymph channels.

5.9.1. Anatomy

The small intestine, which is 670 to 760 cm (22 to 25 feet) in length and 3 to 4 cm (about 2 inches) in diameter, is the longest part of the digestive tract. It begins at the pylorus, the juncture with the stomach, and ends at the ileocecal valve, the juncture with the colon. The main functional segments of the small intestine are the duodenum, the jejunum, and the ileum.

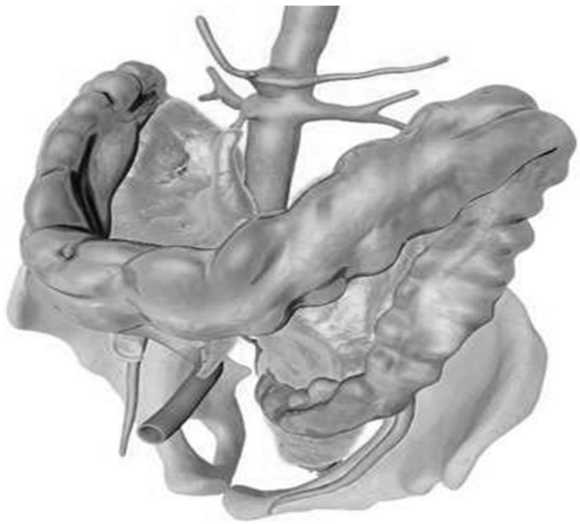
The duodenum is 23 to 28 cm (9 to 11 inches) long and forms a C-shaped curve that encircles the head of the pancreas. Unlike the rest of the small intestine, it is retroperitoneal (that is, it is behind the peritoneum, the membrane lining the abdominal wall). Its first segment, known as the duodenal bulb, is the widest part of the small intestine. It is horizontal, passing backward and to the right from the pylorus, and lies somewhat behind the wide end of the gallbladder. The second part of the duodenum runs vertically downward in front of the hilum of the right kidney (the point of entrance or exit for blood vessels, nerves, and the ureters); it is into this part through the duodenal papilla (papilla of Vater) that the pancreatic juice and bile flow. The third part of the duodenum runs horizontally to the left in front of the aorta and the inferior vena cava (the principal channel for return to the heart of venous blood from the lower part of the body and the legs), while the fourth part ascends to the left side of the second lumbar vertebra (at the level of the small of the back), then bends sharply downward and forward to join the second part of the small intestine, the jejunum. An acute angle, called the duodenojejunal flexure, is formed by the suspension of this part of the small intestine by the ligament of Treitz.

The jejunum forms the upper two-fifths of the rest of the small intestine; it, like the ileum, has numerous convolutions and is attached to the posterior abdominal wall by the mesentery, an extensive fold of serous-secreting membrane. The ileum is the remaining three-fifths of the small intestine, though there is no absolute point at which the jejunum ends and the ileum begins. In broad terms, the jejunum occupies the upper and left part of the abdomen below the subcostal plane (that is, at the level of the 10th rib), while the ileum is located in the lower and right part. At its termination the ileum opens into the large intestine.

The arrangement of the muscular coats of the small intestine is uniform throughout the length of the organ. The inner, circular layer is thicker than the outer, longitudinal layer. The outermost layer of the small intestine is lined by the peritoneum.

5.9.2. Blood and nerve supply

The superior mesenteric artery (a branch of the abdominal aorta) and the superior pancreaticduodenal artery (a branch of the hepatic artery) supply the small intestine with blood. These vessels run between layers of the mesentery, the membrane that connects the intestines with the wall of the abdominal cavity, and give off large branches that form a row of connecting arches from which branches arise to enter the wall of the small bowel. The blood from the intestine is returned by means of the superior mesenteric vein, which, with the splenic vein, forms the portal vein, which drains into the liver.



Mesentery, a continuous folded band of membranous tissue that holds the intestines and other organs in place and which some researchers consider to be a distinct organ. Source: Encyclopædia Britannica, Inc.

The small intestine has both sympathetic and parasympathetic innervation. The vagus nerve provides parasympathetic innervation. Sympathetic innervation is provided by branches from the superior mesenteric plexus, a nerve network underneath the solar plexus that follows the blood vessels into the small intestine and finally terminates in the Auerbach plexus, which is located between the circular and longitudinal muscle coats, and the Meissner plexus, which is located in the submucosa. Numerous fibrils, both adrenergic (sympathetic) and cholinergic (parasympathetic), connect these two plexuses.

5.9.3. Contractions and motility

The contractions of the circular and longitudinal muscles are regulated by electrical impulses that begin with the passage of calcium ions into the muscle cell. The duodenal pacemaker sends electrical impulses down the small intestine at a rate of 11 cycles per minute in the duodenum, gradually decreasing to 8 cycles per minute in the ileum. These electrical changes are propagated in the longitudinal muscle layer of the wall of the small intestine. Occurring simultaneously with the slow-wave electrical activity may be fast, spikelike electrical charges. This type of electrical activity originates in the circular muscle layer of the intestinal wall and occurs when the circular layer contracts to form a segmenting contraction. The depolarization of the muscle cell membranes, or an excess of positive charges on the inside of the cell, causes the myofibrils (the contracting components of the myofilaments that constitute the muscle tissues) to contract. The rate of these contractions is governed by the rate of depolarization of the muscle cell membrane. The two spiral muscle layers then contract, causing the motor activity that permits the mixing and transporting of the food in the small intestine.

The primary purposes of the movements of the small intestine are to provide mixing and transport of intraluminal contents. A characteristic of small intestine motility is the inherent ability of the smooth muscle constituting the wall of the intestine to contract spontaneously and rhythmically. This phenomenon is independent of any extrinsic nerve supply to the small intestine. In the myenteric plexus (a network of nerve fibres in the wall of the intestine), there are several other messenger substances and receptors capable of modulating smooth muscle activity, including somatostatin, serotonin (5-hydroxytryptamine), and the enkephalins. With at least seven such substances in and around the smooth muscle, there is some confusion as to their respective roles. The contractions of the small intestine create pressure gradients from one adjacent segment of the organ to another. The pressure gradients, in turn, are primarily responsible for transport within the small intestine. Two types of motor activity have been recognized: segmenting contractions and peristaltic contractions.

The predominant motor action of the small intestine is the segmenting contraction, which is a localized circumferential contraction, principally of the circular muscle of the intestinal wall. Segmenting contractions mix, separate, and churn the intestinal chyme. The contraction involves only a short segment of the intestinal wall, less than 1 to 2 cm (about 1 inch), and constricts the lumen, tending to divide its contents. As the chyme moves from the duodenum to the ileum, there is a gradual decrease in the number of segmenting contractions. This has been described as the "gradient" of small intestine motility. Although segmenting contractions usually occur in an irregular manner, they can occur in a regular or rhythmic pattern and at a maximum rate for that particular site of the small intestine (rhythmic segmentation). Rhythmic segmentation may occur only in a localized segment of small intestine, or it may occur in a progressive manner, with each subsequent segmenting contraction occurring slightly below the preceding one (progressive segmentation).

A peristaltic contraction may be defined as an advancing ring, or wave, of contraction that passes along a segment of the gastrointestinal tract. It normally occurs only over a short segment (approximately every 6 cm) and moves at a rate of about 1 or 2 cm per minute. This type of motor activity in the small intestine results in the transport of intraluminal contents downward, usually one segment at a time.

When an inflammatory condition of the small bowel exists, or when irritating substances are present in the intraluminal contents, a peristaltic contraction may travel over a considerable distance of the small intestine; this is called the peristaltic rush. Diarrhea due to common infections is frequently associated with peristaltic rushes. Most cathartics produce their diarrheic effect by irritating the intestinal mucosa or by increasing the contents, particularly with fluid.

5.9.4. Absorption

Although the small intestine is only 3 to 4 cm in diameter and approximately 7 metres in length, it is estimated that its total absorptive surface area is approximately 4,500 square metres (5,400 square yards). This huge absorptive surface is provided by the unique structure of the mucosa, which is arranged in concentric folds that have the appearance of transverse ridges. These folds, known as plicae circulares, are approximately 5 to 6 cm (2 inches) long and about 3 mm (0.1 inch) thick. Plicae circulares are present throughout the small intestine except in the first portion, or bulb, of the duodenum, which is usually flat and smooth, except for a few longitudinal folds. Also called valves of Kerckring, the plicae circulares are largest in the lower part of the duodenum and in the upper part of the jejunum. They become smaller and lastly disappear in the lower part of the ileum. The folds usually run one-half to two-thirds of the way around the intestinal wall; occasionally, a single fold may spiral the wall for three or four complete turns. It has been estimated that the small intestine contains approximately 800 plicae circulares and that they increase the surface area of the lining of the small bowel by five to eight times the outer surface area.

Another feature of the mucosa that greatly multiplies its surface area is that of tiny projections called villi. The villi usually vary from 0.5 to 1 mm in height. Their diameters vary from approximately one-eighth to one-third their height. The villi are covered by a single layer of tall columnar cells called goblet cells because of their rough resemblance to empty goblets after they have discharged their contents. Goblet cells are found scattered among the surface epithelial cells covering the villi and are a source of mucin, the chief constituent of mucus.

At the base of the mucosal villi are depressions called intestinal glands, or Lieberkühn’s glands. The cells that line these glands continue up and over the surface of the villi. In the bottom of the glands, epithelial cells called cells of Paneth are filled with alpha granules, or eosinophilic granules, so called because they take up the rose-coloured stain eosin. Though they may contain lysozyme, an enzyme toxic to bacteria, and immunoglobins, their precise function is uncertain.

There are three other cell types in the Lieberkühn’s glands: undifferentiated cells, which have the potential to undergo changes for the purpose of replacing losses of any cell type; the goblet cells mentioned above; and endocrine cells, which are described below. The main functions of the undifferentiated cells in these glands are cell renewal and secretion. Undifferentiated cells have an average life of 72 hours before becoming exhausted and being cast off.

The appearance and shape of the villi vary in different levels of the small intestine. In the duodenum the villi are closely packed, large, and frequently leaflike in shape. In the jejunum the individual villus measures between 350 and 600 µm in height (there are about 25,000 µm in an inch) and has a diameter of 110 to 135 µm. The inner structure of the individual villus consists of loose connective tissue containing a rich network of blood vessels, a central lacteal (or channel for lymph), smooth muscle fibres, and scattered cells of various types. The smooth muscle cells surround the central lacteal and provide for the pumping action required to initiate the flow of lymph out of the villus. A small central arteriole (minute artery) branches at the tip of the villus to form a capillary network; the capillaries, in turn, empty into a collecting venule that runs to the bottom of the villus.

A remarkable feature of the mucosa villi is the rough, specialized surface of the epithelial cells. This plasma membrane, known as the brush border, is thicker and richer in proteins and lipids than is the plasma membrane on the epithelial cells at the side and base of the villus. Water and solutes pass through pores in the surface epithelium of the mucosa by active transport and solvent drag; i.e., solutes are carried in a moving stream of water that causes an increased concentration of solute on the side of the membrane from which the water had originally come. The size of the pores is different in the ileum from in the jejunum; this difference accounts for the various rates of absorption of water at the two sites. The enterocytes are joined near their apex by a contact zone known as a "tight junction." These junctions are believed to have pores that are closed in the resting state and dilated when absorption is required. The brush border is fused to a layer of glycoprotein, known as the "fuzzy coat," where certain nutrients are partly digested. It consists of individual microvilli approximately 0.1 µm in diameter and 1 µm in height; each epithelial cell may have as many as 1,000 microvilli. The microvilli play an important role in the digestion and absorption of intestinal contents by enlarging the absorbing surface approximately 25 times. They also secrete the enzymes disaccharidase and peptidase that hydrolyze disaccharides and polypeptides to monosaccharides and dipeptides to amino acids, respectively. Molecular receptors for specific substances are found on the microvilli surfaces at different levels in the small intestine. This may account for the selective absorption of particular substances at particular sites—for example, intrinsic-factor-bound vitamin B_{12} in the terminal ileum. Such receptors may also explain the selective absorption of iron and calcium in the duodenum and upper jejunum. Furthermore, there are transport proteins in the microvillus membrane associated with the passage of sodium ions, D-glucose, and amino acids.

Actin is found in the core of the microvillus, and myosin is found in the brush border; because contractility is a function of these proteins, the microvilli have motor activity that presumably initiates the stirring and mixing actions within the lumen of the small intestine.

Beneath the mucosa of the small intestine, as beneath that of the stomach, are the muscularis and the submucosa. The submucosa consists of loose connective tissue and contains many blood vessels and lymphatics. Brunner's glands, located in the submucosa of the duodenum, are composed of acini (round sacs) and tubules that are twisting and have multiple branching. These glands empty into the base of Lieberkühn's glands in the duodenum. Their exact function is not known, but they do secrete a clear fluid that contains mucus, bicarbonate, and a relatively weak proteolytic (protein-splitting) enzyme. In the submucosa of the jejunum, solitary nodules (lumps) of lymphatic tissue are located. There is more lymphatic tissue in the ileum, in aggregates of nodules known as Peyer patches.

5.9.5. Secretions

There are many sources of digestive secretions into the small intestine. Secretions into the small intestine are controlled by nerves, including the vagus, and hormones. The most effective stimuli for secretion are local mechanical or chemical stimulations of the intestinal mucous membrane. Such stimuli always are present in the intestine in the form of chyme and food particles. The gastric chyme that is emptied into the duodenum contains gastric secretions that will continue their digestive processes for a short time in the small intestine. One of the major sources of digestive secretion is the pancreas, a large gland that produces both digestive enzymes and hormones. The pancreas empties its secretions into the duodenum through the major pancreatic duct (duct of Wirsung) in the duodenal papilla (papilla of Vater) and the accessory pancreatic duct a few centimetres away from it. Pancreatic juice contains enzymes that digest proteins, fats, and carbohydrates. Secretions of the liver are delivered to the duodenum by the common bile duct via the gallbladder and are also received through the duodenal papilla.

The composition of the succus entericus, the mixture of substances secreted into the small intestine, varies somewhat in different parts of the intestine. Except in the duodenum, the quantity of the fluid secreted is minimal, even under conditions of stimulation. In the duodenum, for example, where the Brunner's glands are located, the secretion contains more mucus. In general, the secretion of the small intestine is a thin, colourless or slightly straw-coloured fluid, containing flecks of mucus, water, inorganic salts, and organic material. The inorganic salts are those commonly present in other body fluids, with the bicarbonate concentration higher than it is in blood. Aside from mucus, the organic matter consists of cellular debris and enzymes, including a pepsinlike protease (from the duodenum only), an amylase, a lipase, at least two peptidases, sucrase, maltase, enterokinase, alkaline phosphatase, nucleophosphatases, and nucleocytases.

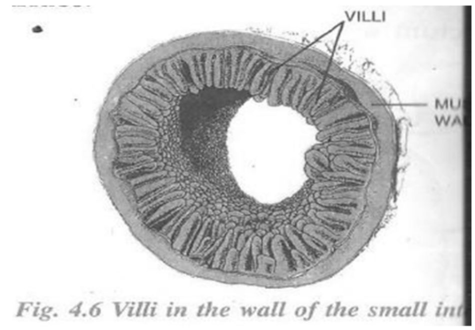
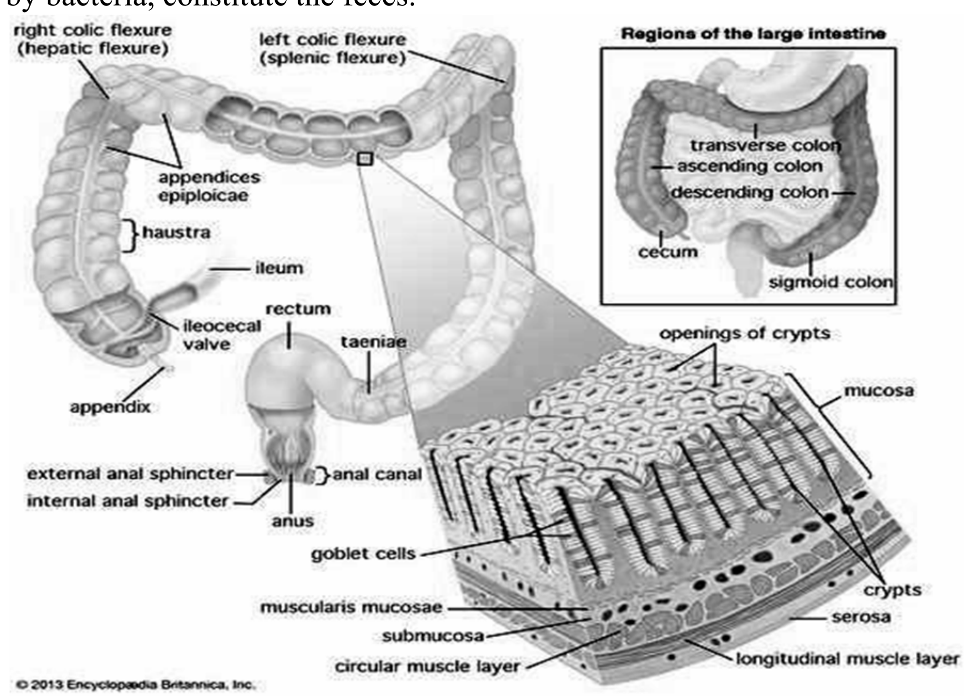


Fig 5.9 Villi structure of small intestine

5.10. **Large intestine**

The large intestine, or colon, serves as a reservoir for the liquids emptied into it from the small intestine. It has a much larger diameter than the small intestine (approximately 2.5 cm, or 1 inch, as opposed to 6 cm, or 3 inches, in the large intestine), but at 150 cm (5 feet), it is less than one-quarter the length of the small intestine. The primary functions of the colon are to absorb water; to maintain osmolality, or level of solutes, of the blood by excreting and absorbing electrolytes (substances, such as sodium and chloride, that in solution take on an electrical charge) from the chyme; and to store fecal material until it can be evacuated by defecation. The large intestine also secretes mucus, which aids in lubricating the intestinal contents and facilitates their transport through the bowel. Each day approximately 1.5 to 2 litres (about 2 quarts) of chyme pass through the ileocecal valve that separates the small and large intestines. The chyme is reduced by absorption in the colon to around 150 ml (5 fluid ounces). The residual indigestible matter, together with sloughed-off mucosal cells, dead bacteria, and food residues not digested by bacteria, constitute the feces.



Structures of large intestine, rectum, and anus. The mucosa of the large intestine is punctuated with numerous crypts that absorb water and are lined with mucus-secreting goblet cells. At the lower end of the rectum, the circular and longitudinal muscle layers terminate in the internal and external anal sphincters source: *Encyclopædia Britannica, Inc.*

The colon also contains large numbers of bacteria that synthesize niacin (nicotinic acid), thiamin (vitamin B_1) and vitamin K, vitamins that are essential to several metabolic activities as well as to the function of the central nervous system.

5.10.1. Anatomy

The large intestine can be divided into the cecum, ascending colon, transverse colon, descending colon, and sigmoid colon. The cecum, the first part of the large intestine, is a sac with a closed end that occupies the right iliac fossa, the hollow of the inner side of the ilium (the upper part of the hipbone). Guarding the opening of the ileum (the terminal portion of the small intestine) into the cecum is the ileocecal valve. The circular muscle fibres of the ileum and those of the cecum combine to form the circular sphincter muscle of the ileocecal valve.

The ascending colon extends up from the cecum at the level of the ileocecal valve to the bend in the colon called the hepatic flexure, which is located beneath and behind the right lobe of the liver; behind, it is in contact with the rear abdominal wall and the right kidney. The ascending colon is covered by peritoneum except on its posterior surface.

The transverse colon is variable in position, depending largely on the distention of the stomach, but usually is located in the subcostal plane—that is, at the level of the 10th rib. On the left side of the abdomen, it ascends to the bend called the splenic flexure, which may make an indentation in the spleen. The transverse colon is bound to the diaphragm opposite the 11th rib by a fold of peritoneum.

The descending colon passes down and in front of the left kidney and the left side of the posterior abdominal wall to the iliac crest (the upper border of the hipbone). The descending colon is more likely than the ascending colon to be surrounded by peritoneum.

The sigmoid colon is commonly divided into iliac and pelvic parts. The iliac colon stretches from the crest of the ilium, or upper border of the hipbone, to the inner border of the psoas muscle, which lies in the left iliac fossa. Like the descending colon, the iliac colon is usually covered by peritoneum. The pelvic colon lies in the true pelvis (lower part of the pelvis) and forms one or two loops, reaching across to the right side of the pelvis and then bending back and, at the midline, turning sharply downward to the point where it becomes the rectum.

The layers that make up the wall of the colon are similar in some respects to those of the small intestine; there are distinct differences, however. The external aspect of the colon differs markedly from that of the small intestine because of features known as the taeniae, haustra, and appendices epiploicae. The taeniae are three long bands of longitudinal muscle fibres, about 1 cm in width, that are approximately equally spaced around the circumference of the colon. Between the thick bands of the taeniae, there is a thin coating of longitudinal muscle fibres. Because the taeniae are slightly shorter than the large intestine, the intestinal wall constricts and forms circular furrows of varying depths called haustra, or sacculations. The appendices epiploicae are collections of fatty tissue beneath the covering membrane. On the ascending and descending colon, they are usually found in two rows, whereas on the transverse colon they form one row.

The inner surface of the colon has many crypts that are lined with mucous glands and numerous goblet cells. It lacks the villi and plicae circulares characteristic of the small intestine. It contains many solitary lymphatic nodules but no Peyer patches. Characteristic of the colonic mucosa are deep tubular pits, increasing in depth toward the rectum.

The inner layer of muscle of the large intestine is wound in a tight spiral around the colon, so that contraction results in compartmentalization of the lumen and its contents. The spiral of the outer layer, on the other hand, follows a loose undulating course, and contraction of this muscle causes the contents of the colon to shift forward and backward. The bulk of the contents, in particular the amount of undigested fibre, influences these muscular activities.

5.10.2. Blood and Nerve supply

The arterial blood supply to the large intestine is supplied by branches of the superior and inferior mesenteric arteries (both of which are branches of the abdominal aorta) and the hypogastric branch of the internal iliac artery (which supplies blood to the pelvic walls and viscera, the genital organs, the buttocks, and the inside of the thighs). The vessels form a continuous row of arches from which vessels arise to enter the large intestine. Venous blood is drained from the colon from branches that form venous arches similar to those of the arteries. These eventually drain into the superior and inferior mesenteric veins, which ultimately join with the splenic vein to form the portal vein. The innervation of the large intestine is similar to that of the small intestine.

5.10.3. Contractions and motility

Local contractions and retrograde propulsions ensure mixing of the contents and good contact with the mucosa. Colonic motility is stimulated by mastication and by the presence of fat, unabsorbed bile salts, bile acids, and the peptide hormones gastrin and cholecystokinin. The hormones secretin, glucagon, and vasoactive intestinal peptide act to suppress motility. The electrical activity of the muscles of the colon is more complex than that of the small intestine. Variations from the basic rhythmic movements of the colon are present in the lower (distal) half of the colon and in the rectum. Slow-wave activity that produces contractions from the ascending colon to the descending colon occurs at the rate of 11 cycles per minute, and slow-wave activity in the sigmoid colon and rectum occurs at 6 cycles per minute. Local contractions migrate distally in the colon at the rate of 4 cm (1.6 inches) per second. Retrograde, or reverse, movements occur mainly in the upper (proximal) colon.

5.10.4. Rectum and anus

The rectum, which is a continuation of the sigmoid colon, begins in front of the midsacrum (the sacrum is the triangular bone near the base of the spine and between the two hipbones). It ends in a dilated portion called the rectal ampulla, which in front is in contact with the rear surface of the prostate in the male and with the posterior vaginal wall in the female. Posteriorly, the rectal ampulla is in front of the tip of the coccyx (the small bone at the very base of the spine).

At the end of the pelvic colon, the mesocolon, the fold of peritoneum that attaches the colon to the rear wall of the abdomen and pelvis, ceases, and the rectum is then covered by peritoneum only at its sides and in front; lower down, the rectum gradually loses the covering on its sides until only the front is covered. About 7.5 cm (3 inches) from the anus, the anterior peritoneal covering is also folded back onto the bladder and the prostate or the vagina.

Near the termination of the sigmoid colon and the beginning of the rectum, the colonic taeniae spread out to form a wide external longitudinal muscle coat. At the lower end of the rectum, muscle fibres of the longitudinal and circular coats tend to intermix. The internal circular muscle coat terminates in the thick rounded internal anal sphincter muscle. The smooth muscle fibres of the external longitudinal muscle coat of the rectum terminate by interweaving with striated muscle fibres of the levator ani, or pelvic diaphragm, a broad muscle that forms the floor of the pelvis. A second sphincter, the external anal sphincter, is composed of striated muscle and is divided into three parts known as the subcutaneous, superficial, and deep external sphincters. Thus, the internal sphincter is composed of smooth muscle and is innervated by the autonomic nervous system, while the external sphincters are of striated muscle and have somatic (voluntary) innervation provided by nerves called the pudendal nerves.

The mucosal lining of the rectum is similar to that of the sigmoid colon but becomes thicker and better supplied with blood vessels, particularly in the lower rectum. Arterial blood is supplied to the rectum and anus by branches from the inferior mesenteric artery and the right and left internal iliac arteries. Venous drainage from the anal canal and rectum is provided by a rich network of veins called the internal and external hemorrhoidal veins.

Two to three large crescent like folds known as rectal valves are located in the rectal ampulla. These valves are caused by an invagination, or infolding, of the circular muscle and submucosa. The columnar epithelium of the rectal mucosa, innervated by the autonomic nervous system, changes to the stratified squamous (scalelike) type, innervated by the peripheral nerves, in the lower rectum a few centimetres above the pectinate line, which is the junction between the squamous mucous membrane of the lower rectum and the skin lining the lower portion of the anal canal.

Once or twice in 24 hours, a mass peristaltic movement shifts the accumulated feces onward from the descending and sigmoid sectors of the colon. The rectum is normally empty, but when it is filled with gas, liquids, or solids to the extent that the intraluminal pressure is raised to a certain level, the impulse to defecate occurs.

The musculus puborectalis forms a sling around the junction of the rectum with the anal canal and is maintained in a constant state of tension. This results in an angulation of the lower rectum so that the lumen of the rectum and the lumen of the anal canal are not in continuity, a feature essential to continence. Continuity is restored between the lumina of the two sectors when the sling of muscle relaxes, and the longitudinal muscles of the distal and pelvic colon contract. The resulting shortening of the distal colon tends to elevate the pelvic colon and obliterates the angle that it normally makes with the rectum. The straightening and shortening of the passage facilitates evacuation.

The act of defecation is preceded by a voluntary effort, which, in turn, probably gives rise to stimuli that magnify the visceral reflexes, although these originate primarily in the distension of the rectum. Centres that control defecation reflexes are found in the hypothalamus of the brain, in two regions of the spinal cord, and in the ganglionic plexus of the intestine. As the result of these reflexes, the internal anal sphincter relaxes.

5.11. Liver

The liver is not only the largest gland in the body but also the most complex in function. The major functions of the liver are to participate in the metabolism of protein, carbohydrates, and fat; to synthesize cholesterol and bile acids; to initiate the formation of bile; to engage in the transport of bilirubin; to metabolize and transport certain drugs; and to control transport and storage of carbohydrates.

5.11.1. Gross anatomy

The liver lies under the lower right rib cage and occupies much of the upper right quadrant of the abdomen, with a portion extending into the upper left quadrant. The organ weighs from 1.2 to 1.6 kg (2.6 to 3.5 pounds) and is somewhat larger in men than in women. Its greatest horizontal measurement ranges from 20 to 22 cm (approximately 8 inches); vertically, it extends 15 to 18 cm, and in thickness it ranges from 10 to 13 cm. The liver is divided into two unequal lobes: a large right lobe and a smaller left lobe. The left lobe is separated on its anterior (frontal) surface by the dense falciform (sickle-shaped) ligament that connects the liver to the undersurface of the diaphragm. On the inferior surface of the liver, the right and left lobes are separated by a groove containing the teres ligament, which runs to the navel. Two small lobes, the caudate and the quadrate, occupy a portion of the inferior surface of the right lobe. The entire liver, except for a small portion that abuts the right leaf of the diaphragm, is enveloped in a capsule of tissue that is continuous with the parietal peritoneum that lines the abdominopelvic walls and diaphragm.

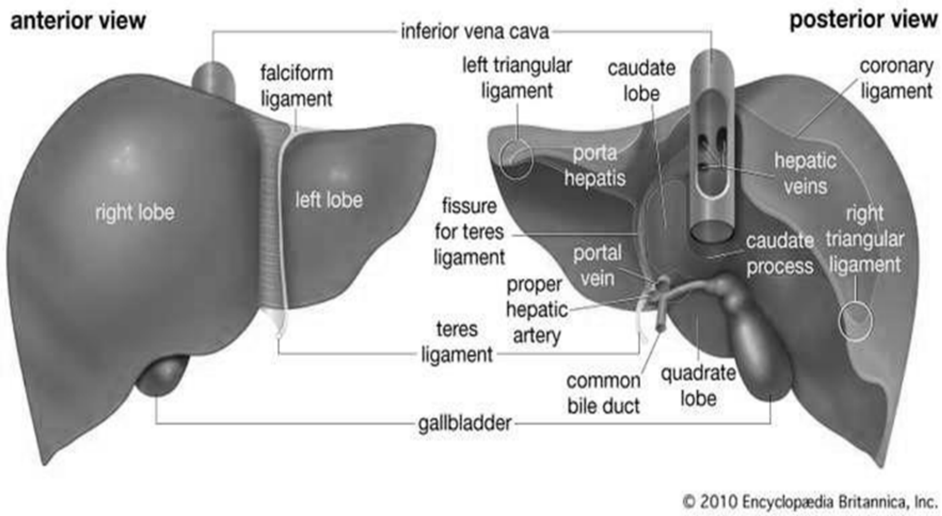


Fig. 5.8: a Antero-posterior view of liver. Source: *Encyclopædia Britannica, Inc.*

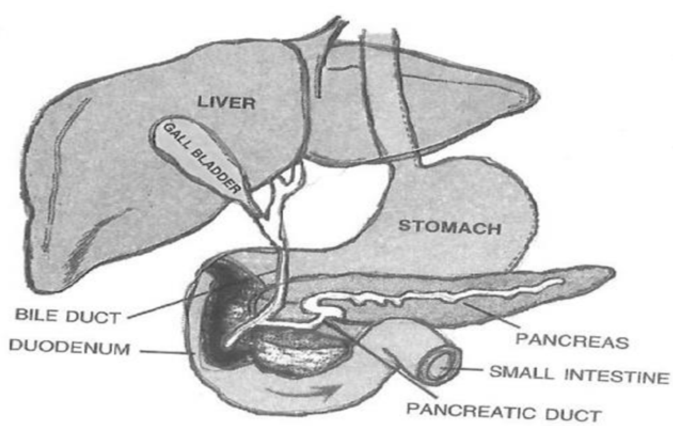
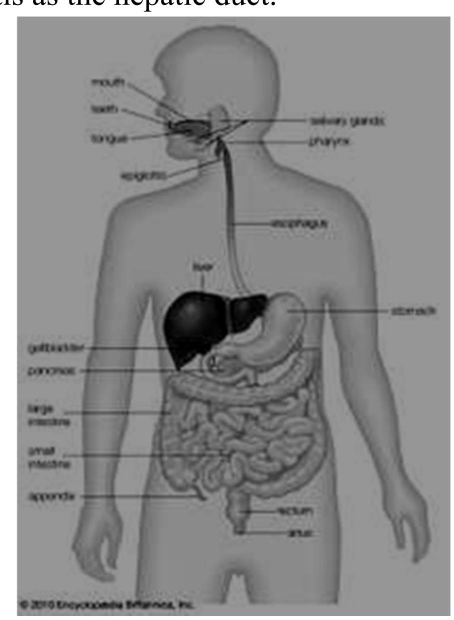


Fig 5.8:b Liver, Pancreas and Gall Bladder sketch

The major blood vessels enter the liver on its inferior surface in a centrally placed groove called the porta hepatis, which anatomically separates the quadrate and caudate lobes. The liver has two sources of blood supply: fully oxygenated blood from the hepatic artery, which is a major branch of the celiac axis (the main artery that crosses the abdomen) after its emergence from the abdominal aorta; and partially oxygenated blood from the large portal vein, which in turn receives all venous blood from the spleen, pancreas, gallbladder, lower esophagus, and the remainder of the gastrointestinal tract, including the stomach, small intestine, large intestine, and upper portion of the rectum. The portal vein is formed by the juncture of the splenic vein with the superior mesenteric vein. At the porta hepatis the portal vein divides into two large branches, each going to one of the major lobes of the liver. The porta hepatis is also the exit point for the hepatic ducts. These channels are the final pathway for a network of smaller bile ductules interspersed throughout the liver that serve to carry newly formed bile from liver cells to the small intestine via the biliary tract.

5.11.2. Microscopic anatomy

The microscopic anatomy of the liver reveals a uniform structure of clusters of cells called lobules, where the vital functions of the liver are carried out. Each lobule, measuring about one millimeter in diameter, consists of numerous cords of rectangular liver cells, or hepatocytes, which radiate from central veins, or terminal hepatic venules, toward a thin layer of connective tissue that separates the lobule from other neighboring lobules. The cords of liver cells are one cell thick and are separated from one another on several surfaces by spaces called sinusoids, or hepatic capillaries. Sinusoids are lined by thin endothelial cells that have openings through which fingerlike projections (microvilli) of the hepatocytes extend, allowing direct accessibility of the hepatocyte to the bloodstream in the sinusoids. The other major cell of the liver, the Kupffer cell, adheres to the wall of the sinusoid and projects into its lumen. It functions as a phagocyte (a cell that engulfs and destroys foreign material or other cells). Small spaces (Disse spaces) are present in places between the hepatocyte and the sinusoidal endothelium, probably for the transport of lymph. On neighbouring surfaces the hepatocytes are bound to one another by dense, tight junctions. These are perforated by small channels, called canaliculi, that are the terminal outposts of the biliary system, receiving bile from the hepatocyte. They eventually join with other canaliculi, forming progressively larger bile ducts that eventually emerge from the porta hepatis as the hepatic duct.



To cut short this complex process, the first step of the digestion system begins from your mouth. First of all, when you bite into the food(s), your front teeth tears it apart and the back teeth crush and grind the food. The tongue rolls the food into a ball. Next, saliva that is released from the glands, moisten the the bolus and breaks it into some nutrients. Then, once it reaches the pharynx, the food would go down the esophagus and into the stomach. The digestion system begins from the mouth.

The second step of the digestive system happens in the stomach. First, the bolus enters the stomach. Next, the stomach's walls create chemicals that break down the bolus into nutrients. Then, the muzzles in the stomach's walls squeeze and repeat over and over. This help mix the bolus and the chemicals together. After about four to six hours, the food becomes a thick, mushy liquid. The second part of the digestive system is performed in the stomach.

The third step of the digestive system happens in the small intestine and the large intestine. First, the liquid leaves the stomach and enters the small intestine. The juices from the pancreas and the liver are mixed with the liquid until it is all broken into nutrients. Next, the nutrients are soaked up by the small intestine's walls. Inside the folds, nutrients go into tiny blood vessels. Then, an undigested part of the food becomes waste. Fourth, the waste moves from the small intestine to the large intestine. The cecum connects the small intestine the large intestine. Inside of the large intestine, the colon takes in some water and minerals from the feces. The rectum is in charge of storing and eliminates the feces. The small intestine and the large intestine and the large intestine is where the third stage of the digestive system is performed.

Lastly by eating food, our body is able to collect nutrients from it with the help of the digestive system. The nutrients from foods are very important for our body to metabolize and survive. The digestive system would bring the food into the stomach, small intestine, and the large intestine where all nutrients will be absorbed. If we didn't have the digestive system, our body wouldn't be able to get nutrients from the foods that we consume. Imagine of situation, what you think will happen to our body if we didn't have the digestive system at all?

5.12. Nervous Regulation of Salivary, Gastric, Pancreatic juices

Enzymes are biological catalysts are the molecules (generally proteins) that significantly speed up the rate of virtually all of the chemical reactions that take place within cells. They are vital for life and serve a wide range of important functions in the body, such as aiding in digestion and metabolism.

The enteric nervous system provides intrinsic innervation, and the autonomic nervous system provides extrinsic innervation. As soon as food enters the mouth, it is detected by receptors that send impulses along the sensory neurons of cranial nerves. Without these nerves, not only would your food be without taste, but you would also be unable to feel either the food or the structures of your mouth, and you would be unable to avoid biting yourself as you chew, an action enabled by the motor branches of cranial nerves.

Intrinsic innervation of much of the alimentary canal is provided by the enteric nervous system, which runs from the esophagus to the anus, and contains approximately 100 million motor, sensory, and interneurons (unique to this system compared to all other parts of the peripheral nervous system). These enteric neurons are grouped into two plexuses. The **myenteric plexus** (plexus of Auerbach) lies in the muscularis layer of the alimentary canal and is responsible for **motility**, especially the rhythm and force of the contractions of the muscularis. The **submucosal plexus** (plexus of Meissner) lies in the submucosal layer and is responsible for regulating digestive secretions and reacting to the presence of food.

Extrinsic innervations of the alimentary canal are provided by the autonomic nervous system, which includes both sympathetic and parasympathetic nerves. In general, sympathetic activation (the fight-or-flight response) restricts the activity of enteric neurons, thereby decreasing GI secretion and motility. In contrast, parasympathetic activation (the rest-and-digest response) increases GI secretion and motility by stimulating neurons of the enteric nervous system.

5.13. Role of Enzymes in Digestive System

Digestive enzymes are a group of enzymes that break down polymeric macromolecules into minimolecules such as peptides and amino acids. The stomach plays a major role in digestion, both in a mechanical sense by mixing and crushing the food, and also in an enzymatic sense metabolizer.

For example, Gastric juice, protease (pepsin) and hydrochloric acid is responsible for digestion of complex proteins and convert it into partly digested proteins. Whereas pancreatic juice secreted by pancreas such as proteases (trypsin) would also digest proteins in to peptides and amino acids and Amylases by salivary and other glands will convert starch in to maltose. Lipases already converted emulsified fats into fatty acids and glycerol. Lastly other enzymes like Erepsin convert peptides in to amino acid, Maltase convert maltose in to glucose, Sucrase convert sucrose into glucose and fructose whereas Lactase convert lactose into glucose and galactose.

5.14. Summary

The digestive system includes the organs of the alimentary canal and accessory structures. The alimentary canal forms a continuous tube that is open to the outside environment at both ends. The organs of the alimentary canal are the mouth, pharynx, esophagus, stomach, small intestine, and large intestine. The accessory digestive structures include the teeth, tongue, salivary glands, liver, pancreas, and gallbladder. The wall of the alimentary canal is composed of four basic tissue layers: mucosa, submucosa, muscularis, and serosa.

To conclude digestion is the breakdown of large insoluble food molecules into small water-soluble food molecules so that they can be absorbed into the watery blood plasma. In certain organisms, these smaller substances are absorbed through the small intestine into the blood stream. The function of the digestive system is to break down the foods you eat, release their nutrients, and absorb those nutrients into the body. Although the small intestine is the workshop of the gastrointestinal system, where the majority of digestion occurs, and where most of the released nutrients are absorbed into the blood or lymph, each of the digestive system organs makes a vital contribution to this process. It is impairment of digestion function gives rise to other physiological abnormalities that are observed in day to day life in the society.

5.15. Terminal questions

Q.1. Discuss the process of digestion in mammals?

Answer:---

Write an account of role gastrointestinal tract in food absorption and assimilation?

Answer:---

Q.2. Discuss the role of salivary gland and its enzymes in digestion?

Answer:---

Q.3. Discuss few methods to avoid consumption of contaminated food?

Answer:---

Q.4. Draw a neat labeled diagram of human gastrointestinal tract?

Answer:---

Q.5. In which part of alimentary canal does most of the digestive process take place?

a) Small intestine

b) Large intestine

c) Stomach

d) All of the above

Answer:---

Q.6. What does the liver do to help digestion?

a) Makes important enzymes

b) Produces bile

c) Neutralizes stomach acid

d) Regulates insulin

Answer:---

Q.7. How does food move through your digestive tract?

a) By wavelike muscle contractions.

b) By gravity

c) By cilia

d) By chemical absorption

Answer:---

Q.8. What causes heartburn?

- **a)** By wavelike muscle contractions.
- **b)** By gravity
- **c)** By cilia
- **d)** D. By chemical absorption

Answer:---

Q.9. Which among the followings is best for intestinal health?

- **a)** Starches
- **b)** Vitamins
- **c)** Fibers
- **d)** Fat

Answers: A, B, A, D, C

Answer:---

5.16. Further readings

1. Guyton and Hall (2011). *Textbook of Medical Physiology*. U.S.: Saunders Elsevier.
2. Hall, John E. (2011). "General Principles of Gastrointestinal Function". Guyton and Hal Textbook of Medical Physiology (12th ed.). Saunders Elsevier. p.
3. Britannica Concise Encyclopedia. Encyclopedia Britannica, Inc. 2007.
4. Drake, Richard L.; Vogl, Wayne; Tibbitts, Adam W.M. Mitchell; illustrations by Richard; Richardson, Paul (2005). Gray's anatomy for students. Philadelphia: Elsevier/Churchill Livingstone. p. 287.
5. The Digestive System by Christine Taylor-Butler
6. The Digestive System: Basic Science and Clinical : Systems of the Body, Textbook by Dion G. Morton and Margaret E. Smith.

UNIT : 6

RESPIRATION

Structure:

6.1. Introduction

The respiratory system (respiratory apparatus, ventilatory system) is a complex biological system comprising of specific organs and structures used for gaseous exchange in animals and plants. The anatomy and physiology that make this happen varies greatly, depending on the size of the organism, the environment in which it lives and its evolutionary history. In land animals the respiratory surface is internalized as linings of the lungs. Gas exchange in the lungs occurs in millions of small air sacs called alveoli in mammals and reptiles, but atria in birds. These microscopic air sacs have a very rich blood supply, thus bringing the air into close contact with the blood. These air sacs communicate with the external environment via a system of airways, or hollow tubes, of which the largest is the trachea, which branches in the middle of the chest into the two main bronchi. These enter the lungs where they branch into progressively narrower secondary and tertiary bronchi that branch into numerous smaller tubes, the bronchioles. In birds the bronchioles are termed parabronchi. It is the bronchioles, or parabronchi that generally open into the microscopic alveoli in mammals and atria in birds. Air has to be pumped from the environment into the alveoli or atria by the process of breathing which involves the muscles of respiration.

Objectives:

- To acquaint with the physiology of respiration its mechanism and types with examples.
- Further the unit elaborates on the structure of respiratory apparatus in relation to its function.
- Discuss the abnormalities and issues pertaining to impairment of respiratory function with some salient examples

6.2. Respiratory system

In humans and other mammals, the anatomy of a typical respiratory system is the respiratory tract fg. (6.1). The tract is divided into an upper and a lower respiratory tract. The upper tract includes the nose, nasal cavities, sinuses, pharynx and the part of the larynx above the vocal folds. The lower tract (Fig.6. 2) includes the lower part of the larynx, the trachea, bronchi, bronchioles and the alveoli. In most fishes, and a number of other aquatic animals (both vertebrates and invertebrates) the respiratory system consists of gills, which are either partially or completely external organs, bathed in the watery environment. This water flows over the gills by a variety of active or passive means. Gas exchange takes place in the gills which consist of thin or very flat filaments and lamellae which expose a very large surface area of highly vascularized tissue to the water. Other animals, such as insects, have respiratory systems with very simple anatomical features, and in amphibians even the skin plays a vital role in gas exchange. Plants also have respiratory systems but the directionality of gas exchange can be opposite to that in animals. The respiratory system in plants includes anatomical features such as stomata, which are found in various parts of the plant.

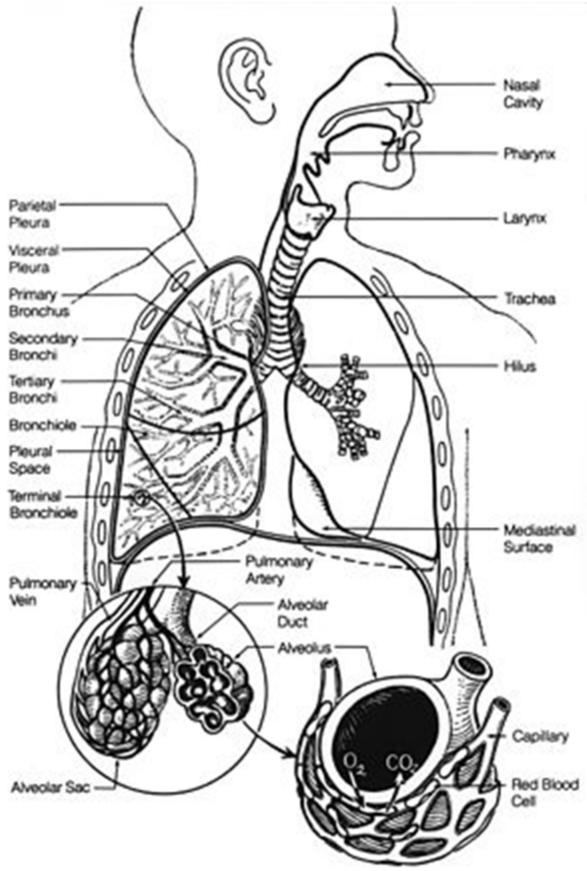


Fig.6.1: Schematic diagram of Respiratory system

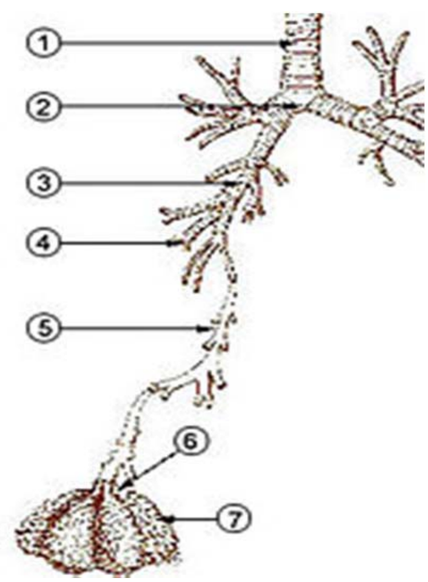


Fig.6.2: Lower respiratory tract or Respiratory tree

1. Trachea
2. Mainstem bronchus

3. .Lobar bronchus

4. Segmental bronchus

5. Bronchiole

6. Alveolar duct

7. Alveolus

The branching airways of the lower tract are often described as the respiratory tree or tracheobronchial tree (Fig. 6.2). The intervals between successive branch points along the various branches of "tree" are often referred to as branching "generations", of which there are, in the adult human about 23. The earlier generations (approximately generations 0–16), consisting of the trachea and the bronchi, as well as the larger bronchioles which simply act as air conduits, bringing air to the respiratory bronchioles, alveolar ducts and alveoli (approximately generations 17–23), where gas exchange takes place. Bronchioles are defined as the small airways lacking any cartilaginous support.

The first bronchi to branch from the trachea are the right and left main bronchi. Second only in diameter to the trachea (1.8 cm), these bronchi (1 -1.4 cm in diameter) enter the lungs at each phylum, where they branch into narrower secondary bronchi known as lobar bronchi, and these branch into narrower tertiary bronchi known as segmental bronchi. Further divisions of the segmental bronchi (1 to 6 mm in diameter) are known as 4th order, 5th order, and 6th order segmental bronchi, or grouped together as sub segmental bronchi. Compared to them, on an average, 23 numbers of branchings of the respiratory tree in the adult human, the mouse has only about 13 such branching.

The alveoli are the dead end terminals of the "tree", meaning that any air that enters them has to exit via the same route. A system such as this creates dead space, a volume of air (about 150 ml in the adult human) that fills the airways after exhalation and is breathed back into the alveoli before environmental air reaches them. At the end of inhalation the airways are filled with environmental air, which is exhaled without coming in contact with the gas exchanger.

6.3. Respiratory volumes

The lungs expand and contract during the breathing cycle, drawing air in and out of the lungs. The volume of air moved in or out of the lungs under normal resting circumstances (the resting tidal volume of about 500 ml), and volumes moved during maximally forced inhalation and maximally forced exhalation are measured in humans by spirometry. A typical adult human spirogram with the names given to the various excursions in volume the lungs can undergo is illustrated below (Fig. 6.3):

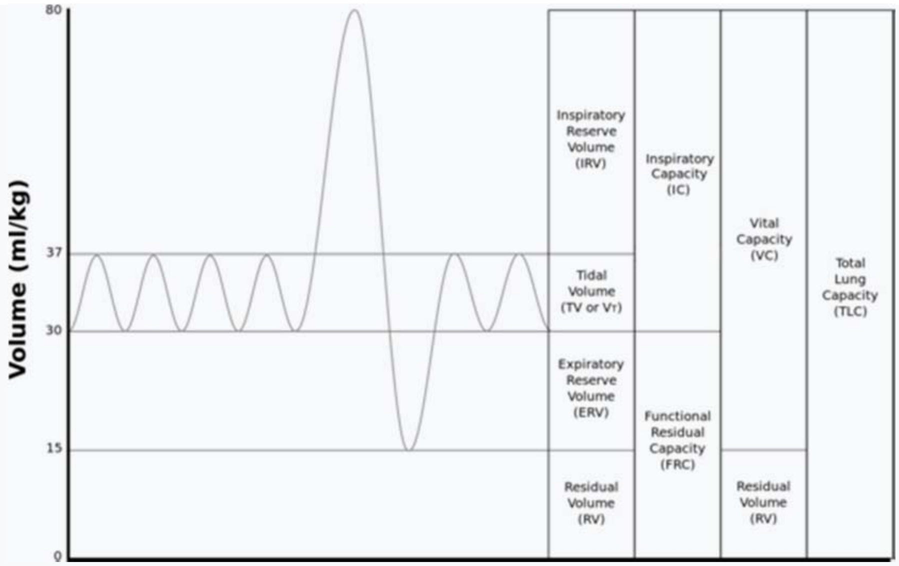


Fig. 6.3 Output of a 'spirometer'. Upward movement of the graph, read from the left, indicates the intake of air; downward movements represent exhalation.

Not all the air in the lungs can be expelled during maximally forced exhalation. This is the residual volume of about 1.0-1.5 liters which cannot be measured by spirometry. Volumes that include the residual volume (i.e. functional residual capacity of about 2.5-3.0 liters, and total lung capacity of about 6 liters) can therefore also not be measured by spirometry. Their measurement requires special techniques.

The rates at which air is breathed in or out, either through the mouth or nose, or into or out of the alveoli are tabulated below, together with how they are calculated. The number of breath cycles per minute is known as the respiratory rate.

Table:6. 1: Measurement ventilation

Measurement	Equation	Description
Minute ventilation	tidal volume * respiratory rate	the total volume of air entering, or leaving, the nose or mouth per minute.
Alveolar ventilation	(tidal volume – dead space) * respiratory rate	the volume of air entering or leaving the alveoli per minute.
Dead space ventilation	dead space * respiratory rate	the volume of air that does not reach the alveoli during inhalation, but instead remains in the airways, per minute.

6.4. Mechanics of breathing

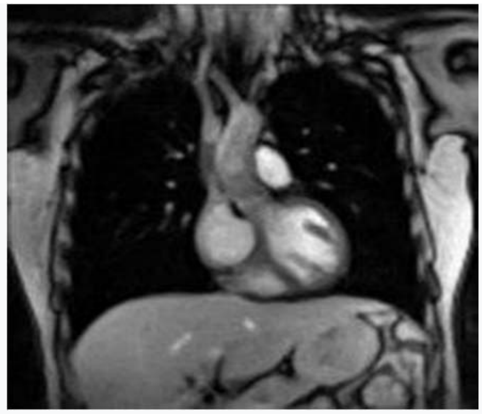


Fig. 6.4: Real-time magnetic resonance imaging (MRI) of the chest movements of human thorax during breathing. The "pumps handle" and "bucket handle movements" of the ribs

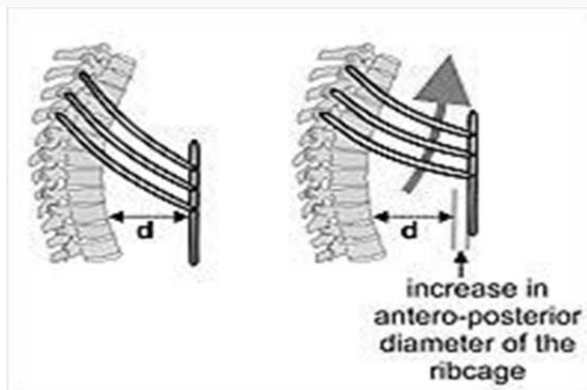


Fig. 6.5: The effect of the muscles of inhalation in expanding the rib cage. The particular action illustrated here is called the pump handle movement of the rib cage.

Fig.6.6: *In this figure view of the rib cage the downward slope of the lower ribs from the midline outwards is seen. This allows a movement similar to the "pump handle effect", but in this case it is called the bucket handle movement. The color of the ribs refers to their classification, and is not relevant here.*

Breathing

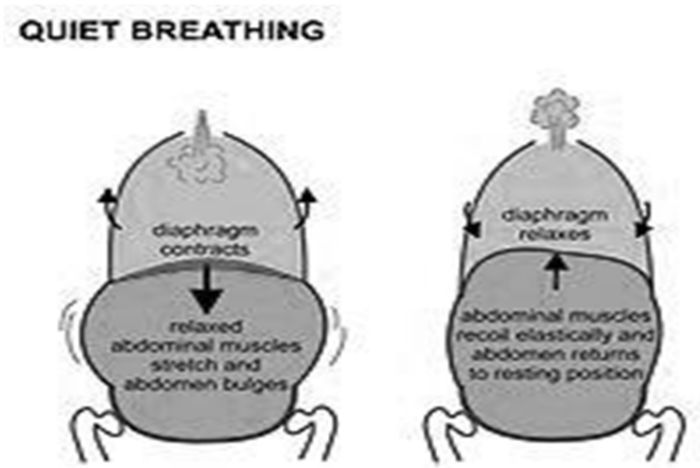


Fig.6.7: *The muscles of breathing at rest: inhalation on the left, exhalation on the right. Contracting muscles are shown in red; relaxed muscles in blue. Contraction of the diaphragm generally contributes the most to the expansion of the chest cavity (light blue). However, at the same time, the intercostal muscles pull the ribs upwards (their effect is indicated by arrows) also causing the rib cage to expand during inhalation (see diagram on other side of the page). The relaxations of all these muscles during exhalation cause the rib cage and abdomen (light green) to elastically return to their resting positions.*

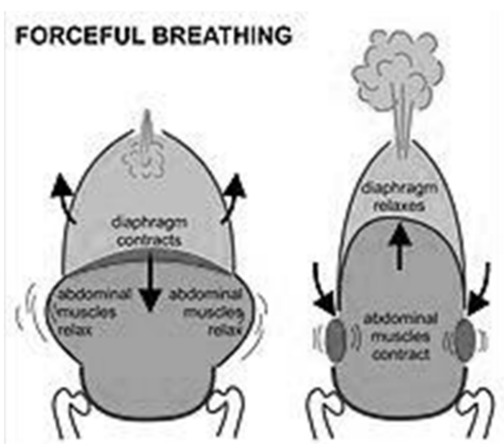


Fig.6.8: *The muscles of forceful breathing (inhalation and exhalation). The color code is the same as on the left. In addition to a more forceful and extensive contraction of the diaphragm, the intercostal muscles are aided by the accessory muscles of inhalation to exaggerate the movement of the ribs upwards, causing a greater expansion of the rib cage. During exhalation, apart from the relaxation of the muscles of inhalation, the abdominal muscles actively contract to pull the lower edges of the rib cage downwards decreasing the volume of the rib cage, while at the same time pushing the diaphragm upwards deep into the thorax.*

In mammals, inhalation at rest is primarily due to the contraction of the diaphragm. This is an upwardly domed sheet of muscle that separates the thoracic cavity from the abdominal cavity. When it contracts the sheet flattens, (i.e. moves downwards as shown in Fig. 7) increasing the volume of the thoracic cavity. The contracting diaphragm pushes the abdominal organs downwards. But because the pelvic floor prevents the lowermost abdominal organs moving in that direction, the pliable abdominal contents cause the belly to bulge outwards to the front and sides, because the relaxed abdominal muscles do not resist this movement (Fig. 7). This entirely passive bulging (and shrinking during exhalation) of the abdomen during normal breathing is sometimes referred to as "abdominal breathing", although it is, in fact, "diaphragmatic breathing", which is not visible on the outside of the body. Mammals only use their abdominal muscles only during forceful exhalation (please see Fig. 8, and text below) but never during any form of inhalation.

As the diaphragm contracts, the rib cage is simultaneously enlarged by the ribs being pulled upwards by the intercostal muscles as shown in Fig. 4. All the ribs slant downwards from the rear to the front (as shown in Fig. 4); but the lowermost ribs *also* slant downwards from the midline outwards (Fig. 5). Thus the rib cage's transverse diameter can be increased in the same way as the antero-posterior diameter is increase by the so-called pump handle movement shown in Fig. 4.

The enlargement of the thoracic cavity's vertical dimension by the contraction of the diaphragm, and its two horizontal dimensions by the lifting of the front and sides of the ribs, causes the intra thoracic pressure to fall. The lungs' interiors are open to the outside air, and being elastic, therefore expand to fill the increased space. The inflow of air into the lungs occurs via the respiratory airways (Fig. 2). In health these airways (starting at the nose or mouth, and ending in the microscopic dead-end sacs called alveoli) are always open, though the diameters of the various sections can be changed by the sympathetic and parasympathetic nervous systems. The alveolar air pressure is therefore always close to atmospheric air pressure (about 100 kPa at sea level) at rest, with the pressure gradients that cause air to move in and out of the lungs during breathing rarely exceeding 2–3 kPa.

During exhalation the diaphragm and intercostal muscles relax. This returns the chest and abdomen to a position determined by their anatomical elasticity. This is the "resting mid-position" of the thorax and abdomen (Fig. 7) when lungs contain their functional residual capacity of air (the light blue area in the right hand illustration of Fig. 7), which in the adult human has a volume of about 2.5–3.0 liters (Fig. 3). Resting exhalation lasts about twice as long as inhalation because the diaphragm relaxes passively more gently than it contracts actively during inhalation.

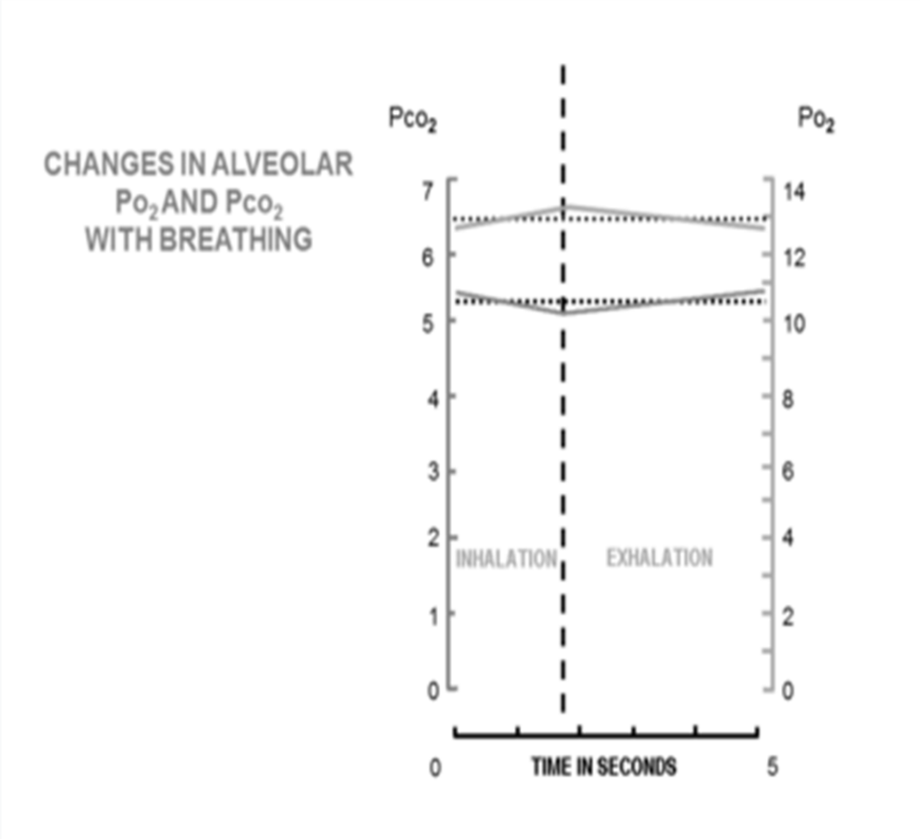


Fig.6.9: *Changes in the composition of the alveolar air during a normal breathing cycle at rest. The scale on the left, and the blue line, indicate the partial pressures of carbon dioxide in kPa, while that on the right and the red line, indicate the partial pressures of oxygen, also in kPa (to convert kPa into mm Hg, multiply by 7.5).*

The volume of air that moves in *or* out (at the nose or mouth) during a single breathing cycle is called the tidal volume. In a resting adult human it is about 500 ml per breath. At the end of exhalation the airways contain about 150 ml of alveolar air which is the first air that is breathed back into the alveoli during inhalation. This volume air that is breathed out of the alveoli and back in again is known as dead space ventilation, which has the consequence that of the 500 ml breathed into the alveoli with each breath only 350 ml (500 ml - 150 ml = 350 ml) is fresh warm and moistened air. Since this 350 ml of fresh air is thoroughly mixed and diluted by the air that remains in the alveoli after normal exhalation (i.e. the functional residual capacity of about 2.5–3.0 liters), it is clear that the composition of the alveolar air changes very little during the breathing cycle (see Fig. 9). The oxygen tension (or partial pressure) remains close to 13-14 kPa (about 100 mm Hg), and that of carbon dioxide very close to 5.3 kPa (or 40 mm Hg). This contrasts with composition of the dry outside air at sea level, where the partial pressure of oxygen is 21 kPa (or 160 mm Hg) and that of carbon dioxide 0.04 kPa (or 0.3 mmHg).

During heavy breathing (hyperpnea), as, for instance, during exercise, inhalation is brought about by a more powerful and greater excursion of the contracting diaphragm than at rest (Fig. 8). In addition the "accessory muscles of inhalation" exaggerate the actions of the intercostal muscles (Fig. 8). These accessory muscles of inhalation are muscles that extend from the cervical vertebrae and base of the skull to the upper ribs and sternum, sometimes through an intermediary attachment to the clavicles. When they contract the rib cage's internal volume is increased to a far greater extent than can be achieved by contraction of the intercostal muscles alone. Seen from outside the body the lifting of the clavicles during strenuous or labored inhalation is sometimes called clavicular breathing, seen especially during asthma attacks and in people with chronic obstructive pulmonary disease.

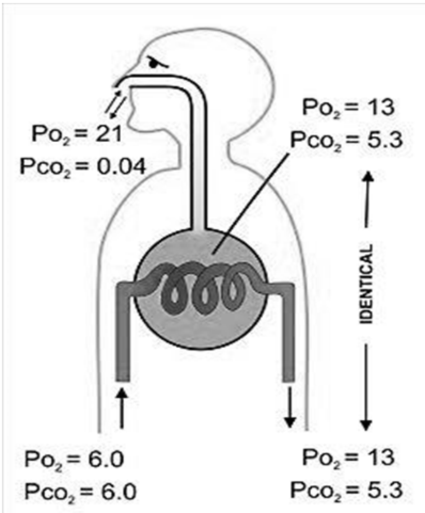
During heavy breathing, exhalation is caused by relaxation of all the muscles of inhalation. But now, the abdominal muscles, instead of remaining relaxed (as they do at rest), contract forcibly pulling the lower edges of the rib cage downwards (front and sides) (Fig. 8). This not only drastically decreases the size of the rib cage, but also pushes the abdominal organs upwards against the diaphragm which consequently bulges deeply into the thorax (Fig. 8). The end-exhalatory lung volume is now well below the resting mid-position and contains far less air than the resting "functional residual capacity". However, in a normal mammal, the lungs cannot be emptied completely. In an adult human there is always still at least 1 liter of residual air left in the lungs after maximum exhalation.

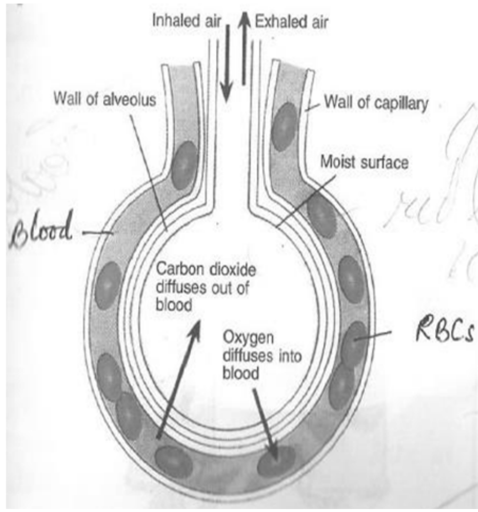
The automatic rhythmical breathing in and out, can be interrupted by coughing, sneezing (forms of very forceful exhalation), by the expression of a wide range of emotions (laughing, sighing, crying out in pain, exasperated intakes of breath) and by such voluntary acts as speech, singing, whistling and the playing of wind instruments. All of these actions rely on the muscles described above, and their effects on the movement of air in and out of the lungs.

Although not a form of breathing, the Valsalva maneuver involves the respiratory muscles. It is, in fact, a very forceful exhalatory effort against a tightly closed glottis, so that no air can escape from the lungs. Instead abdominal contents are evacuated in the opposite direction, through orifices in the pelvic floor. The abdominal muscles contract very powerfully, causing the pressure inside the abdomen and thorax to rise to extremely high levels. The Valsalva maneuver can be carried out voluntarily, but is more generally a reflex elicited when attempting to empty the abdomen during, for instance, difficult defecation, or during childbirth. Breathing ceases during this maneuver.

6.4.1. Gas exchange

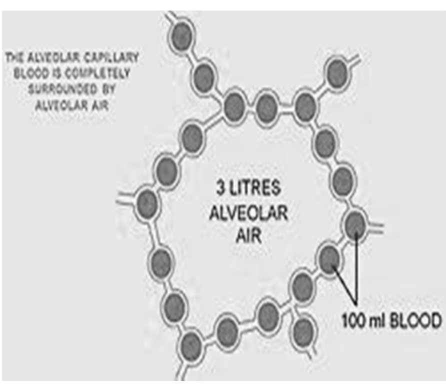
Mechanism of gas exchange





6.10: Diagrammatic sketch

The process of gas exchange in the mammalian lungs, emphasizing the differences between the gas compositions of the ambient air, the alveolar air (light blue) with which the pulmonary capillary blood equilibrates, and the blood gas tensions in the pulmonary arterial (blue blood entering the lung on the left) and venous blood (red blood leaving the lung on the right). All the gas tensions are in kPa. To convert to mm Hg, multiply by 7.5.



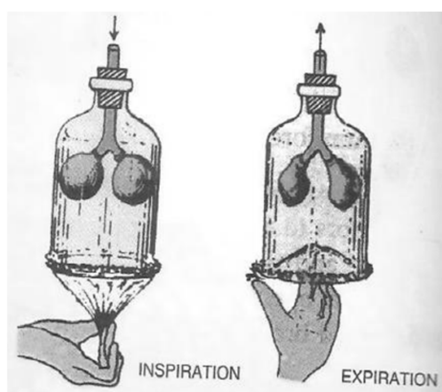
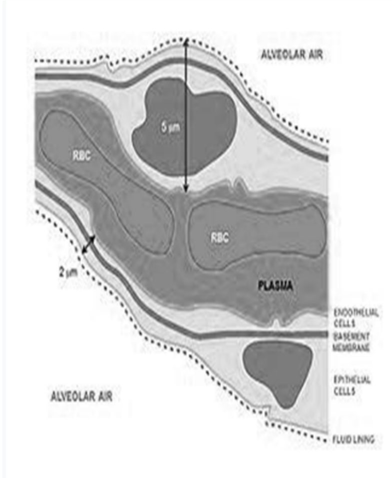


Fig.6.11: *A diagrammatic histological cross-section through a portion of lung tissue showing a normally inflated alveolus (at the end of a normal exhalation), and its walls containing the pulmonary capillaries (shown in cross-section). This illustrates how the pulmonary capillary blood is completely surrounded by alveolar air. In a normal human lung all the alveoli together contain about 3 liters of alveolar air. All the pulmonary capillaries contain about 100 ml blood.*



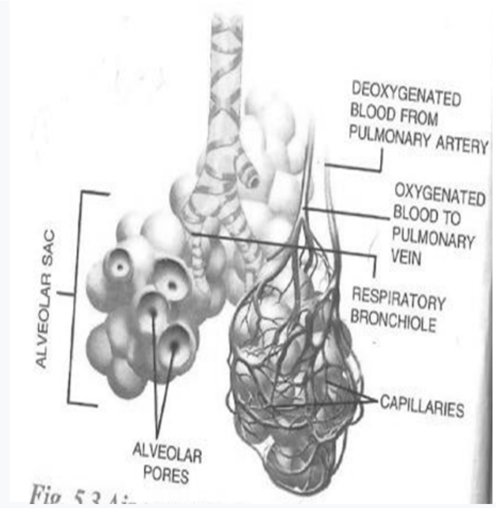


Fig.6.12: *A histological cross-section through an alveolar wall showing the layers through which the gases have to move between the blood plasma and the alveolar air. The dark blue objects are the nuclei of the capillary endothelial and alveolar type I epithelial cells (or type 1 pneumocytes). The two red objects labeled "RBC" are red blood cells in the pulmonary capillary blood.*

The primary purpose of the respiratory system is the equilibration of the partial pressures of the respiratory gases in the alveolar air with those in the pulmonary capillary blood (Fig. 11). This process occurs by simple diffusion, across a very thin membrane (known as the blood–air barrier), which forms the walls of the pulmonary alveoli (Fig. 10). It consists of the alveolar epithelial cells, their basement membranes and the endothelial cells of the alveolar capillaries (Fig. 10). This blood gas barrier is extremely thin (in humans, on average, 2.2 µm thick). It is folded into about 300 million small air sacs called alveoli (each between 75 and 300 µm in diameter) branching off from the respiratory bronchioles in the lungs, thus providing an extremely large surface area (approximately 145 m^2) for gas exchange to occur.

The air contained within the alveoli has a semi-permanent volume of about 2.5-3.0 liters which completely surrounds the alveolar capillary blood (Fig. 12). This ensures that equilibration of the partial pressures of the gases in the two compartments is very efficient and occurs very quickly. The blood leaving the alveolar capillaries and is eventually distributed throughout the body therefore has a partial pressure of oxygen of 13-14 kPa (100 mmHg), and a partial pressure of carbon dioxide of 5.3 kPa (40 mmHg) (i.e. the same as the oxygen and carbon dioxide gas tensions as in the alveoli). As mentioned in the section above, the corresponding partial pressures of oxygen and carbon dioxide in the ambient (dry) air at sea level are 21 kPa (160 mmHg) and 0.04 kPa (0.3 mmHg) respectively.

This marked difference between the composition of the alveolar air and that of the ambient air can be maintained because the functional residual capacity is contained in dead-end sacs connected to the outside air by fairly narrow and relatively long tubes (the airways: nose, pharynx, larynx, trachea, bronchi and their branches down to the bronchioles), through which the air has to be breathed both in and out (i.e. there is no unidirectional through-flow as there is in the bird lung). This typical mammalian anatomy combined with the fact that the lungs are not emptied and re-inflated with each breath (leaving a substantial volume of air, of about 2.5-3.0 liters, in the alveoli after exhalation), ensures that the composition of the alveolar air is only minimally disturbed when the 350 ml of fresh air is mixed into it with each inhalation. Thus the animal is provided with a very special "portable atmosphere", whose composition differs significantly from the present-day ambient air. It is this portable atmosphere (the functional residual capacity) to which the blood and therefore the body tissues are exposed – not to the outside air.

The resulting arterial partial pressures of oxygen and carbon dioxide are homeostatically controlled. A rise in the arterial partial pressure of CO_2 and, to a lesser extent, a fall in the arterial partial pressure of O_2, will by reflex cause deeper and faster breathing till the blood gas tensions in the lungs, and therefore the arterial blood, return to normal. The converse happens when the carbon dioxide tension falls, or, again to a lesser extent, the oxygen tension rises: the rate and depth of breathing are reduced till blood gas normality is restored.

Since the blood arriving in the alveolar capillaries has a partial pressure of O_2 of, on average, 6 kPa (45 mmHg), while the pressure in the alveolar air is 13-14 kPa (100 mmHg), there will be a net diffusion of oxygen into the capillary blood, changing the composition of the 3 liters of alveolar air slightly. Similarly, since the blood arriving in the alveolar capillaries has a partial pressure of CO_2 of also about 6 kPa (45 mmHg), whereas that of the alveolar air is 5.3 kPa (40 mmHg), there is a net movement of carbon dioxide out of the capillaries into the alveoli. The changes brought about by these net flows of individual gases into and out of the alveolar air necessitate the replacement of about 15% of the alveolar air with ambient air every 5 seconds or so. This is very tightly controlled by the monitoring of the arterial blood gases (which accurately reflect composition of the alveolar air) by the aortic and carotid bodies, as well as by the blood gas and pH sensor on the anterior surface of the medulla oblongata in the brain. There are also oxygen and carbon dioxide sensors in the lungs, but they primarily determine the diameters of the bronchioles and pulmonary capillaries, and are therefore responsible for directing the flow of air and blood to different parts of the lungs.

It is only as a result of accurately maintaining the composition of the 3 liters of alveolar air that with each breath some carbon dioxide is discharged into the atmosphere and some oxygen is taken up from the outside air. If more carbon dioxide than usual has been lost by a short period of hyperventilation, respiration will be slowed down or halted until the alveolar partial pressure of carbon dioxide has returned to 5.3 kPa (40 mmHg). It is therefore strictly speaking untrue that the primary function of the respiratory system is to rid the body of carbon dioxide "waste". The carbon dioxide that is breathed out with each breath could probably be more correctly be seen as a byproduct of the body's extracellular fluid carbon dioxide and pH homeostats

If these homeostats are compromised, then either a respiratory acidosis, or a respiratory alkalosis will occur. In the long run these can be compensated by renal adjustments to the H^+ and HCO_3^- concentrations in the plasma; but since this takes time, the hyperventilation syndrome can, for instance, occur when agitation or anxiety cause a person to breathe fast and deeply thus causing a distressing respiratory alkalosis through the blowing off of too much CO_2 from the blood into the outside air.

Oxygen has a very low solubility in water, and is therefore carried in the blood loosely combined with hemoglobin. The oxygen is held on the hemoglobin by four ferrous iron-containing heme groups per hemoglobin molecule. When all the heme groups carry one O_2 molecule each the blood is said to be "saturated" with oxygen, and no further increase in the partial pressure of oxygen will meaningfully increase the oxygen concentration of the blood. Most of the carbon dioxide in the blood is carried as bicarbonate ions (HCO_3^-) in the plasma. However the conversion of dissolved CO_2 into HCO_3^- (through the addition of water) is too slow for the rate at which the blood circulates through the tissues on the one hand, and through alveolar capillaries on the other. The reaction is therefore catalyzed by carbonic anhydrase, an enzyme inside the red blood cells.

The reaction can go in both directions depending on the prevailing partial pressure of CO_2. A small amount of carbon dioxide is carried on the protein portion of the hemoglobin molecules as carbamino groups. The total concentration of carbon dioxide (in the form of bicarbonate ions, dissolved CO_2, and carbamino groups) in arterial blood (i.e. after it has equilibrated with the alveolar air) is about 26 mM (or 58 ml/100 ml) as compared to the concentration of oxygen in saturated arterial blood of about 9 mM (or 20 ml/100 ml blood).

6.4.2. Control of ventilation

Ventilation of the lungs in mammals occurs via the respiratory centers in the medulla oblongata and the pons of the brainstem. These areas form a series of neural pathways which receive information about the partial pressures of oxygen and carbon dioxide in the arterial blood. This information determines the average rate of ventilation of the alveoli of the lungs, to keep these pressures constant. The respiratory center does so via motor nerves which activate the diaphragm and other muscles of respiration.

The breathing rate increases when the partial pressure of carbon dioxide in the blood increases. This is detected by central blood gas chemoreceptors on the anterior surface of the medulla oblongata. The aortic and carotid bodies, are the peripheral blood gas chemoreceptors which are particularly sensitive to the arterial partial pressure of O_2 though they also respond, but less strongly, to the partial pressure of CO_2. At sea level, under normal circumstances, the breathing rate and depth, is determined primarily by the arterial partial pressure of carbon dioxide rather than by the arterial partial pressure of oxygen, which is allowed to vary within a fairly wide range before the respiratory centers in the medulla oblongata and pons respond to it to change the rate and depth of breathing.

Exercise increases the breathing rate (tachypnoea) due to the extra carbon dioxide produced by the enhanced metabolism of the exercising muscles. In addition passive movements of the limbs also reflexively produce an increase in the breathing rate.

Information received from stretch receptors in the lungs limits tidal volume (the depth of inhalation and exhalation).

6.4.3. Responses to low atmospheric pressures

The alveoli are open (via the airways) to the atmosphere, with the result that alveolar air pressure is exactly the same as the ambient air pressure at sea level, at altitude, or in any artificial atmosphere (e.g. a diving chamber, or decompression chamber) in which the individual is breathing freely. With expansion of the lungs (through lowering of the diaphragm and expansion of the thoracic cage) the alveolar air now occupies a larger volume, and its pressure falls proportionally, causing air to flow in from the surroundings, through the airways, till the pressure in the alveoli is once again at the ambient air pressure. The reverse obviously happens during exhalation. This *process* (of inhalation and exhalation) is exactly the same at sea level, as on top of Mt. Everest, or in a diving chamber or decompression chamber.

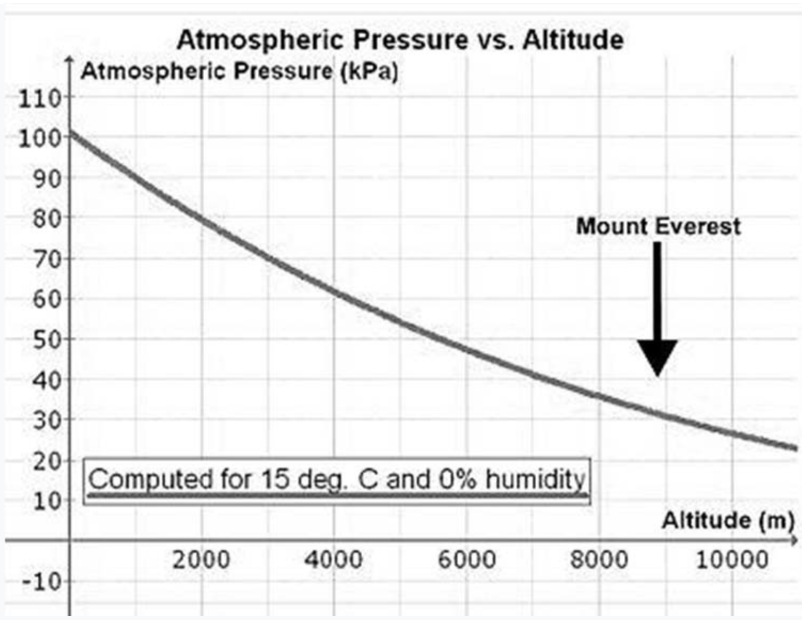


Fig6.13: Graph showing the relationship between total atmospheric pressure and altitude above sea level.

However, as one rises above sea level the density of the air decreases exponentially (see Fig. 13), halving approximately with every 5500 m rise in altitude.[24] Since the composition of the atmospheric air is almost constant below 80 km, as a result of the continuous mixing effect of the weather, the concentration of oxygen in the air (mmols O_2 per liter of ambient air) decreases at the same rate as the fall in air pressure with altitude. Therefore, in order to breathe in the same amount of oxygen per minute, the person has to inhale a proportionately greater volume of air per minute at altitude than at sea level. This is achieved by breathing deeper and faster (i.e. hyperpnea) than at sea level (see below).

There is, however, a complication that increases the volume of air that needs to be inhaled per minute (respiratory minute volume) to provide the same amount of oxygen to the lungs at altitude as at sea level. During inhalation the air is warmed and saturated with water vapor during its passage through the nose passages and pharynx. Saturated water vapor pressure is dependent only on temperature. At a body core temperature of 37 °C it is 6.3 kPa (47.0 mmHg), irrespective of any other influences, including altitude.[26] Thus at sea level, where the ambient atmospheric pressure is about 100 kPa, the moistened air that flows into the lungs from the trachea consists of water vapor (6.3 kPa), nitrogen (74.0 kPa), oxygen (19.7 kPa) and trace amounts of carbon dioxide and other gases (a total of 100 kPa). In dry air the partial pressure of O_2 at sea level is 21.0 kPa (i.e. 21% of 100 kPa), compared to the 19.7 kPa of oxygen entering the alveolar air. (The tracheal partial pressure of oxygen is 21% of [100 kPa – 6.3 kPa] = 19.7 kPa). At the summit of Mt. Everest (at an altitude of 8,848 m or 29,029 ft) the total atmospheric pressure is 33.7 kPa, of which 7.1 kPa (or 21%) is oxygen. The air entering the lungs also has a total pressure of 33.7 kPa, of which 6.3 kPa is, unavoidably, water vapor (as it is at sea level). This reduces the partial pressure of oxygen entering the alveoli to 5.8 kPa (or 21% of [33.7 kPa – 6.3 kPa] = 5.8 kPa). The reduction in the partial pressure of oxygen in the inhaled air is therefore substantially greater than the reduction of the total atmospheric pressure at altitude would suggest (on Mt Everest: 5.8 kPa *vs.* 7.1 kPa).

A further minor complication exists at altitude. If the volume of the lungs were to be instantaneously doubled at the beginning of inhalation, the air pressure inside the lungs would be halved. This happens regardless of altitude. Thus, halving of the sea level air pressure (100 kPa) results in an intrapulmonary air pressure of 50 kPa. Doing the same at 5500 m, where the atmospheric pressure is only 50 kPa, the intrapulmonary air pressure falls to 25 kPa. Therefore, the same change in lung volume at sea level results in a 50 kPa difference in pressure between the ambient air and the intrapulmonary air, whereas it result in a difference of only 25 kPa at 5500 m. The driving pressure forcing air into the lungs during inhalation is therefore halved at this altitude. The *rate* of inflow of air into the lungs during inhalation at sea level is therefore twice that which occurs at 5500 m. However, in reality, inhalation and exhalation occur far more gently and less abruptly than in the example given. The differences between the atmospheric and intrapulmonary pressures, driving air in and out of the lungs during the breathing cycle, are in the region of only 2–3 kPa. A doubling or more of these small pressure differences could be achieved only by very major changes in the breathing effort at high altitudes.

All of the above influences of low atmospheric pressures on breathing are accommodated primarily by breathing deeper and faster (hyperpnea). The exact degree of hyperpnea is determined by the blood gas homeostat, which regulates the partial pressures of oxygen and carbon dioxide in the arterial blood. This homeostat prioritizes the regulation of the arterial partial pressure of carbon dioxide over that of oxygen at sea level. That is to say, at sea level the arterial partial pressure of CO_2 is maintained at very close to 5.3 kPa (or 40 mmHg) under a wide range of circumstances, at the expense of the arterial partial pressure of O_2, which is allowed to vary within a very wide range of values, before eliciting a corrective ventilatory response. However, when the atmospheric pressure (and therefore the partial pressure of O_2 in the ambient air) falls to below 50-75% of its value at sea level, oxygen homeostasis is given priority over carbon dioxide homeostasis.[6] This switch-over occurs at an elevation of about 2500 m (or about 8000 ft). If this switch occurs relatively abruptly, the hyperpnea at high altitude will cause a severe fall in the arterial partial pressure of carbon dioxide, with a consequent rise in the pH of the arterial plasma. This is one contributor to high altitude sickness. On the other hand, if the switch to oxygen homeostasis is incomplete, then hypoxia may complicate the clinical picture with potentially fatal results.

There are oxygen sensors in the smaller bronchi and bronchioles. In response to low partial pressures of oxygen in the inhaled air these sensors reflexively cause the pulmonary arterioles to constrict. (This is the exactly opposite of the corresponding reflex in the tissues, where low arterial partial pressures of O_2 cause arteriolar vasodilation.) At altitude this causes the pulmonary arterial pressure to rise resulting in a much more even distribution of blood flow to the lungs than occurs at sea level. At sea level the pulmonary arterial pressure is very low, with the result that the tops of the lungs receive far less blood than the bases, which are relatively over-perfused with blood. It is only in the middle of the lungs that the blood and air flow to the alveoli are ideally matched. At altitude this variation in the ventilation/perfusion ratio of alveoli from the tops of the lungs to the bottoms is eliminated, with all the alveoli perfused and ventilated in more or less the physiologically ideal manner. This is a further important contributor to the acclimatization to high altitudes and low oxygen pressures.

The kidneys measure the oxygen *content* (mmol O_2/liter blood, rather than the partial pressure of O_2) of the arterial blood. When the oxygen content of the blood is chronically low, as at high altitude, the oxygen-sensitive kidney cells secrete erythropoietin (often known only by its abbreviated form as *EPO*) into the blood. This hormone stimulates the red bone marrow to increase its rate of red cell production, which leads to an increase in the hematocrit of the blood, and a consequent increase in its oxygen carrying capacity (due to the now high hemoglobin content of the blood). In other words, at the same arterial partial pressure of O_2, a person with a high hematocrit carries more oxygen per liter of blood than a person with a lower hematocrit does. High altitude dwellers therefore have higher hematocrits than sea-level residents.

6.4.4. Other functions of the lungs

- **Local defenses**

Irritation of nerve endings within the nasal passages or airways, can induce a cough reflex and sneezing. These responses cause air to be expelled forcefully from the trachea or nose, respectively. In this manner, irritants caught in the mucus which lines the respiratory tract are expelled or moved to the mouth where they can be swallowed. During coughing, contraction of the smooth muscle in the airway walls narrows the trachea by pulling the ends of the cartilage plates together and by pushing soft tissue into the lumen. This increases the expired airflow rate to dislodge and remove any irritant particle or mucus.

Respiratory epithelium can secrete a variety of molecules that aid in the defense of the lungs. These include secretory immunoglobulins (IgA), collectins, defensins and other peptides and proteases, reactive oxygen species, and reactive nitrogen species. These secretions can act directly as antimicrobials to help keep the airway free of infection. A variety of chemokines and cytokines are also secreted that recruit the traditional immune cells and others to the site of infections.

Surfactant immune function is primarily attributed to two proteins: SP-A and SP-D. These proteins can bind to sugars on the surface of pathogens and thereby opsonize them for uptake by phagocytes. It also regulates inflammatory responses and interacts with the adaptive immune response. Surfactant degradation or inactivation may contribute to enhanced susceptibility to lung inflammation and infection.[31]

Most of the respiratory system is lined with mucous membranes that contain mucosa-associated lymphoid tissue, which produces white blood cells such as lymphocytes.

- **Prevention of alveolar collapse by Pulmonary surfactants**

The lungs make a surfactant, a surface-active lipoprotein complex (phospholipoprotein) formed by type II alveolar cells. It floats on the surface of the thin watery layer which lines the insides of the alveoli, reducing the water's surface tension.

The surface tension of a watery surface (the water-air interface) tends to make that surface shrink. When that surface is curved as it is in the alveoli of the lungs, the shrinkage of the surface decreases the diameter of the alveoli. The more acute the curvature of the water-air interface the greater the tendency for the alveolus to collapse.[6] This has three effects. Firstly the surface tension inside the alveoli resists expansion of the alveoli during inhalation (i.e. it makes the lung stiff, or non-compliant). Surfactant reduces the surface tension and therefore makes the lungs more compliant, or less stiff, than if it were not there. Secondly, the diameters of the alveoli increase and decrease during the breathing cycle. This means that the alveoli have a greater tendency to collapse (i.e. cause atelectasis) at the end of exhalation that at the end of inhalation. Since surfactant floats on the watery surface, its molecules are more tightly packed together when the alveoli shrink during exhalation. This causes them to have a greater surface tension-lowering effect when the alveoli are small than when they are large (as at the end of inhalation, when the surfactant molecules are more widely spaced). The tendency for the alveoli to collapse is therefore almost the same at the end of exhalation as at the end of inhalation. Thirdly, the surface tension of the curved watery layer lining the alveoli tends to draw water from the lung tissues into the alveoli. Surfactant reduces this danger to negligible levels, and keeps the alveoli dry.

Pre-term babies who are unable to manufacture surfactant have lungs that tend to collapse each time they breathe out. Unless treated, this condition, called respiratory distress syndrome, is fatal. Basic scientific experiments, carried out using cells from chicken lungs, support the potential for using steroids as a means of furthering development of type II alveolar cells. In fact, once a premature birth is threatened, every effort is made to delay the birth, and a series of steroid injections is frequently administered to the mother during this delay in an effort to promote lung maturation.

- **Contributions to whole body functions with hormones**

The lung vessels contain a fibrinolytic system that dissolves clots that may have arrived in the pulmonary circulation by embolism, often from the deep veins in the legs. They also release a variety of substances that enter the systemic arterial blood, and they remove other substances from the systemic venous blood that reach them via the pulmonary artery. Some prostaglandins are removed from the circulation, while others are synthesized in the lungs and released into the blood when lung tissue is stretched.

The lungs activate one hormone. The physiologically inactive decapeptide angiotensin I is converted to the aldosterone-releasing octapeptide, angiotensin II, in the pulmonary circulation. The reaction occurs in other tissues as well, but it is particularly prominent in the lungs. Angiotensin II also has a direct effect on arteriolar walls, causing arteriolar vasoconstriction, and consequently a rise in arterial blood pressure. Large amounts of the angiotensin-converting enzyme responsible for this activation are located on the surfaces of the endothelial cells of the alveolar capillaries. The converting enzyme also inactivates bradykinin. Circulation time through the alveolar capillaries is less than one second, yet 70% of the angiotensin I reaching the lungs is converted to angiotensin II in a single trip through the capillaries. Four other peptidases have been identified on the surface of the pulmonary endothelial cells.

- **Vocalization**

The movement of gas through the larynx, pharynx and mouth allows humans to speak, or *phonate*. Vocalization, or singing, in birds occurs via the syrinx, an organ located at the base of the trachea. The vibration of air flowing across the larynx (vocal cords), in humans, and the syrinx, in birds, results in sound. Because of this, gas movement is vital for communication purposes.

- **Temperature control**

Panting in dogs, cats, birds and some other animals provides a means of reducing body temperature, by evaporating saliva in the mouth (instead of evaporating sweat on the skin).

6.5. Respiratory disorders

Disorders of the respiratory system can be classified into several general groups:

- Airway obstructive conditions (e.g., emphysema, bronchitis, asthma)
- Pulmonary restrictive conditions (e.g., fibrosis, sarcoidosis, alveolar damage, pleural effusion)
- Vascular diseases (e.g., pulmonary edema, pulmonary embolism, pulmonary hypertension)
- Infectious, environmental and other "diseases" (e.g., pneumonia, tuberculosis, asbestosis, particulate pollutants)
- Primary cancers (e.g. bronchial carcinoma, mesothelioma)
- Secondary cancers (e.g. cancers that originated elsewhere in the body, but have seeded themselves in the lungs)
- Insufficient surfactant (e.g. respiratory distress syndrome in pre-term babies).
- Difficulty in breathing-Dyspnoea.

Disorders of the respiratory system are usually treated by a pulmonologist and respiratory therapist. Where there is an inability to breathe or an insufficiency in breathing a medical ventilator may be used.

Exceptional mammal: Horses, Horses are obligate nasal breathers which means that they are different from many other mammals because they do not have the option of breathing through their mouths and must take in air through their noses.

6.6. Inspiration and expiration

Inspiration or inhalation is the process of obtaining atmospheric oxygen. In this process the diaphragm drops a little and the muscles in the rib cage move up a little. This causes the volume of the thoracic cavity to increase and the air in inhaled. Whereas during expiration or exhalation the diaphragm relaxes, and the volume of the thoracic cavity decreases, while the pressure within it increases. As a result, the lungs contract and air is forced out.

6.7. Lungs structure

The lungs are a pair of spongy, air-filled organs or sacs located on either side of the chest (thorax). Both are similar in shape and size. The trachea (windpipe) carries inhaled air into the lungs through its tubular branches, called bronchi. The bronchi then divide into smaller and smaller branches (bronchioles), finally becoming tiny microscopic tubes. Thus functional lungs are fully developed and differentiated body organ capable to carry out its basic metabolic functions.

6.8. Types of respiration

Biochemically respiration is the chemical process by which organic compounds release energy. The compounds change into different ones by exergonic reactions. There are two main types of respiration that occur in living beings as follows:

1. Aerobic, which requires oxygen and releases lots of energy.
2. Anaerobic, which does not require oxygen but releases much less energy per mole of starting material

6.9. Summary

By definition respiration is the "interchange or exchange of gases between an organism and the medium in which it lives." In the human body, we can further classify respiration by external and internal processes i.e, inhalation and exhalation .The external process of respiration involves the transfer of oxygen (O2) and carbon dioxide (CO2) that occurs in the lungs between the atmosphere and the pulmonary circulation. The internal process of respiration is the similar process that occurs at the cellular level. While both aspects of respiration are essential to life, this unit covered types of respiration and its three primary components: ventilation, perfusion and diffusion. A thorough understanding of each of these components and their potential impairments provides further understanding on the topic in a functional manner.

Physiologically the main function of the respiratory system is gaseous exchange. This gas exchange consists of obtaining O_2 from the atmosphere and removing CO_2 from the blood. It is important to consider that O_2 is necessary for normal metabolism and CO2 is a waste product of this metabolism. CO_2 is only inhaled in negligible quantity and thus the CO_2 we exhale is created within the body. While CO_2 plays a role in acid-base balance, it must be cleared from the body in appropriate levels through ventilation.

6.10. Terminal questions

Q.1. Define respiration? Further elaborate on the process of respiration in general?

Answer: ---

Q.2. Discuss the structure and function of lungs?

Answer: ---

Q.3. Write an account of respiratory homeostasis?

Answer: ---

Q.4. Elaborate on the mechanism of gaseous exchange in the alveolar sacs?

Answer: ---

Q.5. Justify the statement that 'Respiratory system is the system of systems'?

Answer: ---

Choose the correct alternative

Q.6. Oxygen and hemoglobin bind in a reversible manner to form

a. Carboxyhemoglobin

b. Oxyhemoglobin

c. Methoglobin

d. BPG

Q.7. How many oxygen molecules are required to bind to hemoglobin to give 50% saturation?

a. 6

b. 4

c. 2

d. 7

Q.8. Which of this statement is TRUE for pulmonary respiration?

a. Exchange of gases between alveoli of lungs and the blood

b. Exchange of gases between blood and tissue cells

c. Breathing between the atmosphere and the alveoli of the lungs

d. Production of ATP

Q.9. Name the process in which food is oxidized and energy in the form of ATP is released

a. Cellular respiration

b. Excretion

c. Digestion

d. Transpiration

Q.10. The front opening of the wind pipe is guarded by

a. Glottis

b. Epiglottis

c. Exoglottis

d. Trachea

Answers : b, b, c, a, b

6.11. Suggested Readings

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