Lesson 1.1

AIM AND SCOE OF COMPARATIVE PHYSIOLOGY – GENERAL FUNCTIONS AND PRINCIPLES OF PHYSIOLOGY

CONTENTS

1.1.1 INTRODUCTION

Physiology is about the functions of living organisms how they eat; breathe, and move about and what they do just to keep alive. Technically physiology is about food and feeding, digestion, respiration, transport of gasses in the blood, circulation and function of the heart, excretion and kidney functions, muscle and movements and so on. The dead animal has the structures that carryout these functions in the living animals the structures work. Physiology is also about how the living organism adjusts to the adversities of the environment obtains enough water to live or avoids two much water escapes freezing to death or dying from excessive heat moves about to find suitable surroundings food and mates and how it obtains information about the environment through its genses. Finally physiology is about the regulation of all these functions how they are corrected and integrated into a smooth functioning of organisms.

Physiology is not only a description of function; it also asks why and how? To understand how an animal functions, it is necessary to be familiar both with its structure and with some elementary physics and chemistry. For example we cannot understand respiration unless we know about oxygen. Since ancient times breathing movements have been known as a sign of life or death, but the true meaning of respiration could not be understood until chemists had discovered oxygen.

The science of physiology is the analysis of function in living organisms. Physiology is a synthesizing science which applies physical and chemical methods to biology an understanding of comparative animal physiology requires the background in general zoology, animal morphology, biochemistry and cellular physiology.

For practical purposes, physiology can be divided into three categories.

1. Cellular Physiology

Cellular or general physiology treats of those basic characteristics common to most living organisms. A vast amount of biochemical evolution occurred in protoplosm before multicellular organisms appeared, and cells are exceedingly complicated in their functional organization. In any cell yeast, muscle fibre, or leaf parenchyma – the fundamental properties of differential permeability, oxidative enzyme activity, role of nucleotides, nuclear – cytoplasmic interaction, bioelectics of excitable membranes, and may other properties are much the same. At the cellular level all organisms are more alike than they are different, and this basic similarity forms the starting point for evolutionary theory. Cellular speciation has led to some diversity of cell types and has often brought with it the loss of one function with enhancement of another. The characters treated in cellular physiology are nearly universal and are extremely stable with respect to the environment.

1.1.2 Physiology of Special Groups

The physiology of special groups of organisms teats of functional characteristics in particular kinds of plants and animals. Different kinds of animals carry out similar functions in different ways. The physiology of some animal groups has been examined in great detail. Traditionally, the basic animal physiology is human and mammalian physiology, and this science provides the rational basis for much of medicine and animal husbandry. The physiology of higher plants is important as a basis for agriculture. Insect physiology, fish physiology, and the physiology of parasites are other specialities.

Comparative environmental and behavioural physiology constitutes a bridge between molecular and organismic biology, between the reductionistic and holistic philosophies.

An important function of comparative physiology is to put man into perspective in biological history and phylogenetic relationships. Medical physiology is necessarily anthropocentric. Biological man is the result of a long history of natural selection of physiological processes. The physiology of man can sometimes be elucidated by the study of an animal in which a given function is more patent than it is in man.

Since comparative physiology uses taxonomic types – from sub-species to phyla – as experimental variables, it is important to know something of the relationships among organisms and how these evolved. In a survey of some physiological process, e.g., excitation, contraction, coupling in muscle, a knowledge of phylogeny helps in selecting appropriate animals for study and in answering questions such as whether the process arose once or repeatedly. Function in a given group of animals is clearly limited by the ancestry of the group. Physiological analyses are useful in elucidating evolutionary relationships.

The principal phyla evolved more or less simultaneously during the Cambrian; hence, currently accepted evolutionary trees are more polyphyletic and less monophyletic than former ones. There are many phyla which are not fitted with assurance into a given position, and numerous “missing links” between phyla are postulated. A useful phyletic chart is given in Figure1.

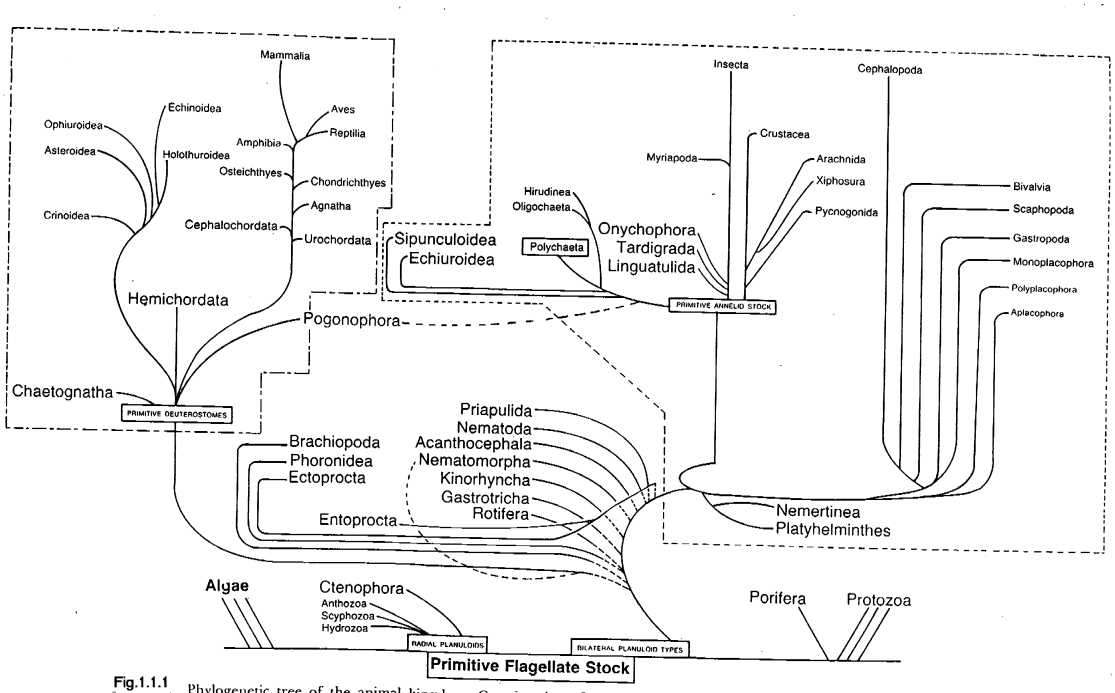

Fig.1.1.1 Phylogenetic tree of the animal kingdom. Current views favor polyphyletic origins. The coelenterates—Ctenophora and Cnidaria (Anthozoa, Scyphozoa, and Hydrozoa)—are related to one another, but are not considered as being the direct ancestors of higher animals; sponges (Porifera) also are not in a direct line. The protostome radiation arose from an extinct flatworm-like stock and consists of three branches: (i) the modern flatworms and nemertines, (ii) the Mollusca (classes shown on the right), and (iii) the annelid-arthropod lineage including various annelid-like worms. The origins and interrelationships of the several pseudocoelomate phyla, such as Rotifera and Nematoda, are uncertain. The position of some coelomate animals, such as the brachiopods, ectoprocts, and phoronids, is similarly obscure. Primitive deuterostomes arose independently, giving rise to the echinoderms and chordates. (Courtesy of M. J. Greenberg; *Syst. Zool. 22*, 1973.)

Speciation

There are several definitions of species, and no one of them can apply to all organisms, largely because of their different types of reproduction. The typological definition of species makes use of stable distinctive characters – usually morphological or protein isozymal – that are not necessarily adaptive characters, and it is most useful in classification. Classification hopefully corresponds to phylogeny, but it need not do so to be useful in its own right. Taxonomy is thus the result of phylogenetic speculation, not the evidence for phylogeny.

The characters of cellular physiology are too universal to be used in detailed classification, although some special cellular characters may distinguish large taxonomic groups. Many physiological characters are highly sensitive to the environment, and hence these are unstable taxonomically.

The second and most useful definition of a species is the biological species, the population of the animals within which there can be flow of genes. Populations which remain distinct when living together (i.e., are sympatric) are clearly different species. When two populations are spatially separated (i.e., are allopatric) there may develop isolating mechanisms which keep them reproductively separated if they come together later in geological time. The biological definition breaks down for series of populations – in clines, circles, etc. – in which the two terminal

populations are incapable of cross-breeding although each population in the series can breed with adjacent ones. In nature, many breeding populations are spatially restricted, yet hybridization between taxonomic species is more common than is sometimes recognized. Reproductive isolation may result from morphological differences, seasonal or diurnal variance in habits, chromosomal, hormonal, or behavioral differences, physiological and psychological incompatibility, and ecological separation.

The third, species concept, the physiological species, is based on two generalizations – (1) that no two species can occupy the same ecological niche at the same time throughout their life cycles, and (2) that no two species from similar niches can simultaneously occupy the same geographic range throughout corresponding stages of their life cycles. This implies that every species is uniquely adapted to its ecological niche and geographic range, and that if the functional adaptations were fully understood, an evolutionarily meaningful description of the species would be possible. Adaptation is a general term referring to any alternation or response of an organism which favors survival in a changed environment. The physiological description of species requires both field and laboratory observations, which are possible with only a few organisms. First there must be a description of physiological variation in natural populations in terms of critical characters, a statistical analysis of a capacity deemed adaptive. Second, such variation as is found must be analyzed for the genetic component and for that which is environmentally induced; this requires cross-acclimatization, transplantation, and breeding experiments. Finally, an analysis of physiological mechanisms underlying the varying characters is needed.

Criteria of physiological variation which can be used in evaluating adaptiveness of genotypes take account of all function systems and all levels of animal organization. Most of these concern environment – organism interactions. Among the most useful are measurements of functional differences between animals under environmental stress. Some of these are the following :

1. Survival tests at environmental limits, for example median lethal values for heat, cold, salinity, or oxygen supply. Survival may be measured for intact animals, for tissues, or for isolated enzymes (inactivation). In general, survival limits are widest for enzymes, narrower for tissues, and most narrow for whole organisms. Not all parts of an animal are equally subjected to functional failure, and in metazoans the nervous system is usually more sensitive than other systems. Survival limits of organisms or parts of an organism can be modified within limits by prior experience with respect to the environmental factor.

2. Environmental limits for reproduction. Embryos are often more sensitive to stresses than adults, yet completion of full life cycles is essential. Too few physiological studies have been made on early stages in life histories.

3. Some animals change internally to conform to the environment, for example, poikilotherms in varying temperature. Other animals maintain relative internal constancy in a changing environment; that is, they regulate (e.g., homeotherms). Measurements of conformity and regulation can be made for all the physical factors of the environment. In general, conformers tolerate wide internal variation but narrow environmental limits, whereas regulators tolerate only narrow internal variation but a wider environmental

range. Acclimation can shift the tolerated internal limits for a conformer; in a regulator it can change the critical limits for either activation or failure of homeostatic controls. Both patterns, conformity and regulation, are homeostatic in the sense of permitting survival in a changing environment, and most animals show elements of both patterns.

4. Recovery from a deviated state: Animals tend toward certain norms, and when deviated, as by excess hydration or dehydration, heating or cooling, they may return in a definite pattern to the original norm. The rate of return is characteristic for a particular kind of animal. Too little attention has been given to what establishes the norm, and to what sensing devices detect deviations.

5. Rate functions. Rates can be measured for movements, for metabolism, and for enzymatic reactions, both *in vivo* and *in vitro*. Rates are critically measured as a function of environmental or of internal condition. For enzymatic rates, two methods are useful: (1) measurement of maximum velocity where enzyme activity is rate limiting, and (2) measurement of Michaelis constants (K_m's), which give rates in the more physiological range of substrate. Variations in reaction rates, for example, as a function of temperature depend on genetic and environmental determinants.

6. Macromolecular diversity. Similar proteins can be separated by electrophoresis, amino acid analysis, or immunological reactions. Similar nucleic acids can be characterized by base ratios. Isozymes are variant forms of the same protein, each determined by a different gene or combination. Allozymes represent multiple alleles of the same gene and occur in balanced polymorphism within a population. Biochemical diversity is meaningful physiologically when adaptive value is discovered for given chemical configurations.

7. Behavior. This is shown in taxic responses, selection of "preferred" environments in gradients, and in complex behaviour, such as courtship, matting, and rearing of young.

The comparative physiologist considers the organism as played upon by a variety of environmental factors – water, inorganic ions, organic food, oxygen and carbon dioxide, light, high and low frequency mechanical waves, pressure, gravity, ionizing and other radiation, and temperature. Comparative physiologists are concerned with the adaptive responses to these environmental factors. In addition, an animal is influenced in its environment by other organisms. Understanding of the biotic environment requires study of animal behavior.

The range of a species is determined through natural selection by its limits of tolerance. Once environmental factor, such as salinity, may limit the distribution of one group; another factor, such as temperature, may limit another group. Over an ecological range, individuals, may vary within limits set by the genotype; a phenotype results from the balance of genetic and environmental factors.

The use of physiological measurements on an animal under various stresses or environmental conditions was mentioned previously. The net effect of adaptive changes in an altered environment is homeokinesis. Homeostasis refers to constancy of internal state and refers usually to physiological characters which are regulated. Homeokinesis refers to constancy of life

functions, such as locomotor activity and energy liberation, all of which permit survival in an altered environment, sometimes even when internal state varies. Thus, homeokinesis for a given function can occur in the absence of homeostasis.

It is evident that the identification of the physiological variations in environment organism interaction, and of the molecular mechanisms underlying these variations, is a challenge for environmental physiologists. An understanding of the interactions is important for theory of the history and distribution of living things. Environmental physiology also provides a rational basis for approaching many practical problems. Man is faced with the need for more food resources and for protection of the physical environment against deterioration. Granted the delicate physiological balance between organisms and their environment, practical action must be based on an understanding of these interactions. Effects to regulate the physical environment, to alter land and water, to cause geographic change as by dams and canals, to dispose of the wastes of civilization, should be preceded by critical studies of the biological effects. Similarly, introduction of new food sources for man and of means of biological control of disease and pests must be based on knowledge of physiological adaptedness of the particular organisms. Comparative environmental physiology has, therefore, much to contribute to both biological theory and human welfare.

The cellular bases of behaviour are general polarized cell membranes, electrical and chemical interaction between cells, use of contractile proteins for movement, and transduction from one form of energy to another. Yet in detail, the methods which have been employed by cells are extremely diverse, and in no other area of physiology has study of specialized structures been so rewarding. For example, understanding of the nature of nerve impulses has come in most detail from study of giant nerve fibers. The goal of comparative behavioral physiology is not only to throw light on animal evolution and distribution but to understand diversity in coping with commonly encountered stresses. The behavioral physiologist seeks the variations on common themes: for example, light sensitivity of different types of photoreceptors; movement by fast and slow muscles, by cilia and by protoplasmic flow; and chemical signaling by neurosecretory, synaptic and endocrine cells.

One of the biological challenges for the future is to learn the basis for central nervous patterns. How much and in what way is behaviour programmed genetically and developmentally? What is the basis for central modification, for the many types of “conditioning”?

1.1.3 Plan for study of comparative physiology

An animal does not react to a complex environmental situation with a single organ or organ system. The parts of an organism interact with one another, and in combination their degrees of freedom are less than if separated. An organism constantly interacts with its micro-environment; hence, it cannot be described without considering its range of environmental interaction. For these reasons the properties of a whole organism can be either or less than those of the sum of its parts, depending on the interactions. Out of the whole organism emerge unique characteristics not present in any of the isolated parts. It is important, therefore, to examine the relation between components of the environment and the whole organism and to analyze the

interactions in terms of organ and cell physiology. The plan of this book is to consider the reactions of animals to transitions in environmental factors and then to consider sensory, effector, and coordinating mechanisms. An attempt is made to arrive at general biological principles which can be reached only with kind of organism as an experimental variable.

1.1.4 Expected Questions

1. Describe the aim and scope of physiology.
2. Explain in detail the physiology related studies and their uses.
3. Give an account are general principles physiology.

1.1.5 REFERENCE BOOKS

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Lesson 1.2

DIGESTION AND METABOLISM OF CARBOHYDRATES PROTEINS & LIPIDS

CONTENTS

1.2.1 INTRODUCTION

Digestion is a physiological process in which insoluble complex substances are converted into soluble, simple and absorbable substances. It is classified into two main types, i.e. intracellular and extracellular.

In lower animals like protozoans, sponges, the food material enters into the cell by pinococytosis or phagocytosis. The cell lysosomes fuse with these verides and the digestive enzymes digest the food, the undigested food will be excreted out.

In higher animals digestion is extracellular, it takes in a separate system called digestive system. In higher animals the digested food absorb into blood, from where they are transported to all parts of the body. In cells for releasing energy the end products of digestion are oxidized so as to release energy. This intracellular oxidation of food stuffs is also known as intracellular digestion.

1.2.2 DIGESTION OF CARBOHYDRATES

Starch grains are polysaccharides and are converted to achrodextrius, erythrodextrius and finally to maltose by the action of salivary amylase or ptyalin. The optimum pH for this enzyme is 6.2 to 6.8. The salivary amylase is secreted by salivary glands. In mammals 4 types of salivary glands are present. There are infra orbotal parotid, sub lingual, sub meaxillary. The stomach does not secret any enzyme that digest carbohydrates.

The pancreatic juice secreted into the small intestine has amylopsin, which is similar in action to ptyaline. This enzyme acts on the starch and convert starch into dextrins and finally to maltose. In the lumen of the small intestine, disacharase digest the disaccharides. Lactase splits the milk sugar to glucose and galactose maltase splits maltose to two glucose molecules. Splits glucose to one molecule of glucose and one molecule of fructose. The principal carbohydrates digested by the animals are given in Table 1.2.1.

TABLE 1.2.1 Principal Carbohydrates Digested by Animals

Carbohydrate	*Structure**	*Enzyme*	*Action*
POLYSACCHARIDES			
Starch — Amylose	(Gluc-$\alpha(1 \rightarrow 4)$ Gluc)$_n$	α-Amylase *or*	Endo-; cleaves $\alpha(1 \rightarrow 4)$ bonds
Starch — Amylopectin	(Gluc-$\alpha(1 \rightarrow 4)$ Gluc)$_m$ branched through $\alpha(1 \rightarrow 6)$ Gluc bonds; $m = 6$ to 12	β-Amylase†	Exo-; removes maltose units stepwise
Glycogen	As for amylopectin, with $m = 3$ to 6	*or* γ-Amylase (Glucoamylase)	Exo-; removes glucose units stepwise
Cellulose	(Gluc-$\beta(1 \rightarrow 4)$ Gluc)$_n$	Cellulase†	Endo-
Chitin	(AcGluc-$\beta(1 \rightarrow 4)$ AcGluc)$_n$	Chitinase†	Endo-
OLIGOSACCHARIDES			
α-Glucosides: Maltose	Gluc-$\alpha(1 \rightarrow 4)$ Gluc	Maltase and γ-amylase	
Isomaltose	Gluc-$\alpha(1 \rightarrow 6)$ Gluc	Isomaltase	
Sucrose	Gluc-$\alpha(1 \rightarrow 2)\beta$-Fruc	Sucrase	
α,α-Trehalose	Gluc-$\alpha(1 \rightarrow 1)\alpha$-Gluc	Trehalase	
β-Glucosides: Cellobiose	Gluc-$\beta(1 \rightarrow 4)$ Gluc	β-Glucosidase	
β-Galactosides: Lactose	Gal-$\beta(1 \rightarrow 4)$ Gluc	Lactase	
α-Galactosides: Raffinose	Gal-$\alpha(1 \rightarrow 4)$ Gluc-$\alpha(3 \rightarrow 2)\beta$-Fruc	α-Galactosidase	Releases α-galactose
β-Fructosides: Sucrose	Fruc-$\beta(2-1)\alpha$-Gluc	Invertase	

*Gluc = D-glucopyranosyl; Fruc = D-fructofuranosyl; Gal = D-galactopyranosyl; AcGluc = 2-N-acetyl-D-glucosaminyl. The linkage between the successive monosaccharide units is from carbon-1 to carbon-4 ($1 \rightarrow 4$), etc. n is a large and indefinite number.

†Secretion by animals is rare (see text).

1.2.3 DIGESTION OF CELLULOSE

The ruminants ingest large quantities of fodder rich in cellulose. Cellulose is digested in the rumen by the enzymes produced by symbiotic bacteria. The main products of fermentation in rumen are acetic, propionic, butynic, and other acids.

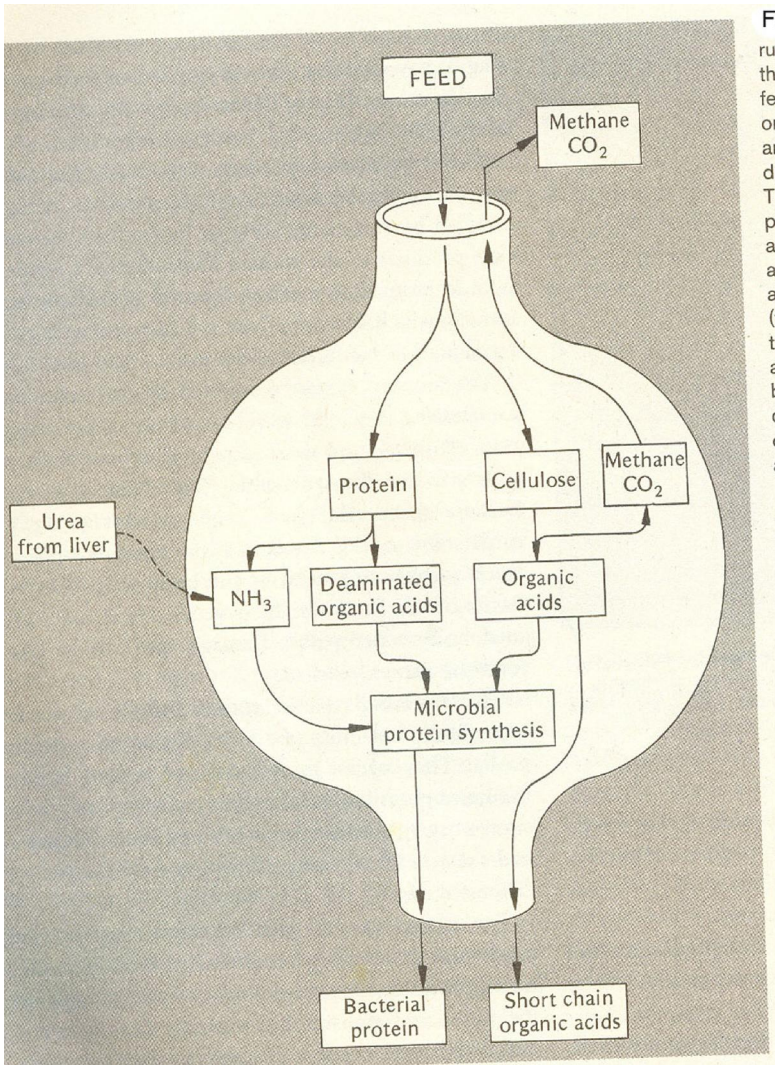
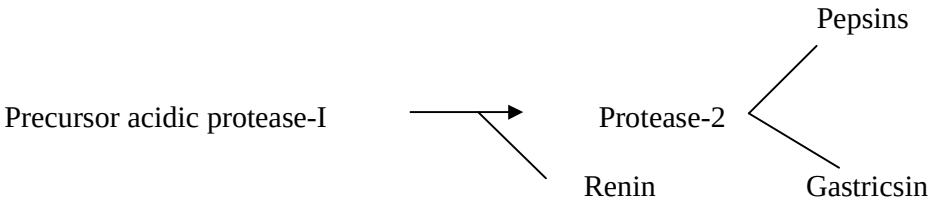


Fig.1.2.2 Major events in ruminant digestion. Cellulose from the feed undergoes microbial fermentation, forming short-chain organic acids that are used by the animal, while methane and carbon dioxide are lost to the atmosphere. The protein from the feed may be partly deaminated, forming organic acids and ammonia. Bacteria use ammonia, and ammonia from ammonium salts or from urea (formed in the liver or supplied in the food), together with organic acids for protein synthesis. The bacterial protein passes further down the digestive tract, is digested, and is used by the animal.

1.2.4 DIGESTION OF PROTEINS

The peptide ($-NH_2$) links of proteins are hydrolyzed by proteolytic enzymes and release aminoacids. The proleotytic enzymes in vertebrates can be divided into two groups 1. Endopeptidases 2. Exopeptidases.



I. Endopeptidases

Protein digestion starts in the stomach. Pepsin is secreted in the Gastric juice as an inactive form pepsiongen. This is converted into active pepsin by HCl which is also present in the gastric juice. Its optimum pH is 1.5 to 2.5 pepsin hydrolyzes peptide bonds in a protein chain where phenylalanine, tyrosin tryptophan, lucine, aspartic acid or glutamic acid are present and release proteases and peptones. Pepsin, like renin, has the property of coagulating milk by converting caseinogen to casein, orcasenate, which forms insoluble complex in the calcium, as calcium para casenate.

Trypsin is secreted by pancreas, in an inactive form trypsinosen. Typsiongen is activated by the enzyme enterokinase secreted by the intestinal mucosa and then auto catalytically by trypsin itself. Trypsin catalyzes the hydrolysis of peptide bonds in a protein chain in which carboxyl function is contributed by lysine, or arginine. Its optimum pH is 7-9.

Chymotrypsinogen is secreted from the pancreas in an inactive form, chymotrypsinogen. Activation of chymotrypsinogen is brought out by the trypsin. The optimum pH of chymotrypsin is 7-8. It attacks the peptide bonds where phenylalanine or tyrosine are present.

The endopeptidases hydrolyze large protein molecules to small peptides, which are further broken down to smaller peptides by the action of exopeptidases and dipeptidases.

Exopeptidases

These remove terminal aminoacids and require a metalic ion as activator for their catalytic activity. There are two carboxy peptidases which are secreted as procarboxypeptidase and activated by trypsin. Carboxypeptidase-A hydrolyzes terminal amino acids with free carboxyl groups with the exception of lysine and arginine. Carboxypeptidase-B hydrolyze peptide with free carboxyl of lysine and arginine. Aminopeptidase prefers the terminal amino acid with free amino group. Dipeptidases act on dipeptides and release amino acids. Prolidase a dipeptide hydrolyze proline a product formed by the breakdown of collagen.

Digestion of nucleic acids

Pancreatic juice consists of nucleic acid digesting enzymes.

Deoxyribonuclease I, an endonuclease hydrolyzes between all pysimidine – purine pairs in a DNA chain, whereas ribonulcease hydrolyzes RNA chains into nucleotides. Nucleosidases attacks on nucleosides and release purine and pyrimidine bases.

Exopeptidases

These require a metallic ion as activator for their catalytic activity.

Two carboxypeptidases which are secreted by pancreas as procarboxypeptidases activated by trypsin. Carboxypeptidase . Hydrolizes terminal amino acids with free carboxyl groups with the exception of lysine or arginine. Carboxypeptidase B will hydrolyze peptide with free carboxyl terminal of lysine or arginine.

Aminopeptidases secreted by the intestine digest the terminal amino acids with free amino group. Dipeptidases digest the dipeptidases into aminoacids. Protease breaks proline a product formed by the breakdown of collagen.

1.2.5 DIGESTION OF FATS:

There is no lipase in the saliva or in the gastric juice. When the chyme passes through duodenum the bile and pancreatic lipase mixed up with the chyme. The bile salts (Sodium glycocholate, Sodium taurocholate) lower the surface tension of the fat droplets in the chyme and emulsify them to facilitate their digestion. The emulsified fats are subjected to the action of pancreatic lipase and forms a mixture of free fatty acids, diglycerides and monoglycerides. The optimum pH for this enzyme is between 7 to 9.

Metabolism

Metabolism can be defined as the sum total of chemical reactions necessary for the foodstuffs to be utilized by the body. Metabolism is absolutely essential to the maintenance of homeostasis. During metabolism energy is required to breakdown the foodstuffs which in turn yield more energy, which is utilizedc in other vital processes. In general metabolism fall under two categories (a) Anabolism, in which simple substances are converted into complex substances.

(b) In Catabolism, complex substances are converted into simple molecules.

1.2.6 PROTEIN METABOLISM

Protein metabolism consists essentially of transformations of amino acids which are more readily absorbed from the intestine. Some proteins are formed from the absorbed amino acids, while a number of proteins are synthesized from amino acids not present in the diet. Amino acids are also oxidized for energy. The body is not capable of storing large amounts of amino acids and proteins, hence inter conversion of amino acids to other compounds like carbohydrates, fats etc., takes place. Proteins suypply required amino acids for growth, repair and maintenance of the body. There are about 20 naturally occurring aminoacids, fall under two categories:

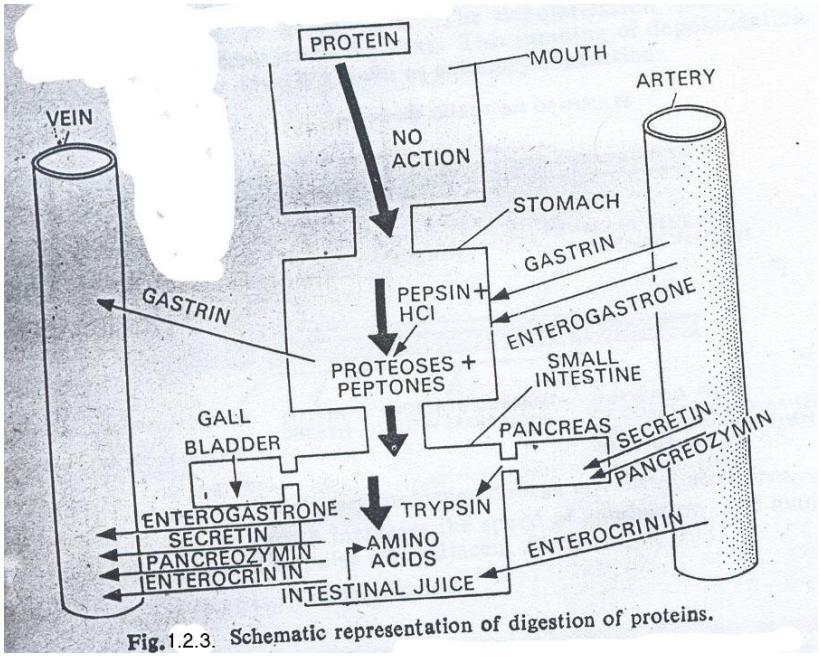


Fig. 1.2.3. Schematic representation of digestion of proteins.

1. Essential amino acids—Threonine, Methionine, Valine, Leucine, Phenylalanine, Isoleucine, Histidine, Tryptophan, Lysine, Arginine, Cystine, Tyrosine.

2. Non-essential aminoacids—Glycine, Alanine, Serine, Aspartate, Glutamic acid, Proline, Hydroxy proline.

Oxidation of amino acids

This is called deamination, which takes place in liver, kidney and intestinal mucosa. Urea formation is confined to liver only. The ammonia liberated in the kidney and in intestine goes into circulation in the form of glutamine. The ammonia produced as a result of deamination of aminoacids is converted into urea in the liver in Ornithine cycle. Arginine is hydrolyzed by an enzyme arginase to yield one molecule urea, one molecule ornithine.

Transformation involves interconversion of a pair of aminoacids and a pair of keto acids catalyzed by transaminases or amino-transferases. The reactions are reversible.

Various aminoacids enter citric acid cycle. Valine, threonine, and alanine are converted into pyruvic acid.

Aspartic acid is converted to oxaloacetic acid, while glutamic acid is changed to α-ketoglutarate.

Decarboxylation: It is aprocess in which certain amines are formed by the removal of CO_2 from the COOH of aminoacids. Decarboxylation is catalyzed by decarboxylases in the presence of coenzyme pyridoxal phosphate.

For ex:-Histidine yields, histamine.
Tyrosine tyramine ---Adrenaline.

Reactions of some aminoacids:

Glycine is the simplest aminoacid, which is precursor for the formation of purine. Glycine can be converteds into serine when it combines with formaldehyde. Glycine, Serine, malanine and glucose are interconvertible.

Phenylalanine and tyrosine are the precursors in the formation of thyroxine, noradrenaline, and Adrenaline. Defective metabolism of these amino acids cause a disease alcaptonurea, are inborn gene error. In this disease the urine turns black when exposed to air. When the conversion of phenylalanine to tyrosine is blocked it is called a disease, phenylketonuria. Consequently, pigment melanine is not produced.

Metabolism of Creatine and Creatinine:

Creatine is synthesized in muscle and composed of amino acids-glycine, arginine and methionine. It provides energy for muscle metabolism (muscle contraction). When it combines with phosphoric acid, creatine serves as a buffer. Creatinine is an anhydride of creatine. Creatinine is an excretory product and will be excreted in the urine. After heavy muscular exercise creatinine output is temporarily accelerated and soon stops during recovery period.

Sulphur metabolism

Sulphur is a component in cysteine, cystine and methionine. It is also found in glycoprotein, and also present in hairs, horns, feathers, tendons, cornea, connective tissue.

Small amounts of sulphur containing amino acids are utilized for the synthesis of insulin. Majority of sulphur-containing amino acids are catabolized in the liver, producing urea and sulphur is oxidized to sulphuric acid. Sulphuric acid will be excreted as sulphate. It is also useful in the formation of heparin(anti coagulant).

Metabolism of nucleoproteins

Nucleoproteins are present in the chromosomes, and also in cytoplasm. They are made up of nucleotides, containing purine, pyrimidine bases, pentose sugar and phosphoric acid. The purines are converted to uric acid and pyrimidines are oxidized to produce CO_2 and NH_3. Nucleotides are nucleoside phlosphates. Nucleosides are formed when the phosphoric acid is removed. Some of the nucleotides Nicotinamide adenine dinucleotide(NAD), Nicotinamide adenine dinucleotide phosphate(NADP) and flavin adenine dinucleotide(FAD) are important coenzymes.

About 80% of RNA is associated with ribosomes, rest is present in cytoplasm. DNA is the primary component of genes.

Protein biosynthesis

Proteins are essential for the body and form structural proteins, multiple enzyme systems, hormones, etc. Proteins cannot be synthesized from any other source except aminoacids. Protein synthesis is under genetic control.

1.2.7 Carbohydrate metabolism

Carbohydrates are main food stuffs synthesized by plants and utilized by animals for their energy requirements. The food of organisms contains large amounts of carbohydrates in the form of sugars and starchs, which are hydrolyzed in digestion into monosaccharides like glucose, fructose, galactose, absorbed by the small intestine and converted into glycogen, may be transformed to fats, while a good portion of the absorbed glucose is oxidized as an immediate source of energy.

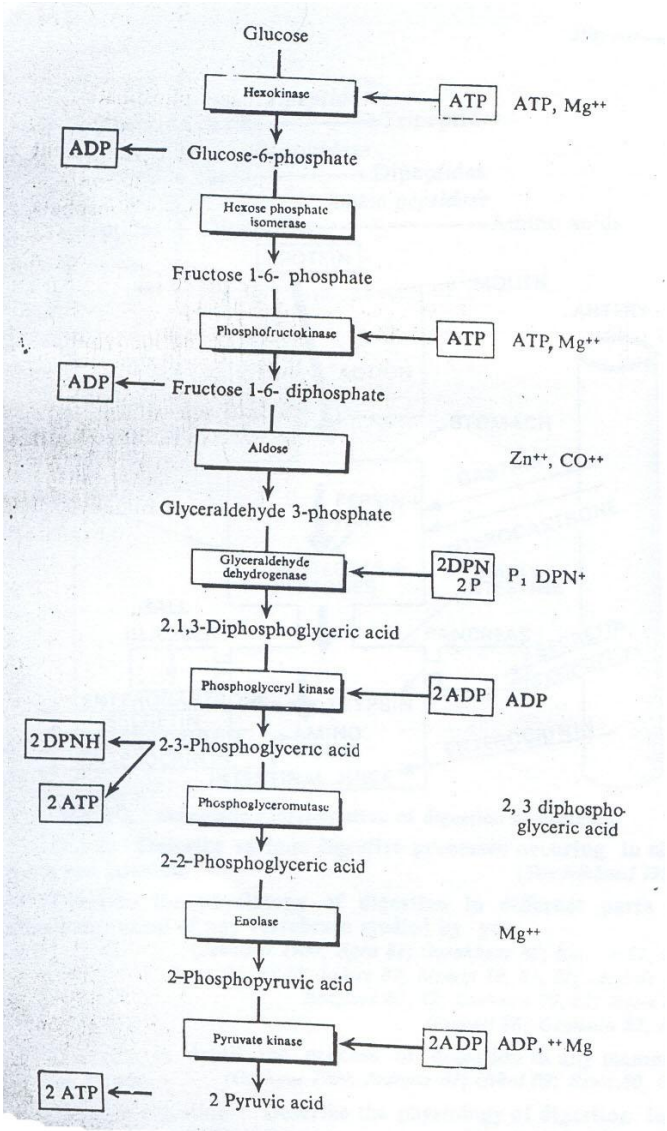


Fig.1.2.2.6 Glycolysis or Embden Meyerhoff pathway.

Blood sugar

Glucose present in blood as free sugar and the level of it maintains almost constant. In case if the blood glucose levels falls, the glycogen in the liver undergo glycogenolysis and release glucose. Pancreas, Adrenal and anterior pituitary control the carbohydrate metabolism. Increase or decrease in the amounts of circulating glucose depends upon insulin efficiency. Insulin speeds the movement of glucose from blood into tissue cells. If insulin levels are more, the blood sugar level drops leads to hypoglycemia. If insulin is not present, the blood sugar level rises which leads to Diabetes mellitus, in which glucose is excreted through urine.

Adrenaline increases the concentration of glucose in the blood by facilitating the breakdown of liver glycogen. Nor-adrenaline also performs the same function to a limited extent.

A steroid hormone of adrenal cortex, hydrocortisone, stimulate the liver to convert proteins and fats to carbohydrates (gluconeogenesis), resulting the increase of blood sugar level.

The hormones of anterior pituitary gland, TSH, ACTH, and GH antagonize the action of insulin and elevate blood sugar level.

Glycolysis

After absorption, the glucose molecule is subjected to series of reactions and is completely oxidized to CO_2, H_2O and energy. The splitting of glucose molecule is referred to as glycolysis. The energy released during carbohydrate metabolism is stored in the form of high energy phosphate compounds as ATP.

I. In the first step each molecule of glucose produces two molecules of pyruvic acid.

   The net yield of energy is 2 molecules of ATP. The series of reactions involved in glycolysis are collectively called as Embden-Meyerhol pathway. This process does not require oxygen.

II. In the second step the pyruvic acid is converted to acetyl coenzyme-A.

This reaction neither requires ATP nor generate ATP.

III. In the third stage, the acetyl-Co A undergoes series of reactions, referred as citric acid cycle or Krebs cycle. This cycle is aerobic and the end products are CO_2, H_2O and the electrons are transported in the fourth step, Electron transport stage and finally energy is trapped in the form of ATP.

Besides Embden-Meyerhof pathway, another pathway for glycolysis is known as hexose monophosphate shunt (HMP). This occurs in the liver, lactating mammary glands. Considerable fraction of glucose is oxidized in this pathway.

First glucose-6-phosphate undergoes dehydrogenation and decarboxylation to yield ribulose-5-phosphate. In the next phase ribulose-5-phosphate is converted back to glucose-6-

phosphate by series of intermediate reactions. In this pathway NADP is used instead of NAD as hydrogen acceptor. The shunt works as a source of chemical rather than energy.

Glycogenesis

Glycogen is formed in the liver and muscle from glucose called glycogenesis.

First, glucose is phosphorylated to glucose-6-phosphate, then to glucose-1-phosphate, catalyzed by phosphoglucomutase. Then glucose-1-phosphate reacts with uridine triphosphate to form uridine diphosphate glucose. Thern the enzyme glycogen synthetase reacts with UDPG and forms a glycosidic bond between '1' carbon of activated glucose and 4 carbon of the glucose residue and release uridine diphosphate.

Liver not only convert the glucose ion to glycogen but also convert the lactic acid to glycogen reached to liver after muscle contraction.

Glycogen in the liver can be converted into glucose, and glucose can be changed to muscle glycogen, which in turn converted into lactic acid, some of which later transformed to liver glycogen. The cyclic pathway involved in this process is called Cori cycle.

Gluconeogenesis

Liver glycogen is also formed from non-carbohydrate sources such as protreins and fats. This process is called gluconeogenesis. The excess amounts of protein are metabolized by the carbohydrate pathway and can be converted into glucose or glycogen by reversal of glycolysis. Gluconeogenesis is most important because it usually occurs when the glycogen store is exhausted.

In this process the excess proteins are hydrolyzed to amino acids. Which are then de-aminated, and later metabolized through either carbohydrate pathway or fat metabolism.

Glucose may also be derived from fat but this conversion is very limited. This process consists of oxidation of long chain falty acids in mitochondria. Then the glycerol component of the fat reach with ATP to form glycerol phosphate which is then oxidized to glycoaldehyde –3-phosphate. This may be further oxidized to pyruvic acid or may be converted to glycogen by reversal of the part of the glycolytic pathway.

Muscle glycogen

Muscles consists more glycogen than liver. Liver is the storage organ for glycogen. Where as muscle glycogen acts as a source of energy during muscle contraction. Starvation does not effect muscle glycogen. Synthesis of muscle glycogen is same with that of liver glycogen. Muscle can not convert muscle glycogen to glucose. However, glycogen is broken down to lactic acid in the muscle from where it is carried to the liver through blood circulation which is converted to glycogen.

Metabolism of other sugars

Galactose and fructose are also metabolically important. The source of galactose is mainly lactose content of the milk. It is first phosphorylated in the presence of an enzyme galactokinase and their reacts with uridine diphosphogalactose to form uridine diphosphoglucose. Which participate in glycogen synthesis. Large quantitive of galactose in blood is toxic and cause a disease called galactosemia.

Fructose is obtained from sucrose and fruits and is readily converted into glucose or glycogen in the liver. It is phosphorylated in the presence of fructokinase into fructose-1-phosphate.

Ocassionally glyceraldehydes can also be reduced to glycerol- dehyde –3-phosphate and two molecules of this can be converted into fructose 1-6-diphosphate.

1.2.8 FAT METABOLISM

Fats and Lipids are important constituents of protoplasm. They may be present in the food or may be formed in the body. The structural fats are complex where as reserve fats are in the form of neutral triglycerides. In the metabolism of fats 3 major processes are involved they are :

(1) Absorption of fats

(2) Mobilization of fat from storage point to other parts

(3) Synthesis of fats in the liver, from carbohydrates and protein sources.

Chylomicrons are the mobile fat molecules in the blood and consists of phospholipids, cholesterol, cholesterols of fatty acids. After starvation for a short period, when glycogen reserve in liver exhausted, fats will be transported to liver (which take part in metabolism) to provide alternate source of energy.

Role of liver in fat metabolism

Liver has a key role in the metabolism of fats. Liver is not normally an accumulator of fats as it is for carbohydrates. Excess of fats in liver is converted to useful substances. Liver is also responsible for transformation of lipids into phospholipids, cholesterol, desaturation of falty acids. Oxidation of falty acids etc. The sluggish function of liver leads to metabolic disorders.

Oxidation of fatty acids

Triglycerides are hydrolysed to fatty acids and glycerol, which takes place in adipose tissue. The produced Free Fatty acids are carried to plasma then to tissue like, liver, kidney, heart, muscle, testis, brain and adipose tissue, where oxidation takes place. The long chain falty acids broken down to 2-carbon units `acetates' then converted to acetyl Co-A. The acetyl Co-A can either combine with oxaloacetate before entering the citric acid cycle or it may be directly

oxidized to acetoacetate, the first ketone body. Acetoacetate may further breakdown to β-hydroxybutyrate and acetone; which accumulate in small amounts in liver. The utilization of glycerol is dependent on the enzyme glycerol kinase, which is sufficiently present in liver, kidney and adipose tissue.

β-oxidation of fatty acids

Fatty acid oxidation takes place in mitochondria. Before fatty acid enter the mitochondria the fatty acid in cytosol is activated by a molecule of ATP in the presence of acetylcoenzyme-A (COASH). This reaction occurs either in the endoplasmic reticulum or at the outer mitochondrial membrane; resulting in the formation of acetyl Co-A derivative. This derivative is transported inside the mitochondria with the help of carnitine a carrin molecule. This reaction is catalysed by an enzyme a cyl Co-A transferase. Then dehydrogenate remove two hydrogen atoms from the α and β carbon of falty aeyl Co-A, resulting in the formation of unsaturated aeyl Co-A. This is subsequently hydrated and dehydrogenated resulting the formation of β-keto aeyl Co-A. This undergoes thiolytic charge by thiolase producing an aeyl-Co-A unit and the remaining aeyl Co-A containing 2-C less than the original fatty aeyl Co-A molecule. This will be oxidized to CO_2 and H_2O through citric acid cycle.

In case of fatty acids with odd number of carbon atoms, oxidation takes place through β oxidation leaving behind propioxyl Co-A, a 3-carbon unit. This enter into citric acid cycle after converted into succinyl coA.

For example one mole of palmitic acid $C_{16}H_{32}O_2$ after β oxidation a net gain is 130 ATP molecules.

$C_{16}H_{32}O_2 + ATP + 7\ FAD + 7\ NAD^+ + 8\ COASH + 7H_2O \rightarrow AHP + Ppi + FADH_2 + 7\ NADH + H^+ + 8\ CH_3CO\text{-}S\text{-}COA$

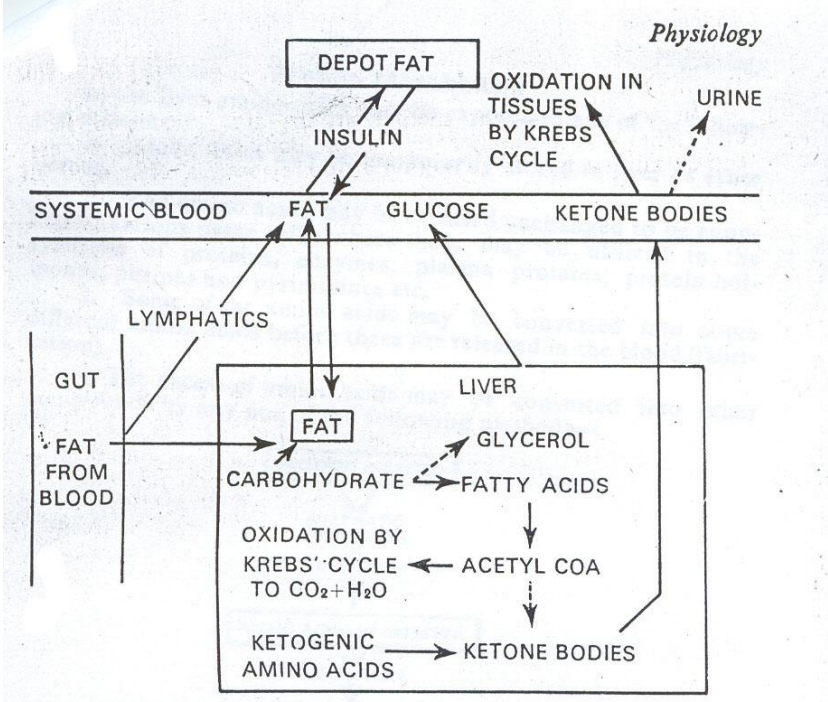


Fig.1.2.2.8. Metabolism of fat.

Oxidation of unsaturated falty acids

It proceeds the usual β oxidation pathway until the double bond is reached. The double bond in cis configuration is not vulnerable to enzymic attack, unless it is isomerised to trans configuration. Poly unsaturated fatty acids, such as linoleic acid, arachidonic etc. are more complex and require additional enzyme for oxidation.

1.2.9 Metabolism of glycerol

One of the hydrolysis products of triglycerides is glycerol, which is metabolized by glycerol kinase. Liver, kidney, intestinal mucosa, lacting mammary glands are rich in the enzyme, where as muscle and adipose tissue contain less mount. Glycerol is predominantly converted into carbohydrate through glycerol phosphate in the presence of glycerol kinase at the expense of ATP.

Glycerol phosphate is then oxidized to triosephosphate by glycerolphopshate dehydrogenase, which ultimately forms glycogen through glycogenesis.

Triose phosphate may be oxidized to pyruvic acid by way of glycolysis.

Synthesis of glycerides and fatty acids

Fats are synthesized from metabolites such as acetate and acetoacetate. They are also synthesized from protein and carbohydrate sources.

Synthesis of glycerides

Triglycerides are formed by reactions between acetyl Co-A compounds and α-glycerophosphate in the presence of glycerol kinase. First phosphatidic acid is formed then it is converted into diglyceride and triglyceride.

Synthesis of fatty acids

Fatty acid oxidation occurs in mitochondria, but the fatty acid synthesis not only takes place in mitochondria, but also in mitochondria free system. The pathway for the synthesis of fatty acids is not exactly reversal of β-oxidiation but it involves some modifications.

Under anaerobic conditions, mitochondria catalyse the incorporation of acetyl Co-A units into long chain fatty acids (stearic acid, palmitic acid) requiring ATP, NADH and NADPH. Synthesis in extra-mitochondrial system, especially in the liver, brain, kidney etc. acetyl – Co-A units are incorporated into fatty acids, catalyzed by cytosolic enzymes and co factors such as ATP, NADPH and Mg^{+2} or Mn^{+2} ions. This system is dependent on CO_2 supplied by bicarbonate. Chain elongation usually takes place in the microsomes.

Metabolism of phospholipids

Phospholipids are synthesized either from phosphatidic acid or phosphatidyl choline. Lacithin is most important phospholipid and is synthesized in the liver. Phospholipids are largely found in combination with proteins. The catabolism of lecithin is as follows:

1.2.10 METABOLISM OF CHOLESTEROL

Cholesterol is an important lipid belonging to the class of sterols. Major part of body cholesterol arises by synthesis. Food provide very small portion. It is also the precursor of steroid hormones and bile acids.

Cholesterol in association with other lipids, is absorbed in the intestine and thereafter incorporated into chylomicrons and very low density lipids. Abut 80% of cholesterol in the lymph undergoes estirification with long chain fatty acids and transported as lipoprotein in the plasma. Five cholerterols in the plasma is usually executed through bile juice. Much of the cholesterol secreted in the bile is reabsorbed and either gets deposited in the arteries in the form of esters or may participate in steroid synthesis.

Although cholesterol is synthesized by many tissue such as adrenal cortex, skin, intestine, testis etc. turn is considered to be the main site. Acety Co-A is the main source of its synthesis, which is a product of carbohydrate and fatty acid metabolism. Two molecules of acetyl Co-A condense to form aceto acetyl Co-A which, again reacts with another molecule of acetyl Co-A to form β-hydroxy methyl glutaryl Co-A leading to the synthesis of mevalonate. This compound becomes cholesterol.

Ketogenesis

Excessive fat metabolism in the liver results in the formation of acetoacetate and β-hydroxybutyric acid, which passes into blood. Acetoacetate is spontaneously decarboxylated to form acetone. These three compounds are called Ketone bodies. Usually the concentration of these 3 compounds in urine is very low. If the amounts are in excess in blood the condition is called ketonemia, and when the amounts increase in urine, ketoneria results. The production of these 3 compounds comes under ketogenesis.

Acetyl Co-A is the starting material for ketogenesis. Oxidation of ketone bodies takes place in extrahepatic tissues because the enzyme 3-oxoacid coA transferase is absent is liver. This enzyme is present in kidney, end muscle, brain and other peripheral tissue. Normally ketone bodies are continuously oxidizing in muscles, therefore only traces maybe found in blood and urine. After a week fasting these may appear in large quantition in blood and urine.

β-hydroxybuty rate appearing in the blood reaches the muscles, where a mitochondrial enzyme 3-hydroxybutyrate dehydrogenase oxidize it into acetoacetate. Acetoacetate in the muscle mitochondria is activated by 3-oxoacid Co-A transferase, catalyzing the transfer of Co-A from succinyl Co-A to acetoacetate. Two moles of acetyl Co-A are liberated from each mole of acetoacetyl Co-A by a thiolytic cleavage.

Acetoacetate + succinyl Co-A $\rightleftharpoons$ succinate + Acetoacetyl Co-A

Acetoacetate Co-A + Co-A SH $\rightleftharpoons$ Acetyl Co-A + Acetyl Co-A

During path a logical condition like diabetes excess of ketone bodies are formed than can be oxidized resulting in Ketosis.

1.2.11 EXPECTED QUESTIONS

1. Describe the process of digestion of carbohydrates & proteins.
2. Explain the digestive process of lipids.
3. Mention the steps involved in metabolism of proteins
4. Describe the process of carbohydrate metabolism?
5. Give an account on the energy synthesis through the metabolism of proteins.

1.2.12 REFERENCE BOOKS

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Lesson 1.3

ENZYMES AND VITAMINS – THEIR ROLE IN BIOCHEMICAL REACTIONS AND SIGNIFICANCE IN METABOLISM.

CONTENTS

1.3.1 INTRODUCTION

Enzymes are biocatalysts of living tissues. These speed up chemical reactions in biological systems so that they can take place at relatively low temperature, but themselves remain apparently unchanged during the process.

All enzymes are proteins. These may be:

1. Simple globular protein: Eg. Insulin, pepsin
2. Globular metalloprotein: Eg. Ascorbic acid oxidase (copper proteinate)
3. Conjugated protein: Eg. Transminases and catalases

Conjugated Enzymes or Holoenzymes

These are globular or metalloprotein attached to a nonprotein prosthetic group. These are called holoenzyms.

1. The protein part of holoenzyme is called aponzyme.

2. The nonprotein part is called cofactor. The cofactor may be-

i. Coenzyme is a small, heat-stable and dialyzable organic molecule, it readily dissociates off the apoenzyme.
Eg. NAD, NADP, COA.

ii. Prosthetic group is firmly bond to porphyrin part of enzyme. It forms an integral part of holoenzyme. It may be an organic molecule or a combination of organic and inorganic molecule.

1.3.2 MODE OF WORKING

The chief types of chemical changes involved in the mode of working of the enzymes are as follows:

1. Hydrolysis: IT consists in taking up of a molecule of H_2O and decomposing substances into smaller molecules. Protein → proteases → Peptones → Polypeptides → amino acids, are all hydrolytic changes. Similarly, conversion of disaccharides lactose or maltose into monosaccharides are also hydrolytic changes.
   The reverse change i.e dehydration is equally possible in the living cells. Thus glucose on dehydration is polymerized into glycogen, and amino acids are resynthesized into protein molecules in the tissue cells.

2. Decarboxylation: This consists in the removal of –COOH group with the formation of CO_2. Pyruvic acid when acted on by an enzyme *decarboxylase* breaks down into acetaldehyde and CO_2.

   $$CH_3.CO.COOH \rightleftharpoons CH_3CHO+CO_2$$

   The pyrophosphoric ester of Vit. B_1 is coenzyme in the above reaction. In bacterial digestion some of the amino acids are converted into amines by losing a molecule of CO_2.

   Histidine → Histamine
   Ornithine → Putrescine

3. Oxidation and reduction: Energy is evolved in the oxidation of foodstuffs during the process of metabolism. Each gram molecule of glucose yields 4.2 cals. Of energy during its conversion into CO_2 and H_2O.

   Oxidation is always accompanied by reduction of some substance, by loss of oxygen or gain of hydrogen. The substance reduced of its oxygen is an oxygen donar and the substance oxidized simultaneously is an acceptor. In the latter case, the substance reduced is a hydrogen acceptor and the reducing substance is a hydrogen acceptor.

   R. CHO → R. COOH

1.3.3 CHARACTERISTICS OF ENZYMES

1. **Protein Nature:** All enzymes are proteins. The protein structure provides for weak associations due to side groups of the amino acids wihin it. The enzyme-substrate complex involves, the association of the enzymeand substrate by weak associations rather than

covalent bondings. Enzymes exhibit all typical properties of proteins viz, high molecular weight, colloidal behaviour, slow diffusion, inability to pass through most living membranes, and movement in resonse to an electric current.

2. **Accelerate the Rate of Reaction:** An enzyme can only change the rate of the reaction. Neither these can inititate a reaction nor they can change the direction of equilibrium. A reaction will proceed at a faster rate in presence of an enzyme, but the equilibrium between the substrate and the product will remain constant.

3. **Reversibility of Enzyme Action:** Certain enzymes exhibit reversibility of their action, this property is very helpful in metabolism. For example, succinic dehydrogenase catalyzes reversibly the dehydrogensation of succinic acid. Lipase, a fat splitting enzyme, hydrolyses ethyl butyrate to butyric acid and ethyl alcohol. If this process continues ethyl butyrate is formed again.

$$C_3H_7COOC_3H_5 \rightleftharpoons C3H7COOH + C_2H_5OH$$

4. Remain unaltered in the End: Enzymes emerge out from a reaction or set of reactions unaltered. These may now enter into another reaction with another molecule of same substrate.

5. Required in small Quantities: Enzymes are reused, and are therefore, required in small quantity by biological systems. A single enzyme molecule can act upon 500,000 substrate molecules per minute. This value is referred to as the turn-over number.

6. Enzyme Specificity: Enzymes catalyze only one specific reaction or act upon only one kind of substrate. The specificity may be any kind, e.g., reaction specificity, substrate specificity, group specificity or optical specificity.

(i) Reaction specificity: Most enzymes can catalyze the same type of reaction (phosphate transfer, oxidation-reduction etc.) with several structurally related substrates.

(ii) Substrate Specificity: A particular enzyme will act only on a certain substrate. For example, urease is a specific enzyme, it acts on urea only, it would not exert any influence on the catabolism of protein or carbohydrate.

(iii) Group Specificity: A particular enzyme acts only on particular chemical groupings, e.g. Glycosidase on glycosides, **alcoholdehydrogenase** on alcohols, pepsin and trypsin on peptide bonds and esterases on ester linkages.

Chmotrypsin hydrolyzes peptide bonds in which the carboxyl group is contributed by the aromatic amino acids phenylalanine, tyrosine, or tryptophan. Carboxypeptidases

and aminopeptidases split of amino acids one at a time from the carboxyl or amino terminal end of polypeptide chains, respectively.

(iv) **Optical Specificity (Stereospecificity):** With the exception of epimerases which interconvert optical isomers, enzyme,es generally show absolute optical specificity, for example, maltase catalyzes the hydrolysis of α-but not β glycosides, while enzymes of the Embden-Meyerhof direct oxidative pathways and catalyze the interconversion of D-but not L-phosposugars.

7. **Denaturation:** the protein enzymes become denatured by acids, high salt concentration, alkaloid reagent or UV-light. The denaturation causes loss of enzymatic activity.

8. Activation: Most enzymes can be activated by addition of specific agents. In absence of such factors enzymes become in active and sluggish. Such agents are called enzyme activators.

9. Inhibition: Enzyme activity is inhibited by the addition of specific agents, called enzyme inhibitiors. For example, physostigmine is a competitive inhibitor of acetylcholine.

1.3.4 CLASSIFICATION OF ENZYMES

According to their function, enzymes have been divided into five main groups.

1. **Hydrolases:** These are the digestive hydrolytic enzymes which act outside the cell which are concerned with the breaking down of larger molecules into smaller or simpler ones, eg. Amylases, saccharases, proteinases, lipases, etc. this group includes certain other enzymes that operate inside the cells and involve the use of water, eg. Deaminases, arginases. Carbonic anhydrases, etc. the hydrolases can further be divided into:

(i) Proteolytic enzymes: Which break down proteins into peptones and peptides, e.g. *pepsin, rennin; trypsin* and *erepsin.*

(ii) Sucrolytic enzymes: That hydrolyse sugar molecules into simpler ones, eog. Cellulose, amylase, lactase, fructose and galactase.

(iii) Lipolytic enzymes: Act upon lipids or neutral fats and break them into glycerol and fatty acids, e.g. lipase.

(iv) Amylolytic enzymes: which bring about hydrolysis of starch into maltose.

(v) Nucleases: Break down nucleic acids into nucleotidies which are again hydrolysed by *mucleotidases* into nucleosides.

(vi) Amidases: bring about further breakage of urea, arginine and purines e.g. urase, arginase, purinamidase.

(vii) Inverting enzymes: Convert disaccharides into monosaccharides, e.g. invertase and maltase.

2. Demolases: These break up the molecules by the process of oxidation, reduction, decarboxylation, etc. these include dehydrogenases, carboxylases, oxidases, catalases and carbonic anhydrases.

(i) Oxidases or oxidizing enzymes are intracellular enzymes which produce oxidative changes in the tissue cells during respiration and metabolism.

(ii) Dehydrogenases bring about the transfer of hydrogen ions from one compound to another bringing about oxidation and reduction simultaneously.

(iii) Decarboxylases bring about removal of carboxyl group from the compounds to form CO_2:

$$CH_3COCOOH \rightarrow CH_3CHO + CO_2$$

(iv) Carbonic anhydrases split up carbonic acids into CO_2 and H_2O.

(v) Catalases enhance or activate catalytic changes in various biochemical reactions.

(vi) Autolytic or intracellular enzymes are present in tissue cells and bring about anabolic and catabolic processes of metabolism.

3. Coagulating enzymes: These bring about coagulation of substances, e.g. coagulase and rennin.

(i) Coagulase in the muscles converts paramyosinogen and myosinogen into paramyosin and myosin respectively.

(ii) Rennin converts soluble calcium caseinogen into insoluble calcium caseinate.

4. Isomerases: These bring about the regrouping of atoms in the molecules (ie. Intramolecualr arrangement) and thus formation of one isomer from another e.g. phosphohexose isomerase, and triose phosphate isomerase. Triose phosphate isomerase

converts 3-phosphoglyceraldehyde to dihydroxyacetone phosphate during the anaerobic breakdown of carbohydrates into lactic acid.

5. **Synthetases:** Synthetases are enzymes which bring about joining together of two separate molecules. This reaction is coupled with the breakdown of an "energy-rich" bond, as for example acetyl coenzyme A (CoA) synthetase.

Adenosine triphosphate (ATP) + Acetate+CoA→
Adenosine monophosphate (AMP)+Acetyle Coa+Pyro-phosphate (PP)
Another example is joining together of activated amino acids in presence of acid amino lipases such as glutamine synthetase.

ATP=L-glutamate+NH3 $\rightleftharpoons$ ADP+ Orthophosphate+L-glutamine.

1.3.5 VITAMINS

In the year 1911 Funk, a Polish biochemist, coined the term "vitamine" to designate the antiberiberi factor. In the term vitamine bvita suggest the essential nature of the factor, and amine indictes the chemical structure. Later the same term was used for several unknown dietary factors. Not all the known factors have the amine structure. Therefore in 1919 the last "e" from the vitamine was discontinued from use thereby removing the implication of chemical structure.

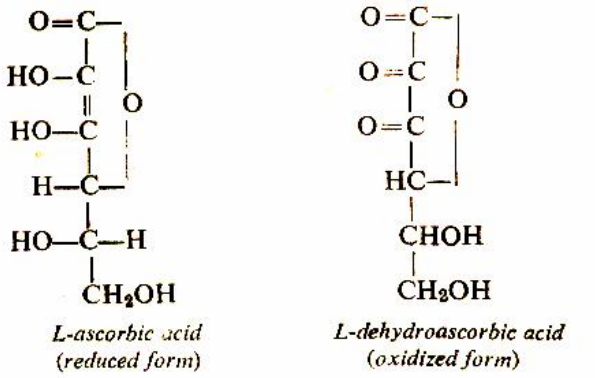
Vitamins are a special group of organic substance which are chemically unrelated. They may be organic acids, amines, amino acids, esters, alcohols, steroids, etc. these vitamins are traditionally divided into two subgroups on the basis of their solubility properties, such as water soluble vitamins and fat soluble vitamins.

1.3.6 WATER-SOLUBLE VITAMINS

Vitamins C and B complex are water soluble substances.

Ascorbic Acid or Vitamin C: Ascorbic acid is a hexose derivative and is lproperly calssified as a carbohydrate. It is a white crystalline substance highly soluble in water. It is easily oxidized in solution and cooking destroys it. The vitamin is highly unstable in alkaline solutions.

This vitamin is required by lprimates and the guinea pig. All other vetebraes and some invertebrates as well as lants and most microorganisms can synthesize ascorbic acid from carbohydrates. It is an essential dietary factor, the deficiency of which causes painful disease of the oints and gums called scurvy.

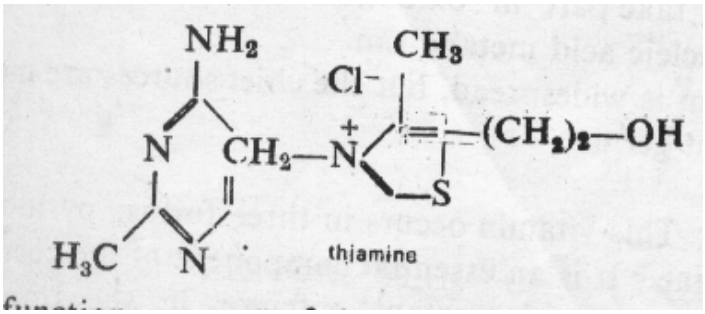


Hydroxyproline is an unusual amino acid found in the collagen and is essential for maintenance of normal tissues. It is formed by the hydroxylation of praline and this process requires vitamin C. in the absence of this vitamin the hydroxyproline production is very much reduced. Therefore, the collagen formed during ascorbic acid deficiency, contains negligible amount of hydroxyprolilne and this brings about structural abnormalities observed in scorbutic tissues.

Vitamin C is contained in fresh vegetables and fruits.

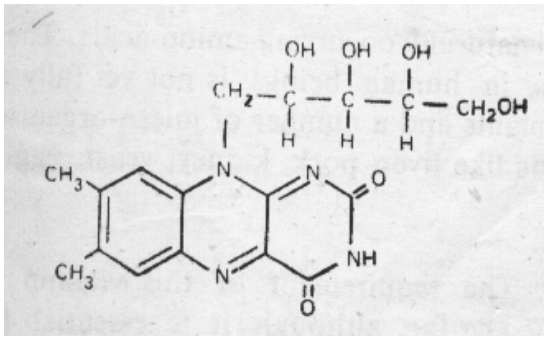
Vitamin B Group: Vitamin B group contains about twelve known vitamins. Each one performs specific function. They are collectively called vitamin B complex and are generally found together.

Thiamine or Vitamin B: This vitamin is contained in yeast, milk, egg, peas and beans hence richly distributed in plants, animals and certain micro-organisms. A deficiency of this vitamin causes a serious disease known as beriberi. Its symptoms are inflammation of nerves, muscular weaknes andparalysis of limbs.

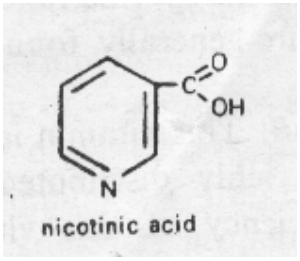


Thiamine functions as part of the coenzyme cocarboxylase which is the coenzyme for pyruvic decarboxylase and for several other enzymes which are necessary for the oxidation of pyruvic acid to acetyl – CoA. And and α-Ketoglutaric acid to succinyl-CoA

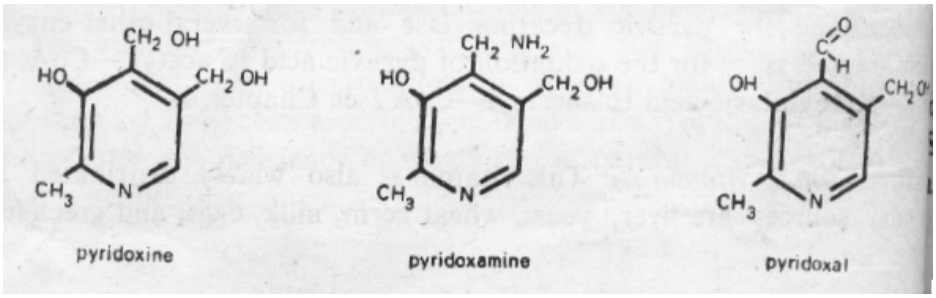
Riboflavin or vitamin B_2: This vitamin is also widely distributed and the rich sources are liver, yeast, wheat germ, milk, eggs, and green leafy vegetables. Its deficiency causes cracks in the corners of the mouth and dermatitis of the face. The eyes become inflamed and there is dimness in vision. This vitamin is a part of two coenzymes, flavin mononucleoide (FMN) and flavin adenine dinucleotide (FAD) which are linked to proteins as flavoproteins.



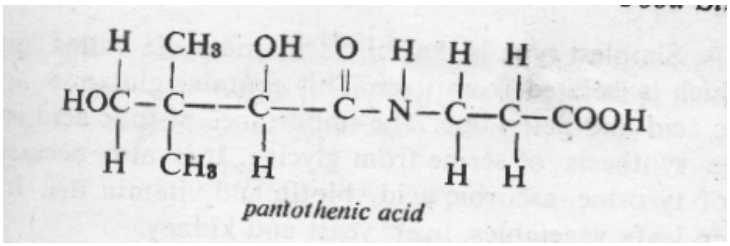
Nicotinic acid or niacin: Nicotinic acid is an essential dietary requirement. Tryptophan is its precursor which is converted into nicotinic acid through a series of biochemical reactions. Its deficiency in dietcauses a disease pellagra wahich is characterized by dermatitis, diarrhea and nervous. Disorder. This vitamin (niacin) is a component of coenzymes like DPN and TPN which take parat in oxidation-reduction of carbohydrates, fats, proteins and nucleic acid metabolism.



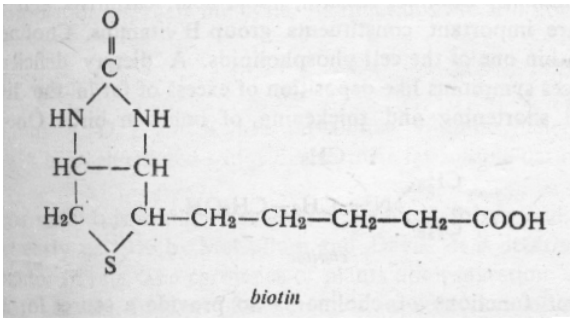
Vitamin B_6: This vitamin occurs inthree forms; pyridoxine, pyridoxal and pyridoxamine. It is an essential component of the coenzyme pyridoxal phosphate which is an important cofactor in the transamination and decarboxylaton of all naturally occurring amino acids. The dietary requirements of vitamin B_6 in human beings is not yet fully established. It is synthesized by green plants and a number of micro-organisms. The vitamin is found in many foods like liver, portk, kidney, yeast, egg-yolk grains and various seeds.



Pantothenic acid: The requirement of this vitamin in human beings has not been established so far, although it is essential for many other animals. Pantothenic acid is essentially a portion of the coenzyme a molecule which has a key role in the metabolism of fats, carbohydrates and amino acids. Its role has been fully determined in rats where the lack of this vitamin induce retardation of growth, reproduction impairment and graying of black hair. The rich sources of this vitamin are liver, yeast, eggs and royal jelly. This is synthesized by green plants and some microorganisms.

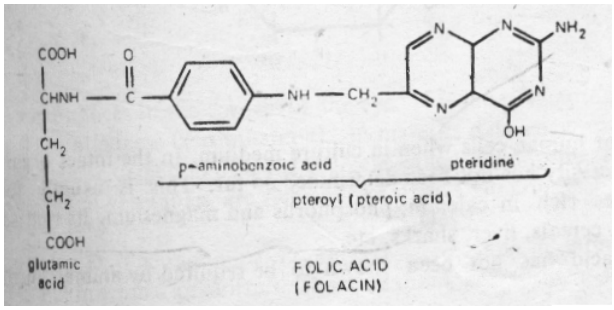


Biotin: Biotin requirements in man have not been determined so far, but its importance in other animals has been amply demonstrated. However, recently it as been shown that this vitamin is necessary in fatty acid synthesis. It is also necessary for growth and respiration of certain species of bacteria. Rich sources of biotin are liver, yeast, kidney and egg-yolk. Some animals obtain their biotin requirements from the biosynthetic activity of their intestinal bacteria.



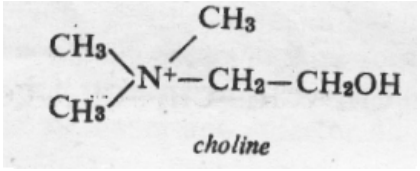
Folic acid: This vitamin exists in several different forms depending upon the biological source. Its importance has been established in a number of animals. Simplest type is the folic acid molecule called pteroylglutamic acid, which is isolated from liver. This contains glutamic

acid,paraaminobenzoic acid and peteridine. The importance of folic acid, biotin and vitamin B 12.It is also necessary in the metabolism of tyrosine, ascorbic acid,bition and vitamin B 12.it is chiefly found in green leafy vegetables, liver ,yeast and kidney.

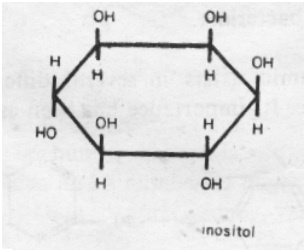


Vitamin B 12.This Vitamin occurs in nature in a variety of forms .Its chemical structure is complex and contains a metal cobalt,cyanide,ribose sugar and other components. This vitamin has been shows as a very important growth factor for many animals,man and micro-organisms.A deficiency of this vitamin causes called pernicious anemia in higher animals.The vitamin is found in-liver,kidney,meat and milk,etc.,and takes part in the metabolism of proteins,fats carbohydrates and nuclic acids.

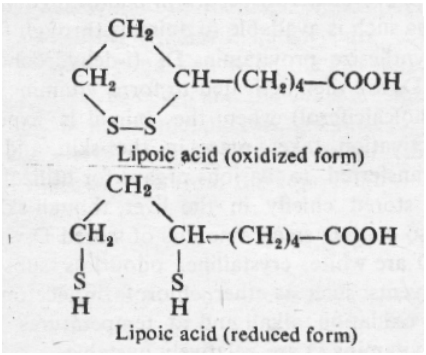
Other B vitamins: Chlorine,inositol,lipoicacid,carnitive and pantothenic acid are important constituents group Bvitamins.Chlorine is a protein of lecithin one of the cell phospholipids. Adietary deficiency of choline produces symptoms like depositionof excess of fat in the liver of mammals and thickening of bones in birds.One of the most important



functions of choline is to provide a source for methyl groups (CH3) in cell metabolism. It is abundantly found in egg,liver ,meat,kidney,and brain.Inositol is a growth factor for several yeasts and fungi and also for human cells when in culture medium.In the intact organisms (man)its necessity has not been determined so far.This is usually found in substanced rich in calsium,phosphosorus,and magnesium.Its rich sources are milk,cererls,liver,shsrks,etc.



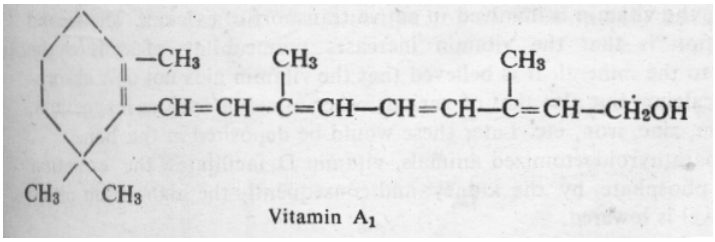
Lipoic acid has not been to be required by animals in their diets although it is a growth factor for certain micro-organisms. It is an 8-corban compound containing sulphur.However,it function in plants,animals and micro-organisms as hydrogen carrier in the metabolism of pyruvic acid. Carnitine is found to be necessary in certain insects and is responsible for the completion of their life cycle.Its functions are still not known.



1.3.7 FAT-SOLUBLE VITAMINS

Vitamins A,D,E and K are fat-soluble vitamins. Their enzymatic role has not been encidated so far due to their fat-soluble nature.

Vitamin A : It is avaible in several chemical forms and was recognized as early as 1913 by Mccollum and Davis. It is determined to be a growth factor in rats. The carotenes of plants upon ingestion are converted into this vitamin. In most of the animals, a deficiency of this vitamin causes retaedation of growth,drying out of epithelial cells and deposition of horny substances in the corner of the eye.This latter symptom leads to conditions of blindness(Xeropthlamia).In man,its deficiency causes night blindness causing depletion of a red pigment called rhodopsin. Fish liver,milk,cheese and vegetables are rich sources of this vitamin.



Vitamin A_1

Vitamin D: The vitamins D are all sterols and in nature they are chiefly found in animal organisms,These vitamins are formed from their provitamins which are also sterols. In mammals vitamin D can cure or prevent rickets-a disease in which bones fail to calcify.For this reason they are also called anti ricketic vitamins.

The provitamins D2 (ergosterol)occurs in plant kingdom(i.e.in ergot and in yeast)and as such is available to animals through food.Man and other animals can synthesize provitamins D3 (i-dehydrocholesterol). The provitamins D2 and D3 are then activated to form vitamin D2 (calsiferol) and vitamin D3 (cholcalciferol) when the animals is exposed to ultraviolet rays. The activation takes place in the skin and the vitamins are subsequently transferred to various organs for utilization. A part of the vitamins D is storsed chiefly in the liver, through skin,brain,lung,spleen,and bones also contain small amounts of stored D- vitamins.

Pure vitamins D are white, crystalline, odourless substances soluble in fats and fat solvents such as ether, chloroforms, acetone and alcohol. They are resistant to oxidation, alkali and to temperatures below 140^0C. in acid media these vitamins D are relatively unstable.

Functions of vitamins D: Vitamin D is essential for the normal growth of the bone. In case of deficiency of this vitamin, deposition of inorganic bone minerals fail to occur in the newly formed bone matrix, but the matrix continues to form. The provisional zone of calcification would no longer be clearly demarcated, but is irregular and deformed. In children rickets is a skeletal deformation and can be noticed in the form of bowlegs, knock-knees, rachitic rosary (beaded appearance on ribs at the juncture of the rib bones and the costal cartilage), and pegion-breast. In adults it leads to late rickets (osteomalacia).

Another important function of vitamin D is to increase the intestinal absorption of calcium. To explain the mechanism by which the vitamin aids calcium absorption, two explanations have been given. According to the first, the vitamin is involved in active transport of calcium. The second explanation is that the vitamin increases permeability of cells of the mucosa to the mineral. It is believed that the vitamin aids not only absorption of calcium but also that of various other minerals such as magnesium, beryllium, zinc, iron, etc. later these would be deposited in the bone.

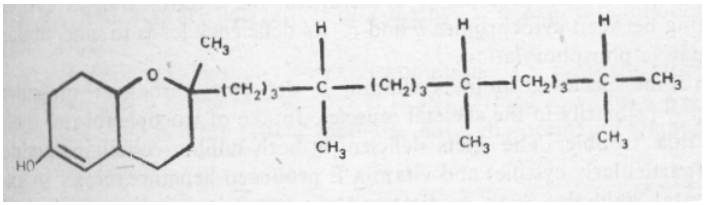
In parathyroidectomized animals, vitamin D facilitates the excretion of the phosphate by the kidney, and consequently the high serum phosphate level is lowered.

Sources of vitamin D: The main source of vitamin D are fish liver, oils and milk. Vitamin D are not widely distributed in nature but both provitamins are widely distributed. Although

provitamin D_2 is a common occurrence in vegetation, vitamin D_2 is not lpresent in living plants. Animals are the only source of 7-dehydrocholesterol. These provitamins require sunlight, to be transformed into active form.

Vitamin E: Vitamin E was discovered in the year 1922 and it has been known as antisterility vitamin. First discovered as an essential compound for the normal reproduction in male and female rats. Its absence causes death and resorption of fetuses, and testicular degeneration in rats. Compounds possessing vitamin E activity are chemically known as tocopherols. This name is derived from the Greek in which tokos means child birth; perhos means to bear; and the suffix –ol signifies an alcohol.

These are seven forms of tocolpherols and each form, despite its difference due to the position of methyl groups, is called vitamin E. all these different E-vitamins are derived from the compound –tocol



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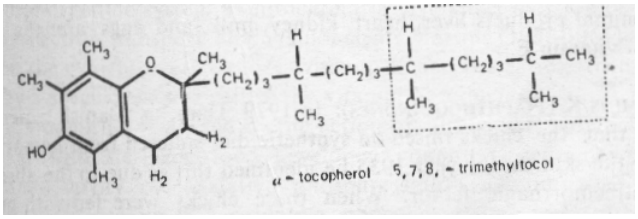
The difference between the various forms of tocopherols is in the structure of the molecule. The various tocopherols are:

α-tocopherol: 5, 7, 8—trimethyltocol
β-tocopherol: 5, 8-dimethyltocol
γ-tocopherol: 7, 8-dimethyltocol
η-tocopherol: 7-methyltocol

of these tocopherols, the α-tocopherol is mot widely distributed among animals.



Function of vitamin E: The absence of vitamin E in the diet hampers the normal reproduction in both the sexes in rats. In females it causes death and resorption of fetuses and in males it brings degenerative changes in the testes. In the mouse, only the females seem to suffer from this vitamin deficiency resulting in death and resorption of foetueses. However, in case of hamsters only the males are affected and result in testicular degeneration. In cattle, sheep, or goats

neither the deficeiency nor the concentrated doses of this vitamin seems to have influence on the reproductive performance.

Vitamin E has a powerful antioxidant property and protects vitamin A, carotene and ascorbic acid from oxidative destruction both in the digestive tract and in the body tssues. As a result of this protection these vitamins retain their properties long enough to facilitate the body to use them more efficiently.

In some species of animals vitamin E deficiency produces muscular dystrophy primarily in the skeletal muscles. Intake of trocopherol-rich diets cures this trouble. The diets deficient in both sulphur-containing amino acids (particularly cystine) and vitamin E produced hepatic necrosis in experimental animals. Such a dietary liver necrosis can be prevented by providing the animals with adequate amounts of sulphur-containing aminoacids, and vitamin E along with selenium.

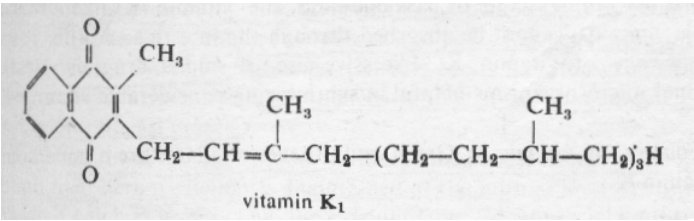
Vitamin E increase the nucleic acid turnover rate in skeletal muscles.

There is no clear evidence to suggest that vitamins E is essential to man. Even though its level in the serum is considerably reduced for 10 to 22 months, no significant clinical or physiological effects have been noticed. In human beings the administration of this vitamin neither brought any relief from sterility, nor cured human muscular distrophy.

A deficiency of vitamin E is unlikely to occur firstly because of the ability of the body to store it. Storage is mostly in the liver though small quantities do exit in other organs and tissues.

Sources of vitamin E: Richest sources of this vitamin are vegetable oils such as wheat germ oil and cotton seed oil. Leafy-green plants and vegetables as well as whole grain cereals are also rich sources of vitamin E. among animal products liver, heart, kidney, milk, and eggs are the best sources of vitamin E.

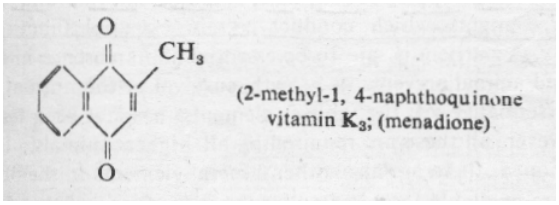
Vitamins K (Naphthoquinones): In 1929 Dam, a Danish scientist observed that the chicks raised on synthetic diet suffered from hemorrahage under the skin. In the year 1935 he identified this as due to the absence of an antihemorrhagic factor. When these chicks were fed with green leaves, the hemorrhagic syndrome disappeared. He therefore reasoned that these foods contained the antihemorrhagic factor and named it as vitamin K-symbolizing the Danish term, "Koagulation Faktor". The vitamin was isolated in apurified form from alfalfa by Dam and his associates in the year 1939. in nature it occurs in two forms-as K_1 in green leaves and as K_2 when produced by bacterial sysnthesis.



vitamin K_1

These K_1 and K_2 are derivatives of 2-methyl-1, 4 naphthoquinones and soluble in oils.

The compound 2-methyl- 1, 4-naphthoquinone is a synthetic form of this vitamin and is called menadione. It is also termed as vitamin K_3. It is water soluble and is more potent than the naturally occurring vitamins K.



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Functions of vitamin K: The arenchyma in normal liver produces prothrombin which is one of the factors required for blood clotting. The function of vitamin K is to catalyze the synthesis of prothrombin. In the absence of vitamin K, hypoprothrombinemia occurs and this greatly delays the blood clotting. Administration of vitamin K alleviates hypoprothrombinemia if the hepatic parenchyma is healthy enough to produce prothrombin. In cirrhosis the lparenchyma fails to lproduce prothrombin and in such a case vitamin K has no effect.

It is known that vitamin K functions in electron transport and oxidative phosphorylation system in mitochondria. The exact location of vitamin K in the electron t ransport chain is not clear. Martium (1956-1961) suggests that first the cytochrome b oxidizes vitamin K and reductase.

The vitamin K_1 is altered by the action of ultraviolet radiation. Rats when fed with sterilized food developed vitmin K deficiency and as a result the activity of oxidative phosphorylation was impaired. When supplied with vitamin K, oxidative phosphorylation was restored as usual. This suggests the important role of this vitamin in oxidative phosphorylation.

Normally, dietary vitamin K deficiency is unlikely to occur firstly, because it is fairly well distributed in foods and, secondly because the micro-organisms in the intestinal tract synthesize considerable amounts of it. However, deficiency of this vitamin can occur when liver or gall bladder fail to secrete or pass bile fluid, the vitamin K like other fat soluble vitamins, cannot be absorbed through the intestine and this results in deficiency of vitamin K. excessive use of sulpha drugs can destroy intestinal micro-organisms helpful in synthesizing considerable vitamin K.

Sources of vitamin K: Green leafy tisues of plants are a good source of vitamin K.

1.3.8 CONCLUSION

Vitamins can be described as accessory food factors which are essential for some metabolic reactions within the cell and which must be provided in the diet in minute amounts. In many animals they cannot be synthesized by the body. Certain animals do synthesize a few vitamins in very minute quantities but they fall short of the requirements. Ina any case the animals

should procure them through food. Vitamin deficiency results in several diseases characteristic of each vitamin deficiency.

1.3.9 EXPECTED QUESTIONS

1. Write in detail the role of enzymes in digestion
2. Describe the functions of vitamins and their defficency diseases
3. Write short notes on
    a. Water soluble vitamins
    b. Role of E vitamin

1.3.10. REFERENCE BOOKS

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Lesson 1.4

MINERALS AND THEIR ROLE IN BIOCHEMICAL REACTIONS AND SIGNIFICANCE IN METABOLISM.

CONTENTS

1.4.1 INTRODUCTION

In addition to proteins, carbohydrates and lipids animal body requires mineral elements which serve structural and physiological functions. Calcium, phosphorus, sodium, potassium, magnesium, iron, selenium, molybdenum, manganese, copper, cobalt, zinc, sulphur, chlorine and iodine are the mineral elements which conduct certain essential functions in the animal body a nutrient is said to be essential if its absence in the diet of the concerned animal prevents its growth, survival or the normal functioning the essentiality of the above elements has not been tested for all species; however, all these are required by all higher animals. Besides the above mentioned, there are also other mineral elements in the body tissues. All these ae available to animals through diet. Some of the elements are merely retained in the body while the essential function of a few others is yet to be discovered. Recent investigations have been bringing to light the useful functions of fluorine and chromium. These two elements may also be entitled to be classified under essential elements.

1.4.2 CALCIUM

Calcium goes in the formation of hard structures like bones and teeth and about 90 percent of all body calcium is concentrated in these structures. Small amounts of calcium are present in blood, inter and intracellular fluids, laying a fundamental role. About half of the calcium in these fluids is present in the form of free joins and this is essential for a variety of processes. A major role of calcium is in the regulation of ion transport across the cell membranes. Calcium exerts a profound effect upon neuromuscular irritability. High concentration of calcium stimulates the contraction of heart muscle

Calcium level in the blood is maintained independent of its intake through diet. Serum calcium is maintained at the normal level by the parathyroid. If calcium level is low the calcium from the bones is added into the blood. Certain enzymes-lipases, ATPase of actomyosin and myosin, cholinesterase, and succinic dehydrogenase-require calcium for their activation. Calcium is necessary for blood coagulation.

1.4.3 PHOSPHORUS

Phosphorus accounts for 12 gm/kg of fat free tissue in the human body. Out of this abut 85 percent is present in skeletal tissue in the inorganic form. The total phosphorus content in both the plasma and the RBC may range from 30 to 45 mg/100 ml blood.

Organic phosphates are very much involved in the cellular functions in all cells. The high energy compound ATP supplying energy to all cellular activities contains phosphorus. Phospholipids in cellular membranes help in the permeability.

Phosphorus is a widely distributed mineral in the food stuffs. Hence dietary deficiency of it is unlikely to occur in the human body. Grazing livestock depending on grass and herbage of the phosphorus deficient soils, lose appetite and appear emaciated. Such animals resort to eating materials such as bones wood, clothing, etc. depending on accessibility.

1.4.4 MAGNESIUM

The body magnesium is about 0.5 gm/kg of fat-free tissue. Of this, bones hold about 60 percent. Small amounts of magnesium is present in the extra cellular fluid the normal amount of magnesium is 1-3 mg/100 ml of serum.

Next to potassium, the concentration of magnesium is greater in the cells of the soft tissues, and a loss of magnesium would mean tissue breakdown and cell destruction. Magnesium is necessary in oxidative phosphorylation leading to the formation of ATP.

All enzymatic reactions requiring thiamine pyrophosphate (TPP) and the various reactions in the lipid and protein metabolism also need magnesium. Magnesium deficiency does not appear to occur in human beings because of their universal distribution in foodstuffs. Green vegetables

contains fairly good amounts of magnesium. Severe diarrhea or excessive vomiting however, cause magnesium deficiency in human beings.

Magnesium deficiency brings about personality changes, muscle tremor, gastro-intestinal disturbances. Decrease in magnesium also brings down the levels of serum calcium and potassium.

1.4.5 SODIUM, POTASSIUM AND CHLORINE

These, unlike the previously described minerals, are largely present in the fluids and soft tissues. Maintenance of osmotic pressure and acid-base equilibrium, regulation of the movement of nutrients into the cells, and participation in the water metabolism are some of the functions carried out by these minerals. These minerals need to be regularly taken through diet because the body has limited storage capacity. When the availability of these minerals to the body is limited, they are excreted in lesser quantities. The body thus conserves them. The deficiency of any one of these elements is followed by lack of appetite, loss of weight and production in the adult, reduction in growth, and decreased blood levels.

Sodium:

The body contains approximately 1.8 gm of sodium per kg fat-free body weight. Although a larger proportion of it is found in the extracellular fluids, studies indicate that some of the sodium is bound in the bones. Sodium together with calcium, magnesium, and potassium in the extracellular fluid are basic in reaction. Sodium forms about 93 percent of the bases in the blood serum and hence is highly concerned in maintaining neutrality.

Sodium is capable of passing across the cell membrane. During the process of nerve transmission and muscle contraction, a temporary exchange of extracellular sodium and intracellular potassium takes place. Subsequently this sodium is pumped out of the cell.

A dietary deficiency of sodium does not occur in human beings. His diet generally contains more sodium than necessary. Sodium is readily absorbed and it circulates through the entire body. It is excreted through the kidneys as chlorides and phosphates. Aldosterone, a hormone of the adrenal cortex is responsible for the reabsorption of sodium from kidney tubules. Absence of this hormone increases sodium excretion and brings out deficiency symptoms. A major portion of sodium is lost in man at hard work, particularly in summer. Vomiting, diarrhea, or profuse sweating would result in increased loss of sodium. A lack of this mineral would also reduce the utility of digested protein and energy and prevents reproduction.

Potassium

The human body contains about 2.6 gm of potassium/kg fat-free body weight. Unlike sodium a larger proportion of potassium is present as a chief caution in the intra-cellular fluid. The body conserves more potassium than sodium. Potassium is concentrated mainly within the cells. Potassium aids in the maintenance of osmotic pressure and acid-base balance in the cells-sodium and chloride mostly located outside the cells, potassium inside the cells.

Potassium is required in carbohydrate and protein metabolism, in the formation of glycogen, and in the degradation of glucose. Investigations suggest that potassium is an activator of enzymes. It may play an important role in the amino-acid uptake by the cell.

Potassium transfer across the membrane takes place more easily than that of sodium. Most of excessively absorbed potassium is normally excreted through urine and sweat.

Like that of sodium, the potassium deficiency does not occur in human beings under normal conditions of health. Hypopotassiemia results due to excessive excretion of potassium through the kidney. Body burns, excessive vomiting and diarrohea also result in the loss of potassium. Such a loss is supplemented by the depletion of body potassium.

Potassium deficiency is characterized by muscular weakness; and weakness of skeletal muscle results in paralysis. Its deficiency in chicks retards growth, incapacitates legs and finally leads to death.

Chlorine:

Unlike sodium and potassium, chlorine is distributed in large concentrations both in intracellular and extracellular fluids. It is the chief anion of the extracellular fluid and a greater part of it occurs in combination with sodium. A small amount, i.e. about 15 to 20 percent of the chlorine is in combination with protein and other organic substances. Chlorine with phosphate and sulphate groups, and protein is acidic in reaction. The chlorine transfer between the serum and erythrocytes is easily performed and this phenomenon is termed as the chloride.

This is an example of homeostatic mechanism by which the pH of the blood is maintained. In addition, chlorine is an essential component of the gastric hydrochloric acid, and activates the amylase of saliva for the starch splitting process.

Dietary deficiency of chlorine is unlikely to occur owing to its abundance in the normal diet. Moreover, the body is capable of storing certain amount of chlorine in the skin and subcutaneous tissues. The chloride content of a teaspoon full salt is about 4.2 gm. The chlorine transfer across the membranes generally takes place by passive diffusion. However, in gastric and intestinal mucosa the transfer is by active transport.

The same factors causing sodium loss are responsible for chloride loss. However, its loss due to vomiting is high because of excessive lose of hydrochloric acid from the stomach.

1.4.6 IRON

The iron content in human body is about 75 mg per kg of fat-fee body weight. It is widely distributed throughout the body. Though the element is present insmall quantities, it plays a key role in life processes. It is a constituent of the respiratory pigment, the haemoglobin. The haemoglobin. Four haeme molecule is also a component of cytochrome C peroxidase, catalase, and other enzymes. Iron is also present in the plasma bound to a specific globulin called transferring. About 55 to 60 percent of the body iron is in the blood.

Some iron is also present in the myoglobin a compound present in skeletal and heart-muscle; and it has greater affinity to oxygen. A considerable amount of iron (about 26 percent of total body content) is stored in the liver and, secondarily, in the spleen, in the kidneys and in the bonemarrow.

Intestine, excepting the colon part, is capable of absorbing iron. The absorptionis highest in the duodenum and it decreases progressively towards ileum (Brown, 1963; Mjoore and Dubach, 1962). The absorption is efficient in the ferrous (reduced) state. The absorbed iron goes directly into the blood. Once iron enters the blood stream it would be held by the body. The excretion of iron through the blood in the intestine is very minute. Iron excretion through urine is less than 0.2 mg per day. The iron released from the breakdown of RBC is saved and reused.

The absorbed iron would leave the body in significant quantities as a result of loss of blood. Iron deficiency anemia occurs in women and children due to the lack of building stone necessary for haemoglobin synthesis. Iron deficiency anemia is the commonest of the nutritional amemias. Its deficiency may be due to dietary inadequacy or due to poor absorption, or due to excessive loss of blood. The haemoglobin level of a person with iron deficiency is lower than the normal, and the size of the RBCs are smaller that normal (hypochromic microcytic anemia). As a result of this condition the oxygen carrying capacity is lessened, and the tissues receive less oxygen resulting in fatigue.

Iron requirement through diet varies in various animals. Chickens require 40 mg per kg of diet, while pigs need 80 mg per kg. ruminants requirement varies between 25 to 40 mg per kg. young people between 15 and 18 years of age and women between 18 and 55 of age require an intake of 15 mg of iron per day. Adults require 10 mg per day.

Liver, as food, is an excellent source of iron. Meat products and eggs also contain iron in generous amounts. Iron content of leafy-green vegetables is fairly good.

1.4.7 SULPHUR

The body has abut 0.15 percent of sulphur. Sulphur. Sulphur is principally located in the sulphur-containing amino acids, i.e. cystine and methionine. This element is also present in saliva, bile, glutathione and insulin. But these are synthesized in the body with the help of cystine and methionine

Sulplhur is present as chondroitin sulphate in the cartilage. It is also present in minute quantities in the blood. Thiamin and biotin also have small quantities of sulphur but these vitamins are not synthesized inside the body.

Sulphur is excreted through faeces and urine. In urine it is present as inorganic sulphates, ethereal sulphur and neutral sulphur. Neutral sulphur occurs in the form of cystine, thiosulphates, and other compounds.

Little is known about the effects of sulphur deficiency in man and animals. Wool contains about 13 percent of cystine. However, cystine feeding did not improve the wool production in sheep. There is also no evidence of any relationship between these dietary deficiency of sulphur and the lack of hair growth in humans.

Body acquires sulphur in the form of organic complexes, i.e. amino acids. These amino acids are constituents of proteins and hence available to the body through protein diet. Wheat germ, cheese, kidney beans are very rich in sulphur .

1.4.8 TRACE ELEMENTS

Body contains many t race elements, of which only a few are known to take part in cellular metabolism. Dietary deficiency of iodine and cobalt are known to obstruct normal physiological functioning. Trace elements are required in minute quantities. They are widely distributed in most of the foods and hence are available to the body in sufficient quantities. The very fact that these trace elements are in small amounts in the body, suggests that they play primarily catalytic roles in the cellular metabolism.

Deficiencies of some trace elements have been reported in cattle grazing on plastures grossly deficient in these elements. Excess intake of certain trace elements may result in toxic effects. Studies on trace mineral metabolism were handicapped by two basic problems. First being the precise determination of infinitesimal quantity of trace element in foods, blood and other tissues, second being the total purification of the diet form the trace element. Essential nutrient is that substance which by its absence in the diet of experimental animals would effect growth, survival or the normal functioning.

1.4.9 COPPER

The human body has about two mg of copper per kg of fat-free body weight. Though present in all body tissues, copper is observed in highest amounts in brain, heart and kidneys.

Copper deficiency causes an anemia in which the erythrocyte synthesis and the level of total body iron is reduced. Inadequate copper in sheep cattle, and pigs results in abnormalities in bone structure. Extreme loss of protein under certain pathological conditions would result in low copper level in serum. Evidence on specific dietary deficiency of copper in human body is lacking. However, there are reports when anemia in children has responded to the administration of copper but not to iron.

1.4.10 MANGANESE

Very loaw concentrations of this mineral are found in all animal tissues, but high concentration of it is present in pituitary, liver, pancreas, skin, bones and muscles. Highest concentration of manganese is in the bone.

Managane se is required in the body since it can replace magnesium as cofactor for certain phosphorylations. It is probably also required to incorporate acetate into fatty acids, and in the conversion of mevalonic acid to squalene in the cholesterol synthesis.

Dietary deficiency of manganese is unlikely to occur in human, but such a deficiency has been demonstrated in rats, chicks, pigs, etc. In rats, its deficiency effects the normal process of reproduction and lactation. In such cases the females fail to suckle their young, and the lactation. In such cases the females fail to suckle their young, and the males suffer degeneration of reproductive organs. In chicks the deficiency results in an abnormality of leg bones known as perosis or slipped tendon. The leg bones shorten and undergo physical and chemical changes.

High intke of manganese retards growth in rats; and in dogs it causes only gastric disturbances. Men inhaling ore dust containing managanese oxide develop manganes toxicity, the symptoms of which are a peculiar mask-like expression of the face, involuntary laughing, low voice with indistinct speech, apastic gait, and tremors of the hands.

Manganese requirement in man is not known. The average diet of man contains about 4 mg of this substance per day. Wheat brain, blueberries, whole wheat are the richest sources of managanese.

1.4.11 IODINE

Iodine is an important dietary nutrient required for a normal functioning of thyroid gland. Body contains infinitesimally small quantity of iodine. The quantity of total iodine in the body varies from 20 to 30 mg. one-third of this is concentrated in the thyroid gland. Next to thyroid, highest concentrations of iodine have been found in ovary, muscles, and blood. Small quantities of the remaining iodine are lpresent in the other tissues.

Though this element is observed as iodine, in the thyroid gland it quickly gets oxidized to iodine and goes in the formation of thyroglobulin. The thyroid gland serves as a store house for

iodine. The body conserves some iodine when thyroxine, one of the iodine containing compounds breaks down in the normal process. This is again reused by the body. Iodine is excreted chiefly through the kidney. It is also excreted through intestine, and through the skin by way of perspiration. Iodine is secreted into the milk during lactation.

Thyroxine and other ompounds of thyroid gland which contain iodine as an essential component, serve important physiological functions. The function of thyroxine is therefore attributed to that of iodine. Increase in the secretion of thyroid hormone would slpped up the rate of oxidation in the cells. In the absence of thyroxine, this rate of energy metabolism is retarded. Thus the rate of metabolism or the basal metabolic rate is an indicator of the normality of thyroid function. Hypersecretion of the hormone increases the basal metabolic rate and hyposecretion results in low rate.

Thyroxine is also essential for the normal growth and development. Undersecretion of thyroxine retards growth and a prolonged undersecretion lprevents physical and mental maturity. In children thyroxine deficiency causes cretinism. Its symptoms are retarded growth; arrested development; coarse and swollen facial features; thick, dry wrinkled skin; enlarged tongue; thickened lips and partly opened mouth. In adults the deficiency causes myxodema awhich is symptomized bythe thickening of subcutaneous tissues, in particular that of face and extremities. The face is expressionless and the person becomes lethargic. Besides iodine is also necessary for normal reproduction, absence of iodine supply for a prolonged lperiod may result in sterility or the birth of deformed progeny. Lack of iodine in the foods is due to deficiency of this mineral in the regional soil from where they are grown. This causes simple goiter which is endiemic. Endemic goiter can be cured by constantly providing iodized table-salt in the food.

Iodine content in foods is extremely small and a quantitative determination of this element is possible only by sensitive chemical method. Its content in foods varies greatly and is dependent on the soil condition. Marine or deep-sea fishes and shell fishes have high iodine content. Anadromous fishes (Salmon, sea trout, etc.) have higher iodine content than those fishes that live all the time in fresh water. The leaves of vegetables such as spinach, turnip, and broccoli have higher iodine content than in their roots.

1.4.12 ZINC

Animals and plants have small quantities of zinc in their body, most of this mineral is present in the liver, bones, and blood. The exact function of this element in the body is unknown, though its presence is reported in several enzymes and hormones. The respiratory enzyme carbonic anhydrase present in the RBCs contains zinc. The zinc in this enzyme hastens the breakdown of carbonic acid in lings in the process of exchanging carbon dioxide for oxygen. Zinc is an essential component of one of the protein splitting enzymes of the pancreas. Several dehydrogenases present in the liver also have zinc in their structure. Zinc is present in the crystalline styructure of insulin. Of the several types of insulins manufactured, the protamine-zinc insulin is in wide use, because in this from the insulin is absorbed more slowly into the tissues.

Zinc deficiency in rats and mice results in the reduction of growth rate, and loss of hair around neck and shoulders, in pigs in causes parakeratosis the symptoms of which are retarded growth, a lesion of the horny layer of the skin, and lowered feed utilization. In chicks it deficiency symptoms are slow growth, shortened and thickened long bones and poor feathering. Calves supplied with low zinc ration develop alopecia, parakeratotic skin lesions.

High level of zinc in the body would cause zinc toxicity the symptoms of which are growth depression, anemia, and decreased copper level in the liver. When in excess, it interferes with the function of copper in the formation of iron-prophyrin compounds, and thus leads to anemia. Excessive amounts o zinc also interfere in the iron metabolism. Zinc deficiency is unlikely to occur in animals and man, firstly because of its presence in most natural diets and secondly because of its retention power. Oysters, wheat germ, and brain are richest inzinc. Fruits and vegetables contain only small amounts.

1.4.13 COBALT

Animal body requires cobalt in small amounts and gets it through the diet. Cobalt is present as a part of the vitamin B_{12} and this is synthesized in the rumen with the help of bacteria. This vitamin is not present in the plant foods consumed by t he ruminants. Since vitamin B_{12} is synthesized in the body it is not a dietary essential vitamin B_{12} and thus the cobalt is necessary in the formation of RBCs.

The cobalt requirement in animals varies. T eh requirement of cobalt in mg per kg of ration is 0.05-0.07 in cattle, 0.08 in sheep and 5.8 in the case of horses. Animals grazing in deficient soils do not get cobalt and consequently they fail to synthezsize vitamin B_{12}. in case of cattle and sheep, absence of vitamin B_{12} leads them to restlessness, loss of appetite and weight, weakness and anemic, and finally to death.

If cobalt intake exceeds the normal requirement, the RBC number in blood increases. This increase is called polycythemia and has been observed in rats, guinea pigs, rabbits, dogs, pigs, children and man. Polycythemia is a normal occurrence in people living at high altitudes and this helps them cope with the lower percentage of oxygen there. The daily need of cobalt in different animals has not been established. The average diet normally supplies the required amounts of cobalt to man.

1.4.14 MOLYBDENUM

Moybdeum is another trace element which is found essential in nutrition. Molybdenum is an essential factor for the formation and maintenance of xanthine oxidase of some animals. In man the function of this mineral is yet to be known. This enzyme, essential in the oxidation of aldehydes and purines, is present in liver and intestinal tissue, and also in milk, molybdenum is an essential nutrient and is always available to the animals through their diet,. For this reason neither animals Norman show the symptoms of molybdenum deficiency. However, excess intake of this element causes reduced growth rae and death in rats; retarded growth, loss of weight, low haemoglobin and RBC counts, alopecia and malformed leg bones in rabbits; loss of weight and change in hair coat in calves.

Legumes, cereal grains, dark green vegetables, liver and kidney are rich in molybdenum.

1.4.15 SELENIUM

Dietary intake of traces of selenium is required in certain foods (milk, brewer's yeast, meat, and some kinds of cereals) is capable of preventing ill effects caused by vitamin E deficiency in rats and chicks. This is termed factor 3. from this factor, Schwarz and Foltz 91957) isolated selenium salts are also effective in the prevention of exudative diathesis in chicks, and the muscular dystrophy in lambs.

The mechanism of selenium function is not completely established, but it clearly has a role in metabolism of tocopherol compound.

Selenium toxicity in farm animals grazing on selenium rich soils is well known. The symptoms of selenium poisoining are emaciation, loss of hari and hoofs, cirrhosis of liver, and skeletal erosions.

The toxicity seems to be due to inhibition of certain enzyme systems. Linseed oil meal, arsenilic acid, and organic arsenicals effectively counter the selenium toxicity.

1.4.16 CHROMIUM

Schwarz and Mertz (1959) suggested that trivalent chromium is an essential dietary requisite in rats. Chromium probably acts as a cofactor with insulin in carrying out the glucose metabolism. Chromium deficiency retards growth in male and female rats and results in a syndrome similar to that caused by diabetes mellitus (Schroeder, 1966).

1.4.17 CONCLUSION

Though all these elements are needed by the animal body, the quantity of requirement of certain elements such as calcium, phosphorus sodium, potassium, magnesiu,, sulphur and chlorine is fairly large. Iron. Managanese, copper, cobalt, zinc, iodine and molybdenum are required in minute quantities. Elements like selenium and chromium appear to serve certain functions in metabolic systems.

Minerals from organic complexes can be removed either by dry ashing or by wet ashing. In the former process the material is heated to high temperatures in muffle furnace, and in the latter process materials are dissolved in strong acids. In addition there are other techniques for assaying trace minerals in organic complexes (Sandell 1959, AOAC 1960, and Oser 1965).

1.4.19 EXPECTED QUESTIONS

1. Describe the role of calicum and phosphorus in the process of digestion and metabolisam
2. Write short notes on the role of the following in metabolisam
    a. Sodium
    b. Potasium
    c. Chlorine
    d. Megnesium

3. Write in detail the role of minerals in the process of digestion.

1.4.20 Reference Books

1. Hoar, W.S. General and comparative physiology. Prentice Hall of Inida, New Delhi
2. Harper, H.A., Rodwell, V.W. and mayes P.A. Review of physiological chemistry. Lange medical publications, California.
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Lesson 2.1

RESPIRATION AND TRANSPORT OF GASES IN ANIMALS

CONTENTS

2.1.1 INTRODUCTION

Respiration is a physiological process occurring in all living organisms. It involves oxidation of food stuffs by which they obtain energy for carrying out all other metabolic activities. On taking in of the fresh air from atmosphere into the lungs and expelling out of the used air from lungs to the exterior.

Initially the term respiration (Latin: respirare=to breath or to exhale) was applied to the exchange of gases between the organism and its environment. But once it was realized that the actual exchange of gases occurs at the cellular level, the process of inhaling and exhaling the air was described as breathing, the process of exchange of gases occurs at the cellular level, the process of inhaling and exhaling the air was described as breathing, the process of exchange of gases at cellular level is described as internal respiration or tissue respiration and respiration is the chemical process of oxidation of food stuffs taking place within the cell cytoplasm (mitochondria) and results in the release of energy.

2.1.2 Mechanism of breathing

The process of breathing can be separated into two distinct steps:

1. Inspiration or breathing air into the lungs.
2. Expiration or expelling out air from the lungs.

The movement of air in and out of the lungs occurs because of alternate changes in intrapulmonary pressure which is brought about both during inspiration and expiration by the contraction and relaxation of diaphragm and the intercostals muscles.

A. Inspiratory mechanism

During inspiration the size of the thoracic cavity increases in all directions. The enlargement is brought about by the flattening of diaphragm and lifting up of the thoracic basket.

The diaphragm is formed of a thin sheet of radial muscles present on the floor of thoracic cavity. Its margins are attached to lumbar vertebrae posteriorly and laterally and to the sternum anteriorly. In resting position it is dome-shaped. During inspiration, when the radial muscles contract, the diaphragm flattens and descends down into the abdominal cavity. As a result thoracic cavity enlarges in antero-posterior direction.

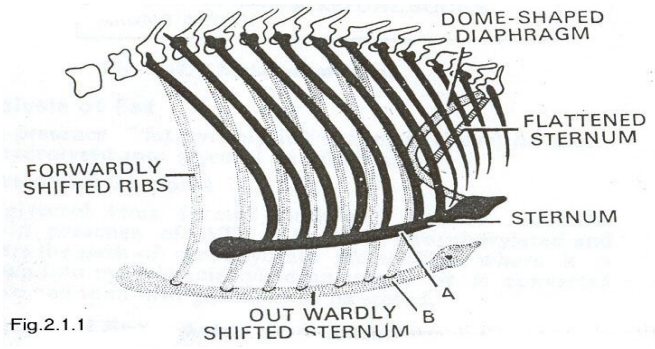


Fig.2.1.1

The ribs are provided with two sets of muscles- external intercostals muscles and internal intercostals muscles. During inspirations the external intercostals muscles and the intercartilaginous portion of the internal intercostals muscles contract pulling the ribs forward and outward and thereby bringing about the enlargement of thoracic cavity. When the thoracic cavity increases in size, the pleural cavities expand and negative pressure is increased in it. Now the lungs enjoy greater space and expand. As a result pulmonary pressure is lowered below the atmospheric pressure. Therefore, a suction force is created and the atmospheric air rushes in through the respiratory passage.

B. Expiratory movements

During expiration, the changes occur in opposite direction. Due to relaxation of radial muscles of diaphragm and contraction of internal intercostal muscles the diaphragm and ribs are brought to their original position and form. The diaphragm assumes dome-shaped appearance. Therefore, the volume of thoracic cavity is reduced and so also the negative pressure of the pleural cavities. This exerts pressure on lungs and the air filled in the lungs is compressed and is squeezed out. As a matter of fact the expiratory phase is a passive event in breathing.

The extent to which the movements of thoracic cage and diaphragm play part in respiration varies from animal to animal and from year to year in the same animal. The lungs are not totally emptied by any movement of breathing and some air is left in air passages. Therefore, the air is never changed completely during inspiration but is merely freshened up.

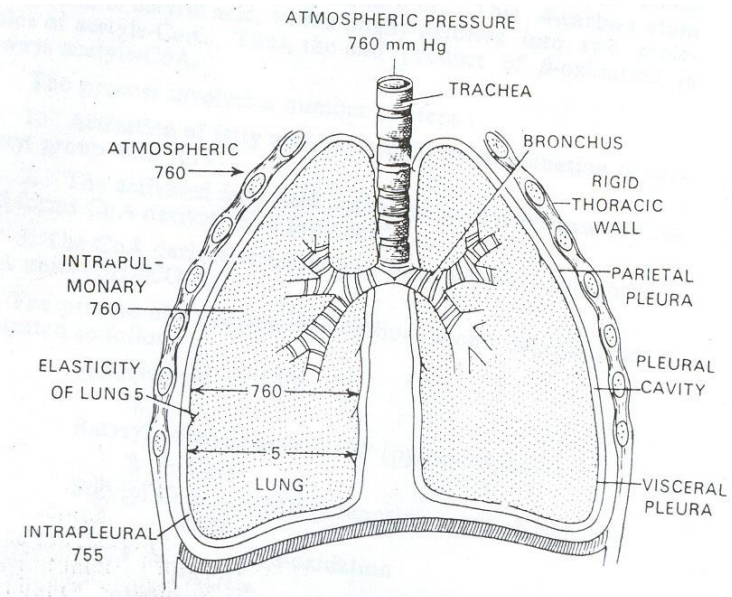


Fig. 2.1.2 Diagrem of thoracic cavity showing intrapulmonary and intrapleural pressures with chest wall in resting position.

Respiration is an involuntary process and is carried out automatically at a constant rate under normal conditions. The contraction of various respiratory muscles at proper time and with proper strength to secure adequate gaseous exchanges is coordinated by a complex series of reflexes maintained by the nervous system and also to some extent by CO_2 concentration. The breathing reflexes are controlled in the following ways:

2.1.3 PHYSIOLOGY OF RESPIRATION

The physiological aspect of respiration can be conveniently studied under the following heading:

1. External respiration
2. Transport of oxygen byblood
3. Internal respiration
4. Transport of carbon dioxide by blood

1. External respiration

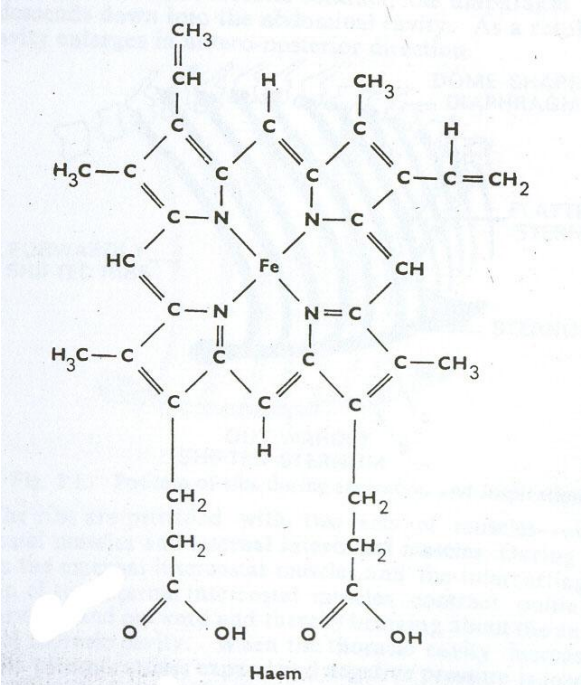
a. Exchange of gases in lungs – the exchange of oxygen and carbon dioxide inside the lungs is known as external respiration. The exchange takes place between the alveolar air and the blood present in the pulmonary capillaries in the wall of alveoli.

As a result of breathing, fresh air with more oxygen reaches the lungs and fills in the alveoli. The wall of the alvoli is very thin and possesses a network of capillaries. The blood inside the capillaries has a low concentration of oxygen, but higher concentration of CO_2. Oxygen from the alveolar air passes into the oulmonary capillaries and CO_2 from the capillaries passes into the alveolar air simply by the process of diffusion, i.e. each gas diffuses from a region of higher concentration to one of a lower concentration. Diffusion of gases occurs only in dissolved condition. For this reason the inner surface of the alveoli is lined with mucus.

b. Formation of oxyhaemoglobin – In mammals about 15-20 ml. Oxygen is carried per 100ml. Of blood. This all is not carried in free state. Since only 2% oxygen can dissolve in 100ml. Of plasma at normal atmospheric pressure, the rest combines with the respiratory pigment, haemoglobin, present, in the R.B.Cs. In region of high oxygen concentration haemoglobin combines with oxygen and forms a temporary compound, the oxyghaemoglobin.

$$\underset{\text{Haemoglobin}}{Hb} \rightleftharpoons \underset{\text{Oxyhaemoglobin}}{HbO_2}$$

There is a definite (proportion of oxyhaemoglobin to haemoglobin; present in the blood at any time. It depends upon the tension or partial pressure of oxygen in the blood and is represented by the dissociation curve of oxyhaemoglobin. At a partial pressure of oxygen of approximately 70mm. Hg, a molecule of haemoglobin becomes fully saturated and is completely converted into oxyhaemoglobin. Any increase in oxygen tension does not change the amount of oxyhaemoglobin formed.



Fi . 2.1.3. Structural formula of heme.

c. Release of CO_2-CO_2 in blood is always in combined state which forms bicarbonates, carbonic acid and loose carbamino compounds. These compounds are carried to the lungs where these break down under the influence of following factor and liberate CO_2:

(i) $H_2CO_2 \xleftarrow[\text{Carbonic anhydrate}]{} H_2O + CO_2$

(ii) $2NaHCO_2 \xleftarrow[\text{Acidity of oxyhaemoglobin}]{} NaCO_2 + H_2O + CO_2$

(iii) $2HbNHCOOH \xleftarrow[\text{Reduction}]{} HbNH_2 + CO_2$

The CO_2 liberated in this manner diffuses out of the capillary walls into the alveolar air.

3. Transport of Oxygen :

Oxygen in combined state (oxyhaemoglobin) is carried by blood to different organs and tissues, where it is enclosed inside thin-walled capillaries.

Internal Respiration or Cellular Respiration :

(i) Dissociation of oxyhaemoglobin :

Inside the tissues the continuous metabolism of glucose and other substances results in a continuous production of CO_2 and utilization of O_2. Consequently, the concentration of oxygen in the tissue fluid and cells is always lower and concentration of carbon dioxide is always higher than in the capillaries. In the regions of low oxygen concentration, oxyhaemoglobin breaks down, releasing oxygen which diffuses out from the blood capillaries to the tissue fluid and from there to each and every cell.

$$HbO_2 \rightarrow Hb + O_2$$

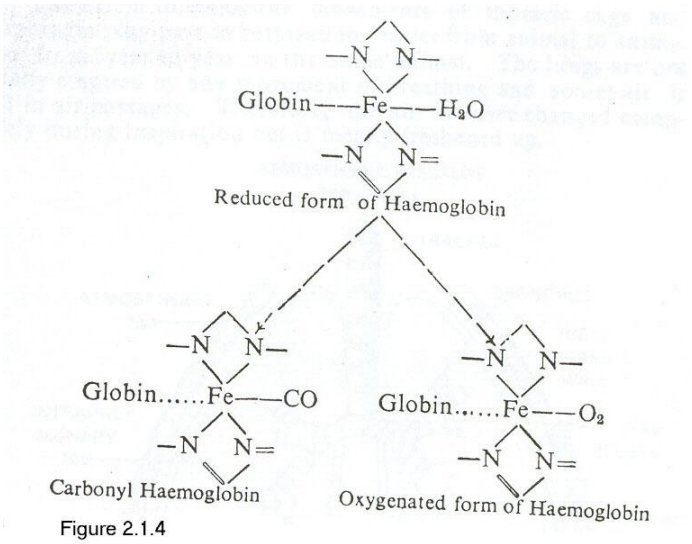


Figure 2.1.4

The dissociation of oxyhaemoglobin is also controlled by the concentration of CO_2, which of course does not occur in free state but dissolves in water to form H_2CO_3 and increases acidity and thus results in the dissociation of oxyhaemoglobin.

$$CO_2 + H_2O \rightarrow H_2CO_2$$

(ii) Oxidation of foodstuffs :

The oxygen, which enters the cell cytoplasm oxidizes the glucose or other food substances in presence of special respiratory enzymes and liberates energy, breaking down glucose into water and CO_2.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6HO_2 + (\text{energy})$$

4. Transport of CO_2 :

The CO_2 produced as a result of oxidation of foodstuffs diffuses out of the cell into the tissue fluid and then into the blood of capillaries. This is transporated both by plasma as well as by erythrocytes in three different conditions :-

(1) In Simple Physical Solution in the Plasma as Carbonic acid

As soon as CO_2 enters the blood, a part (5-10% or about 2.7 c.c.) of it dissolves in water of 100 ml venous blood to form carbonic acid. It dissolves in plasma and is transporated as simple solution.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

(2) As Chemical Compounds

Two types of compounds are formed with CO_2 in blood –

(i) As Bicarbonates in the R.B.C

Only 5-10% of the total amount of carbon dioxide is transporated as carbonic acid. In the normal course the formation of carbonic acid is a slow process and much of the CO_2 diffuses into the red blood corpuscles, where in the presence of enzyme carbonic anhydrase the speed of carbonic acid formation is considerably enhanced. The carbonic acid ionises to form bicarbonate with the release of hydrogen ions.

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

H_2CO_3 combines immediately with the potassium salt of haemoglobin.

H_2CO_3 + KHb	→	$KHCO_2$	+	Hb
Potassium Haemoglobinate		Potassium bicarbonate		free haemoglobin

(ii) As Bicarbonates in Plasma

The potassium bicarbonate formed in the R.B.C. immediately ionises into –

$$KHCO_3 \rightleftharpoons K^+ + HCO_3$$

The bicarbonate ions diffuse out in the plasma and the chloride ions from the plasma diffuse in the corpuscles. The chloride ions probably diffuse into the RBCs and combine with K^+ ions to form KCl,

$$H_2CO_3^- + 2\ NaCl \rightarrow NaHCO_3 + Cl^-$$

The exchange of Cl^- and HCO_3^- ions between plasma and R.B.Cs in known as chloride shift.

The above reactions are reversible. Hb in lungs combines with oxygen and forms oxyhaemoglobin and H^+ ions are liberated. In presence of H^+ ions KCl dissociates and Cl^- ions again diffuse into the R.B.Cs, Where these decompose liberating CO_2. These reactions helps in maintaining a constant pH in the plasma.

(b) By phosphate buffers :

The alkaline phosphate present in plasma combines with carbonic acid that is formed by the combination of H_2O and CO_2. This results in the formation of sodium bicarbonate :

$$Na_2HPO_4 + H_2CO_3 \rightleftharpoons NaH_2PO_4 + NaHCO_3$$

(iii) In combination with plasma proteins as temporary carbamino compound (NHCOOH)
(a) With plasma proteins in blood plasma :

About 10% carbon dioxide forms loose carbamino compounds. The amino acids on oxidation produce two different groups, the amino group (NH_2) and carboxyl group (COOH). The amino group combines with carbon dioxide and forms carbamin proteins. These occur in 1% conc. in arterial blood and 1.1% in venous blood.

$$NH_2 + CO_2 \rightarrow NHCOOH$$

Carabmino compound

(b) With haemoglobin in RBCs :

Some CO_2 forms loose chemical compounds haemoglobin with of blood. For example, haemoglobin combines with CO_2 to form carbamino haemoglobin.

$$HbNH_2 + CO_2 \rightarrow HbNHCOOH$$

Thus in the process of respiration the oxygen moves from a region of high concentration to one of low concentration (from lungs to blood and from blood to tissue) and is finally used in the cells. Similarly, CO_2 moves from high concentration to one of low concentration but course is reversed i.e. it passess from the cells, where it is produced, through the blood to the lungs and out.

Bohr's effect :

The oxygen and carbon dioxide transport are closely associated because increase in the concentration of CO_2 decreases the amount of oxygen that can be carried in the blood at a given partial pressure of oxygen. It means higher concentration of CO_3 stimulates more of oxyhaemoglobin to dissociate and release oxygen. In other words increase in the partial pressure of CO_2 accelarates the rate of oxyhaemoglobin dissociation. This fact can be represented by plotting a graph to show relationship between the partial pressure of oxygen and the percentage of oxyhaemoglobin in the blood at a given partial pressure of CO_2.

shows the oxygen dissociation curve of oxyhaemoglobin at 20, 40, 60 mm Hg partial pressure of CO_2. This shows that increase in the partial pressure of CO_2 shifts the O_2 dissociation curve towards right indicating that the concentration or percentage of oxyhaemoglobin in blood decreases with an increase in CO_2 concentration. This effect of CO_2 concentration on dissociation of oxyhaemoglobin was discovered by Christian Bohr and is known as Bohr's effect after his name.

2.1.4 NERVOUS CONTROL

1. Medullary respiratory centre (the vital knot of Flourens) is situated in the flooor of 4^{th} ventricle present in the medulla. The centre is bilateral and two halves are connected together b commissural neurons. The sides of this centre are connected with the motor respiratory neurons. The neuron cells of the centre are connected to the breathing apparatus with the motor as well as sensory or afferent and efferent nerves and thus maintain a reflex arc. These cells are sensitive to changes in the chemical organization of blood and concentration of CO_2 in plasma. Each half of the respiratory centre is composed of two parts: inspiratory centre and expiratory centre. The expiratory centre lies above the inspiratory centre. Out of the two only one works at a time. According to Pitts, Magoun and Ranson, the inspiratory centre worked in normal breathing and expiratory centre during forced expiratory conditions like sneezing, laughing and Coughing. The expiratory neurons are excited by the aforesaid stimuli, whereas inspiratory neurons discharge spontaneously.

In the wall of alveoli of lungs are present stretch receptors, which are stimulated by the expansion and relaxation of lungs and propagate inhibitory impulses to the inspiratory and expiratory parts of the respiratory cetre respectively.The receptors are innervated by the branches of vagus cranical nerve.

In addition, a pneumotoxic centre is present in the pons, which acts as an inhibitory nerve centre and connected with both inspiratory and expiratory parts of respiratory centre.

The respiratory centre is connected with the lungs, carotid sinuses, aortic arch etc. through afferent nerves, with the respiratory muscles through efferent nervs and with the pneumotaxic centre by both afferent and efferent nerves. The inspiratory centre propagates impulse spontaneously to the intercostals muscles. As a result of their contraction, the thorax and lungs expand and in doing so stimulate the stretch receptors. The stretch receptors initiate impulses at a

very high rate which are propogated by afferent neurons in the vagus nerve to the pneumotaxis centre. The activated pneumotaxic centre is inhibitory in nature and sends impulses to the expiratory centre. The expiratory centre then inhibits inspiratory centre. As a result inspiration ends and expiration starts. This reflex was described by Hering and Breuer and is described as Hering and Breuer reflex.

B. Chemical Control

Respiration is controlled to some extent by the concentration of respiratory gases in blood. The respiratory centre is very sensitive to CO_2 concentration. If increase in tension is slight, breathing becomes deep and fast permitting more CO_2 to leave the blood. Similarly, O_2 concentration in blood affects the breathing rate but in opposite direction.

2.1.5 EXPECTED QUESTIONS

1. Explain the mechanism of respiration.
2. Give an account on physiology of respiration.
3. Describe tissue respiration.
4. Describe in detail, the transport of oxygen and carbondioxide through blood during respiration.
5. Describe the chemistry of respiration in vertebrates.
6. What is biological oxidation? Describe how energy is released in oxidation.

2.1.6 REFERENCES

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Lesson 2.2

GENERAL ACCOUNT OF CIRCULATORY SYSTEM IN ANIMALS

CONTENTS

2.2.1 INTRODUCTION

The efficient system of blood circulation is responsible for the maintenance of homeostatic mechanisms in the body. It is essential that the volume and the composition of the intracellular and extracellular fluids are maintained constant since the proper fluid balance would help the animal maintain its steady state. The volume of water and the concentration of the electrolytes are regulated through the circulatory system.

2.2.2 The blood volume

The volume of blood remains constant. In adult human beings the total volume of blood is about 5 litres. The average volume of blood is calculated on the weight basis, i.e. approximately 70 ml of blood for each kilogram body weight. The fluid volume of blood is not affected even when large volume of water is taken. T he excess amount of water is got rid of by enhanced urine output. Similarly, during haemorrhage, considerable amount of blood is lost which is soon restored to normal volume. After haemorrhage, the fluids from the tissues move into the blood vessels to restore the blood volume. At the same time the urine output is also lowered considerably to make good the losses. Apart from restoring the fluid volume of blood, the loss of

erythrocytes is also compensated by their increased rate of production in the spleen and the bone marrow.

Several methods are in use for determining the total blood volume in the body. The most reliable and efficient method is the radio isotope I^{131}. albumin does not diffuse through the capillaries. And I^{131} can be determined easily. If the plasma volume and the percentage of the blood corpuscles are known, the total amount of blood can be calculated as follows:

$$\text{Blood volume} = \frac{\text{Plasma volume X } 100}{100\text{-haematocrit}}$$

Generally, blood volume remains constant since the normal blood pressure has to be maintained at all times. However, under certain conditions the volume may vary within narrow limits. The plasma volume of mammals decreases at high altitudes, whereas the volume of the red blood cells increases.

2.2.3 Laws of circulation

Three major factors are involved in circulation and maintenance of pressures within circulatory channels:

1. Active state of the animal
2. Cardiac out put.
3. Peripheral resistance.

In small and primitive animals, the general activity of the animal is largely responsible for the blood flow. In higher animals too. The blood flow in certain specialized areas depends on this factor (for example, in small veins of birds and mammals). The cardiac output is largely responsible for the circulation since the blood volume and the force of the heart vary considerably. Peripheral resistance is an important factor in the vertebrates and larger invertebrates with closed circulation. The velocity and pressure of blood vary considerably within different areas governed by physical principles.

2.2.4 The components of circulatory system

The blood circulation has two purposes: it serves to supply nutrients and oxygen to the tissues, and removes wastes like carbon dioxide and others from the tissues. The essential components of the circulatory system are the heart, arteries, veins and the capillaries. Some information about their anatomy would be useful for the purpose of a better understanding of the circulatory process.

Arteries: The arteries are thick-walled and muscular vessels that carry the blood away from the heart. Structurally arteries are made up of three laryers: intima, media and externa. They may be large, medium and small. The medium sized arteries contain well developed musculature and are

further divisible into small arteries or arterioles. The walls of the arterioles also possess muscle layers which cause these vessels to constrict or dilate. This property of *Vasoconstriction* of arterioles is responsible for increasing the blood pressure to enable it to flow with a greater velocity. Arterioles are supplied with neurons which respond to sympathetic stimulation. In response to sympathetic stimulation chemical agents like norepinephrine are secreted with produce vasoconstriction. Other chemical agents like epinephrine, serotonin and angiotensin also produce the smme effect. If the vasoconstrictor neuron is severed, the arteriole dilates. Vasodilation can also be caused by the action of chemicals like acetylcholine, bradykinin, histamine, etc.

Veins: Veins are thin walled with fewer elastic fibers. The three layers present in the arteries are also present in the veins, but they are much thinner. Small veins are called venules. T eh larger vins of the abdomen and lower limbs possess valves which open in the direction in which the blood is flowing, i.e. towards the heart.

Capillaries: Capillaries are very fine blood vessels which are composed of a thin wall made up of a single layer of flat endothelial cells. The cells have a basement membrane which is continuous. Capillary wall is so thin that it allows transfer of gases or substances through it. Two types of capillaries can be distinguished:

1. True capillaries.
2. Sinusodial capillaries.

True capillaries are present in most tissues and have a lumen diameter ranging from 4 to 8 μ. Sinusoidal capillaries are channels with irregular diameter ranging form 5 to 30 μ. Such capillaries are generally found in blood forming tissues like thymus, lymph nodes, bone marrow, liver, spleen and adrenal cortex.

The capillary walls are permeable, but the permeability is not the same throughout the body. The capillaries of the liver are most permeable. In conditions of trauma permeability increase to the extent that even cellular elements can also pass through it. Although the capillary walls are very thin, yet they are capable of withstanding pressures as high as 90 m Hg or even higher.

2.2.5 Heart

The heart is a muscular organ which propels blood to various parts of the body. It is responsible for maintaining the direction of the flow with the help of the valves present in it. The heart contracts periodically to ensure continuous circulation and its stoppage would mean the death of the animal. In order to study the physiology of the heart, it is necessary to consider the action and the control mechanism of the heart.

2.2.6 Heart of Invertebrates

Acoelomaes do not possess blood vessels and hearts (exception Nemertines). Coelomic invertebrates have hearts which can be classified into three types:

1. Tubular hearts.
2. Pulsating hearts.
3. Ampullar hearts.

Tubular hearts

In arthropods, the systemic hearts consist of long, tubular contractile structures. The heart may be suspended in a large *pericardial chamber* by means of elastic ligaments or it may be free without any support. The heart is bathed in the surrounding haemolymph. In most arthropods (insects), the heart is held in position by special alary muscles and receives blood by means of lateral paired openings called ostia. The ostia are guarded by valves. These ostial openings close when the alary muscles contract, and the blood is pushed through the artery. Consequent upon the contractions of the heart, a negative pressure is created within the pericardial chamber thereby forcing the fresh supply of blood from the haemocoel into the heart throughteh ostia. The entire heart may show wave of contraction. In case of crustaceans, the blood passes from the heart into the arteries and arterioles and from there to the gills. The veins then bring back the blood to the pericardial chamber. The heart of tunicates is a convoluted tube situated in the pericardium. The heart pumps blood in one direction for some time and then the direction of the flow is reversed.

Pulsating hearts

Pulsating hearts are characteristic of annelids which have a closed circulatory system. These pulsatile hearts contract in peristaltic fashion. In the earthworm, rhythmic pulsatile movements are observed in the dorsal tubular vessel from the sposterior end to the anterior end. The lateral vessels, commonly known as hearts, also beat rhythmically independent of each other. In *Hirudinaria,* there are tow lateral channels which show alternate contractions.

Ampullar hearts

In certain animals ampullar hearts or accessory booster hearts are present which function as booster pumbps to force the blood with increased pressure. Such accessory hearts are commonly found in cephalopods and insects. In cephalopods, these hearts help in forcing the bloodinto small peripheral vessels. In insects they are situated at the base of the antennae. Wings and legs. In aphids. Booster hearts force the extracellular fluids into the legs.

2.2.7 Heart of vertebrates

The hearts of vertebrates are known as chambered hearts. Chambered hearts are also found in molluscs where one or two auricles and one ventricle are present. In the vertebrate series, fishes have tow chambers in the heart, the auricle and the ventricle. In addition, two

antechambers, the sinus venosus and the conus arteriosus are also present. The sinus venosus opens into the auricle and the conus arteriosus springs from the ventride. The venous blood entering the sinus venosus is brought into the auricle from where the blood comes into the ventricle which distributes arterial blood through the conus arteriosus. The two chambered hart attained more specialization in its structure with the evolution of land vertebrates. In reptiles for the first time the ventricle became incompletely divided by an incomplete ventricular septum. This ventricular septum became complete in birds and mammals. Birds and mammals have four chambered hearts, having two auricles and two ventricles. These hearts are highly specialized in their structure and function.

2.2.8 Structure of mammalian heart

The heart of mammals has attained a high functional efficiency. In order to understand the physiology, we can examine the human heart. In man the heart is situated in the thoracic cavity slightly displaced towards the left side. T eh wall of the heart is composed of three layers, namely, the *endocardium*, *myocardium* and the *epicardium.* The endocardium consists of connective tissues lined with a thin layer of endothelium. The myocardium is the principal muscle layer which is thin in the auricles and thick in the ventricle. The epicardium is make up of epithelial cells and connective tissue. The heart is enclosed in a pericardial membrane. The space between the pericardium and epi μ cardium is known as pericardial space which contains a fluid. The pericardial fluid lubricates the heart.

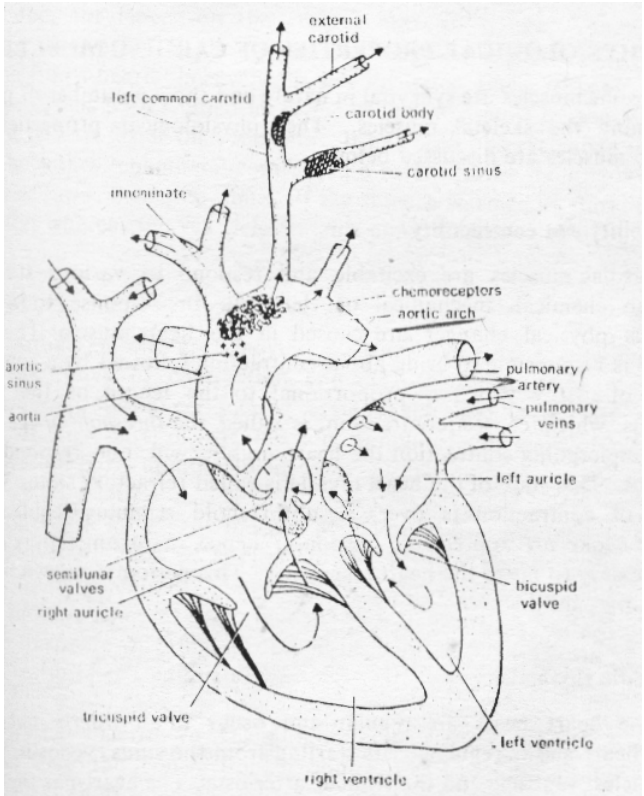

Figure 9.1. *Internal structure of the mammalian heart.*

The heart is four chambered. There are two auricles and two ventricles ensuring complete separation of oxygenaed and deoxygenated blood enters the right auricle from systemic circulation through the bvena cavae. The left auricle receives blood from the puhmonary circulation. The blood is then pushed into the two ventricles. The right ventricle receives deoxygenaed blood from the right auricle and pumps it into the pulmonary circulation. The left ventricle receives oxygenated blood form the left auricle and pumps it into the systemic circulation through the aorta.

The circulation of blood through the heart is guided by four valves. The left auricle opens into the ventricle guarded by a mitral valve which is bicuspid, and the opening of the right auricle into the ventricle is guarded by a *tricuspid valve* there is an aortic valve between the left ventricle and the aorta. The opening of the pulmonary artery into the right ventricle is guarded by a pulmonary valve.

2.2.9 Regulation of the heart

From the preceding descriptions it is clear that the heart possesses automatic rhythmicity and is governed by a self-regulatory mechanism. The greater the elasticity, the greater is the force

of contraction. However, the force of contraction depends upon nervous regulation and a number of other factors such as temperature and hormones.

2.2.10 Nervous regulation

The force of contraction is governed by the nerves innervating the heart. In many invertebrates, such as molluscs and arthropods, the heart beats are regulated by certain nerve centres. These nerve centres are localed in the centrally placed ganglia and may have acceleratory or inhibitory effect.

In vertebrates too, the heart beat and the blood flow are controlled by the nerves. The heart is innervated by the autonomic nerves and the integration is achieved through medulla oblongata.

The vagus nerves

The heart of mammals has a dual control. The vagus nerve (X Cranial nerve) contains both parasympathetic (motor) and sensory nerve fibres. The heart receives outgoing braches of the vagus and sympathetic nerve fibres from the upper thoracic region of the spinal cord coordinated through the medulla where the control centres are located. These control centres ae made up of a number of cell bodies which are of two types A. cardioinhibitor cente, and B. the cardoaccelerator centre. The inhibitor centre gives rise to parasympathetic nerves that travel to the heart and produce inhibitory effect. The accelerator centre gives rise to accelerator nerves that travel to the heart and produce inhibitory effect. The accelerator centre gives rise to accelerator nerves that travel down the spinal cord and have an accelerator effect on the heart. The cardiac activity is regulated by these centres through vagal and accelerator functions. Both the centres also send short neurons to each other, so that the activity of inhibitory centres can depress the accelerator centres and vice versa. The cardiac functions are also influenced by other parts of the brain such as thalamus and hypothalamus. These parts of the brain contain such centres which, upon stimulation, affect the emotional states of individuals and increase rate of heart beat, blood pressure during sleep and exercise.

The sinu-auricualr and auriculo-venticular nodes are innervated by the parasympathetic neurons. When the vagus neurons are stimulated, the force of contraction is decreased showing slow heart beats. The heart may stop completely, if stronger stimulation is given. Continued stimulation, however, induces the ventricles to regain contractions. The phenomenon is called *vagus escape.* In other words, the ventricles continues to beat independently without getting impulses from the auricles. This shows that the vagus has no direct effect on the ventricular activity, since the ventricles escape from the inhibitory influence of the vagus. The vagus has an inhibitory influence in suppressing the sinu-auricular and auriculoventricular nodes which stops the ventricle. But the continued beating of the ventricle is due to the action of the ventricular pacemaker.

The vagus nerves always send impulses to the heart which have a retarding influence on the rate of heart beat. This is called the vagal tone. When the vagus nerves are cut, the heart rate is accelerated owing to the loss of the inhibitory action of the vagus.

The sympathetic nerves

The sympathetic nerves or accelerator nerves arise from the second, third and fourth thoracic segments of the spinal cord and reach the cervical sympathetic ganglia. From these ganglia postganglionic sympathetic nerve fibres travel to the heart and innervate the sine-auricualr, auriculoventricular nodes and the muscle fibres of the heart. The sympathetic fibres, upon stimulation, accelerate the heart rate and increase the force of contraction. If the sympathetic nerves are cut, there is decrease in the heart rate, but if the parasympathetic nerves are cut, the heart rate increases. The two systems have an antagonistic function.

2.2.11 Chemical regulation

The cardiac functions are greatly modified by chemical substances which are eithe4r administered, or founding the blood. They may be secreted by the nerves innervating the heart muscles. These chemical substances may be classified as follows:

A. Neurotransmitters.
B. Drugs acting on the heart.

Neurotransmitters

The parasympathetic nerve fibres innervating the heart muscles secrete acetylcholine; hence, they are called cholinergic nerves. Acetylcholine reduces the frequency and force of contraction of the heart. When injected. Acetylcholine brings about ventricular arrest, but the auricular contractions continue as usual.

The sympathetic nerve fibres upon stimulation secretc noradrenaline which serves to accelerate the rate of heart beat and force of contraction. When injections of noradrenaline or adrenaline are given, they serve to increase the blood pressure and reflexly slow the heart. The smooth muscles of coronary arterioles are innervated by sympathetic fibres. The smooth muscles of arterioles in the viscera, muscles and the skin are also innervated by the sympathetic fibres. Upon stimulation by adrenaline or noradrenaline vasodilation occurs in the coronary arterioles, but in the arteroles of the skin and muscles vasoconstriction occurs.

In resting condition very little amount of adrenaline is present in the blood. Additional amounts of adrenaline are released in the blood when more energy is needed. Increased amounts of adrenaline cause vigorous supply of blood to the heart and muscles and elevation of blood sugar level. More blood supply to the heart is owing to accelerated heart rate and vasodilation in the heart and the muscle. Enhanced adrenaline secretions increase the breakdown of glycogen reserves; hence, increase in blood sugar is noticed.

2.2.12 Effect of drugs on the heart

1. Digitalis: It acts directly on the heart muscles and peripheral circulation. The drug has been in use for long since it increases tonicity of heart muscles, contractility and irritability. Hence the drug serves as a powerful cardiac tonic in increasing the force of contraction.

2. Pilocarpine, Muscarine, etc: When administered, cause slowing of the heart by acting on the heart muscles or vagal terminations. The effect of these drugs can be removed by atropine.

3. Atropine causes acceleration of the heart beat.

4. Serotonin (5-hydroxytryptanine) influences the blood pressure, in dogs it has a pressor influence whereas in cats it acts as a depressant.

2.2.13 Effect of temperature

The rate of heart beat is profoundly influenced by temperature. In most terrestrial poikilotherms, increase in the rate of heart beat is recorded with the increase in ambient temperature. This is owing to large amounts of blood needed for circulation. In homeotherms, however, the temperature of the body is maintained constant irrespective of change in the ambient temperature. The rate of heart beat remains constant, although while sweating and panting increased blood flow in the skin regions may be caused.

2.2.14 CONCLUSION

Lower groups of animals have very simple structure and do not require an elaborate circulatory system. In such animals the metabolic rate is low and the surface area body volume ratio is very high. In sample animals like Coelenterates, the transport of food particles and dissolved oxygen is achieved by water currents created by slow flagellar movements of endoderm cells. In small crustaceans blood is pushed through tissue sinuses by the movements of legs and internal organs. In large crustaceans, there is a dorsal tubular heart which pumps blood to different parts of the body through arterial vessels. The abdominal vessels open into the cavities or sinuses which are filled by the blood. The blood comes in direct contact with the tissues. Such circulatory systems are called open systems.

Vertebrates, on the other hand, have a closed circulatory system and the blood does not come in direct contact with the cells and tissues; however, the diffusion of gases, water and other smaller molecules is possible through the walls of the fine capillary network.

2.2.15 EXPECTED QUESTIONS

1. Describe the structure and fuction of mammalian heart.
2. Double circulation mammals.
3. General account of circulatory system in animals
4. Give the patterns of vertebrate circulation.
5. Give the patterns of invertebrate circulation.

2.2.15 REFERENCE BOOKS

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Lesson 2.3

PHYSIOLOGY OF HEART

CONTENTS

Each class of vertebrates has a quite uniform type of circulation, but differences among the classes are substantial. As vertebrate life changes from aquatic to terrestrial, the circulation becomes more complex.

There are two important consequences of the arrangement of mammalian circulation, both immediately apparent from the blood flow through the lungs and it must equal the blood flow through the entire remaining part of the body (except for minute transient variations that can be caused by slight changes in heart volume during one or a few strokes). Second, because both halves of the heart contract simultaneously, as blood is ejected from the heart, the entire ejected volume must be taken up by changes in the volume of the elastic blood vessels.

Fish and mammals represent two extremes in vertebrate circulation. The gradual separation of the heart into two separate pumps as the vertebrates progress from aquatic life to fully terrestrial respiration is shown is.

2.3.2 CYCLOSTOMES

The circulatory system of hagfish differs from that of all other vertebrates. It is partly an open system with large blood sinuses, rather than a closed system as in other vertebrates. Its notable characteristic is that in addition to the regular heart (the branchial heart), the hagfish has several accessory hearts, especially in the venous system. There are three sets of such accessory hearts: the portal heart, which receives venous blood from the cardinal vein and from the intestine and pumps this blood to the liver; the cardinal hearts, which are located in the cardinal veins and help to propel the blood; and the caudal hearts, which are paired expansions of the caudal veins. In addition to these accessory hearts, all located in the venous system, the gills take active part in the forward propulsion of the arterial blood. This is accomplished by contraction of striated muscular elements in the gills and gill ducts that helps propel the blood in the arterial system (Johansen 1960).

The caudal hearts of the hagfish are particularly interesting because they differ in design from all other hearts. A longitudinal rod of cartilage separates two chambers, and alternate contractions of muscles on the two sides cause the rod to be flexed. As the muscles on one side contract, those on the opposite side provide pressure for expulsion of the blood on that side. Simultaneously, the volume on the contracting side increases, so that this chamber becomes filled with blood. By alternate contractions, the two chambers fill and empty in opposing phase, while appropriate valving assures a unidirectional flow.

2.3.3 FISH

The circulation in fish, both teleosts and elasmobranches, is shown in . The heart consists of two chambers in series, an atrium and a ventricle. On the venous side the heart is preceded by an enlarged chamber or sinus on the vein, the sinus venosus, which helps assure a continuous flow of blood to the heart.

On the arterial side the teleost heart is immediately followed by a thickened muscular part of the ventral aorta, the bulbus arteriosus. The elasmobranch heart has a similarly located thickened part,the conus arteriosus, developed from the heart muscle, it is fibrous and is equipped with valves that prevent backflow of blood into the ventricle. This is particularly important because the elasmobranch heart, located in a rigid chamber, can produce negative pressures. A negative pressure in the heart facilitates the filling by “suction” of the atrium from the large sinus venosus.

The sequence of events in a fish heart during one contraction cycle can be followed on the pressure tracing shown in Fig.4.8. During contraction of the ventricle, the blood pressure rises and this pressure is transmitted to the bulbus arteriosus. As the ventricle relaxes, back-flow from the bulbus is prevented by valves, and the high pressure therefore persists in the bulbus after the ventricle begins to relax. The elastic properties of the filled

bulbus serve to maintain a flow of blood in the ventral aorta during the diastolic period of the heartbeat.

During contraction of the ventricle, the systole, the heart decreases in volume, and because the elasmobranch heart is located in a rigid chamber, the decrease in volume causes a negative pressure to develop in this chamber. In the Port Jackson shark the pressure in the ventricle during its contraction rises to above 30mm Hg (4.0kPa), and the sinus venosus may be as low as –4mm Hg (-0.6kPa) (Satchell 1970). Unless the large sinus and the adjoining veins could provide an equal volume of blood to flow into the atrium as the ventricle contracts, the negative pressure would only impede the contraction. With the inflow of blood, however, the negative pressure does not become excessive, but merely serves to fill the atrium. The filled atrium then contracts and forces blood into the ventricle that now is empty and relaxed, backflow into the sinus being prevented by valves. Thus, in this part of the cycle blood is merely shifted from atrium to ventricle, while the volume of the pericardial contents remains unchanged (Randall 1970).

In an air-breathing vertebrate, the sinus venosus and bulbus arteriosus decrease in importance, and in the mammalian heart they are not present as separate structure.

2.3.4 LUNGFISH

The major evolutionary change in lungfish is that, in addition to gills, they have lungs as respiratory organs. The gills in part receive blood that has already passed through the lungs. If the gills were similar to the gills of ordinary fishes, this might be a disadvantage, for a lungfish swimming in oxygen-depleted water would then lose oxygen from the blood to the water that flows over the gills. The lungfish gills, however, have degenerated, and some of the gill arches permit a direct through flow of blood.

The atrium of the heart is divided into two chambers by a septum, and the ventricle is partially divided. In this way the lungfish heart somewhat resembles the completely divided heart of mammals, birds, and crocodiles. The lungfish heart, in fact, shows an amount of structural division greater than that of any amphibian.

Blood from the lungs returns to the left atrium, and the right atrium receives blood from the general circulation. The partial division of the ventricle tends to keep the two blood-steams separated, so that oxygenated blood tends to flow into the first two gill arches and supply the head with relatively oxygen-rich blood. The less well oxygenated blood from the right side of the heart flows through the posterior gill arches and passes on to the dorsal aorta and in part to the lungs. The lungfish represents the beginning of a complete separation between circulation to the lungs and to the remaining parts of the body.

The anatomy of the lungfish does not explain how blood actually flows. Studies of live Aftrican lungfish (Protopterus) show that circulation to the lungs and circulation to the systemic vascular circuit have a high of functional separation, with preferential passage of oxygen poor blood to the lungs and oxygen-rich blood to the systemic circulation. It is particularly significant that the functional separation is highest immediately after a breath of air when the oxygen in the lungs is highest, whereas later in the interval between breaths, the degree of separation diminishes. This is of obvious importance for the efficiency of gas exhange in a lung that is filled with fresh air only at intervals.

2.3.5 AMPHIBIANS

The heart of the modern amphibians (frors, toads, salamanders) has two completely separate atria, but only one divided ventricle. The left atrium receives oxygenated blood from the lungs, and the right atrium receives venous blood from the general systemic circulation. Although the ventricle is undivided, the two kinds of blood tend to remain unmixed, so that oxygenated blood enters the general circulation and oxygen-poor blood flows separately into the pulmonary circulation.

The pulmonary artery also sends branches to the skin; this is important because the moist amphibian skin is a major site of oxygen up-take. The anatomical arrangement of the heart includes a longitudinal ridgelike baffle in the conus arteriosus (known as the spiral valve), which seems important in keeping the blood-streams separate.

Let us follow the circulating blood and its oxygen content in a bullfrog. The single ventricle of the heart pumps blood into the conus arteriosus, which separates the flow into two nearly equal streams, one running in the systemic artery that supplies the general body with blood of high saturation (S=85%), and the other stream with low oxygen (S=47%) running in the pulmocutaneous artery. This artery in turn supplies both skin and lungs.

When the frog breathes air, the blood leaving the lungs is well oxygenated (S=96%), and the blood coming from the skin also has an increased oxygen content but is mixed with venous blood from the tissues. The two streams that return to the heart remain almost completely separate within the one-chambered ventricle. The result is that mixing is of little significance and the systemic artery can carry blood with a high oxygen saturation.

Is there any advantage to this arrangement ? When the frog is submerged, there is no pulmonary gas exchange and the skin takes on the role as the only organ of gas exchange. There is now a further change; that is an increase in the systemic blood flow to the skin and as a result the mixed venous blood returning to the heart carries more oxygen.

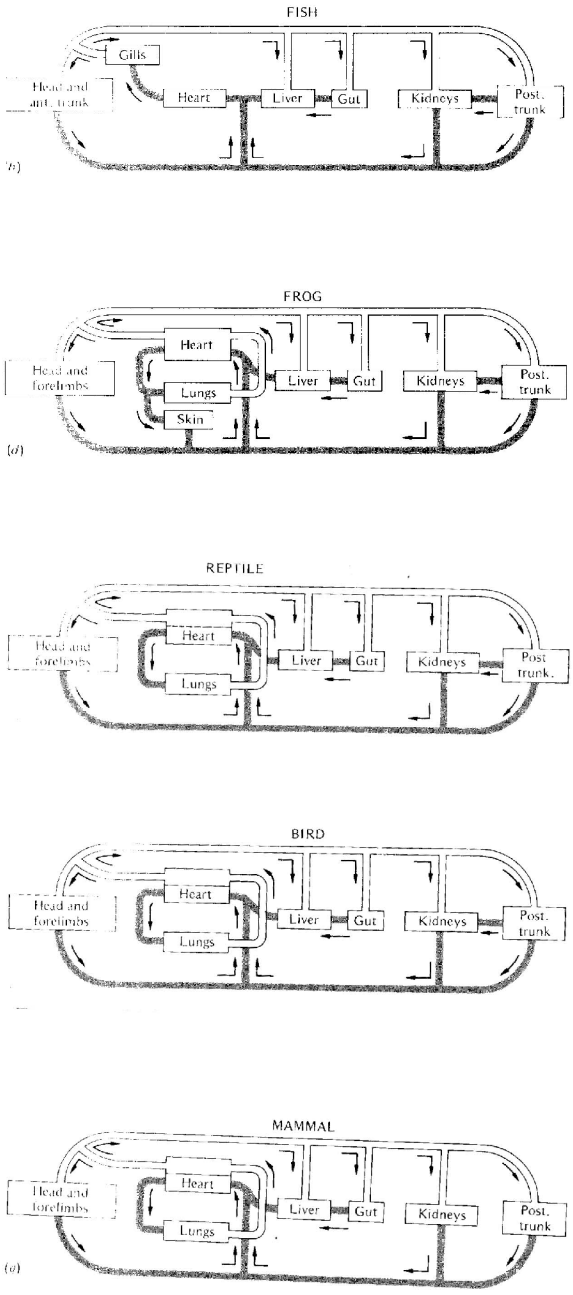


Fig. 2.3 Patterns of circulation in vertebrates

2.3.6 REPTILES

In a noncrocodilian reptile the atria are completely separated, but the ventricle is only partially divided . Even so, the streams of oxygenated and nonoxygenated blood are kept well separated so that there is very little mixing of the blood and there is, in effect, a well-developed double circulation. Thus, the incomplete division of the ventricle in amphibians and noncrocodilian reptiles cannot be interpreted simply on the basis of anatomical appearance; the bloodstreams remain much more separated than anatomical considerations would indicate.

In crocodiles both chambers of the heart are completely divided. This complete separation is confounded by the peculiar fact that the left aortic arch originates from the right ventricle and thus should receive venous blood. There is, however, a hole or foramen connecting the two aortic arches.

On an anatomical basis this has been used to argue that crocodilian circulation allows mixing of oxygenated and nonoxygenated blood, but more careful study shows that both types of blood remain separate and that both aortic arches carry unmixed oxygenated blood. During diving, however, the circulation changes: Blood flow to the lungs is decreased, and a major part of the output of the right ventricle is ejected into the left aortic arch. This shunt permits a rerouting of the blood during diving and a partial or complete bypass of the lungs.

2.3.7 BIRDS AND MAMMALS

The division of the heart and separation of pulmonary and systemic circulation are complete in birds and mammals (Fig.). This has one important consequence: The pressure can be different in the pulmonary and the systemic circulation. The resistance to flow in the pulmonary system is much lower than in the systemic circulation, and the blood pressure in the pulmonary circulation is only a small fraction of the pressure in the systemic part. Such a difference is, of course, not possible if separation of the heart is incomplete. Because incomplete separation has been retained in both amphibians and reptiles, this arrangement may have other advantages that are not well understood.

There are some differences between the circulation in birds and mammals that are of great significance in comparative anatomy. For example, mammals retain the left aortic arch, whereas birds retain the right. A difference of physiological importance is that the kidneys of all nonmammalian vertebrates receive venous blood from the posterior part of the body (the renal portal circulation). Birds have retained this renal portal circulation, but it is absent in mammals. This difference is important to the understanding of renal function.

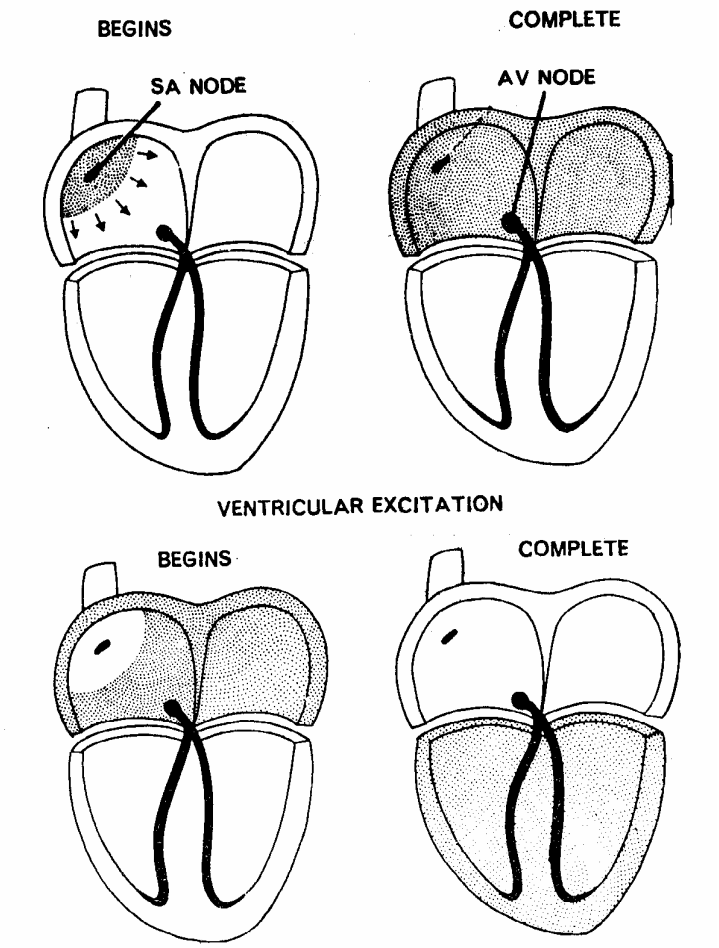


Fig. 2.3 Path of exitation and contraction and relaxation of heart chambers during heart beat in a myogenic heart.

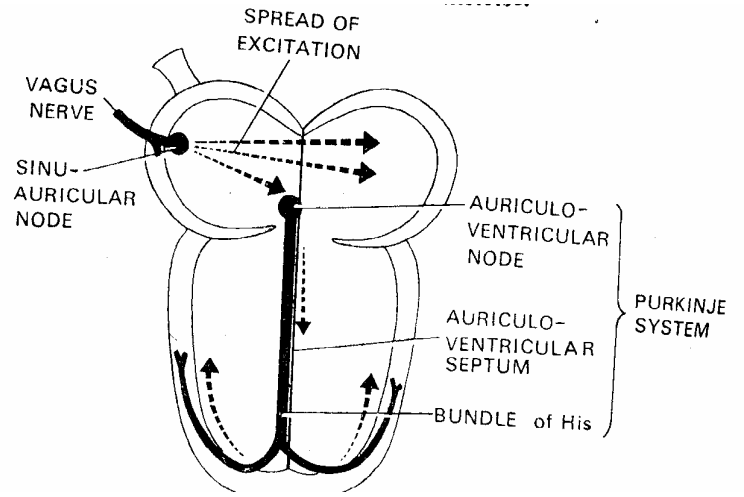
Heart and cardiac output

As a rule, a small animal has a higher rate of oxygen consumption per unit body weight than a large animal, and thus the heart of the small animal must supply oxygen at a higher rate. We have already seen that the oxygen capacity of the blood of small and large mammals is similar; as a consequence the heart of the small mammals must pump blood at a higher rate. Is the necessary increase achieved by a larger pump, by a larger stroke volume, or by a higher frequency ?

Size of vertebrate hearts

The heart sizes of a number of mammals are plotted in Fig. 4.10. As expected, heart size increases with body size, but surprisingly, relative to body size, small and large

mammals have about the same heart size. If the heart mass were exactly proportional to body mass, the slope of the regression line in Fig. would be 1.0; the actual slope is 0.98, which



Is statistically indistinguishable from exact proportionality. The equation for the line is $M_h = 0.0059\ M_b^{0.98}$, which says that the average mass (M_h) of the mammalian heart is 0.59% of the body mass (M_b in kilograms), irrespective of the size of the mammal.

The heart size of birds can be described by a similar equation: $M_h=0.0082\ M_b^{0.91}$. This equation says that heart size is not strictly proportional to body size; the body mass exponent is significantly less than 1.0, which means that, relative to body size, larger birds tend to have slightly smaller hearts than birds of small body size. A 1-kg bird can be expected to have a heart of 8.2 g; for a mammal of the same size the expectation is a heart of 5.9g.

The heart sizes of reptiles and amphibians are less well studied, but available data indicate that a reptile's heart size is about 0.51% of body weight; an amphibian's, 0.46%. These proportions are only slightly lower than in mammals, although the metabolic rates of reptiles and amphibians are about one-tenth the mammalian rate. Fish have smaller hearts again, about 0.2% of body weight.

To summarize, whether we compare the different classes, or animals of different body size within one class, the large differences in metabolic rates of vertebrates are not conspicuously reflected in the size of the heart. Differences in the need for oxygen must therefore be reflected primarily in pumping frequency, for the stroke volume depends on heart size, and the amount of oxygen contained in each volume of blood is not body-size-dependent.

Heartbeat frequency :

The heartbeat frequency, or pulse rate, is usually given as the number of heartbeats per minute. The pulse rate for an adult human at rest is about 70 per minute; in exercise the rate increases several-fold.

The heart frequency is clearly inversely related to body size. An elephant that weights 3000 kg has a resting pulse rate of 2.5 per minute, and a 3-g shrew, the smallest living mammal, has a resting pulse rate of over 600 . This means that in shrew the heart goes through 10 complete contraction cycles per second which is almost unbelievable rate. During activity, the heart frequency increases further, as much as 1200 beats per minute have been measured in hummingbirds and in small bats in flight.

If heart frequency is plotted relative to body mass on logarithmic coordinates, the are located close to a straight line. The equation for the line is $f_h = 241\ M_b^{-0.25}$. The slope of the regression line is negative; that is, the larger the body mass (M_b, in kilograms), the lower is the heart frequency (f_n).

In addition to the negative slope, the most significant information contained in this equation is the numerical value of the slope, which is 0.25. This is exactly the same as the slope of a regression line between body mass and resting oxygen consumption per unit body mass, the specific oxygen consumption.

There is now two important pieces of information: (1) the size of the pump, the heart, remains a constant percentage of the body mass, and (2) the increase in the pumping rate (the heart rate) in the smaller mammal increases in exact proportion to the need for oxygen.

2.3.8 EXPECTED QUESTIONS

1. Explain the physiology of heart beat in vertebrates.
2. What is heart beat? Explain the physiology of heart beat in detail.
3. Give an account of the conduction of impulses through the mammalian heart.
4. What is cardiac cycle? Describe pressure changes, sound changes and electric changes during cardiac cycle.

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Lesson – 2.4

ROLE OF RESPIRATORY PIGMENTS IN TRANSPORT OF GASES

Contents

2.4.1 INTRODUCTION

The substances as oxygen carriers in blood are proteins that contain a metal i.e., iron or copper commonly. They are coloured and therefore they are called as respiratory pigments. In some animals the respiratory pigment occurs dissolved in the blood fluid while in others such as vertebrates it is enclosed in cells and the blood fluid contains no dissolved respiratory pigment. When the pigments occur enclosed in cells, their molecular weights are relatively low ranging from 20,000 to 1,20,000; if the pigments occur dissolved in plasma, their molecular weights are much higher, from 400000 to several millions. The advantages of respiratory pigments are discussed in two types i.e., respiratory pigment dissolved in plasma, and respiratory pigment enclosed in cells. A large increase in the number of dissolved particles would raise the colloidal osmotic pressure of plasma, which in turn would influence many other physiological processes such as the passage of fluid through capillary walls and ultra filtration i.e., the initial process in the formation of urine in kidney.

The most important advantage is probably that the chemical environment within the red cell can differ from that of the blood plasma. The reaction between oxygen and hemoglobin is greatly influenced by inorganic ions as well as by certain organic compounds, notably organic phosphates, and hemoglobin located within cells can be provided with a separate well-adjusted environment different from the plasma. The respiratory pigments are mainly helpful in transport of gases as well as in storage. The pigments are

1. Hemoglobin
2. Hemocyanin
3. Chlorocruonin
4. Hemerythrin

In these only hemoglobin and chlorocruorin have the porphyrin nucleus. The remaining respiratory pigments does not have the porphyrin nucleus although they go by the names hemocyanin, hemerythrin and sometimes hemovanadium, there is in fact no heme, component.

The type of pigments, its occurance in animals, its descreption and its colour are discussed in the form of tables.

PIGMENT	DESCRIPTION	OCCURANCE IN ANIMALS	
		IN CELLS	IN PLASMA
Hemoglobin	Iron-porphyrin protcin carried in solution or in cells; most exten-sively distributed pigment	Mammals Birds Fish Cyclostomes Lanpetra Myxine Polychaetes Notomastus Echinodcims Thyore Mollusks Arca Insects Gaslrophilus	Oligochaetcs Lunbricus Polychactes Arericola Serpula Mollusks Plarorbis Insects Chironomus
Hemocyanin	Copper – contain-ing protein carried in solution		Gastropods Helix Cephalopods Rossia, octopur and Eledore Arachrids Limulus Crustacea Pandalus, Palinurus, Nephrops and Homarus
Chloro	Iron-porphyrin protein, carried in solution		Polychaetes Spirographics
Henerythrin	Iron-containing protein, always in cells,norporphyrin structure	Sipurculids phascolosome	

As in the case of chlorocruorin, it is restricted to four families of polychactes. They are sabcllidae, scrpulidae, chlorhaenidae, ampharetidac. Prosthetic group alone are found in star fish.

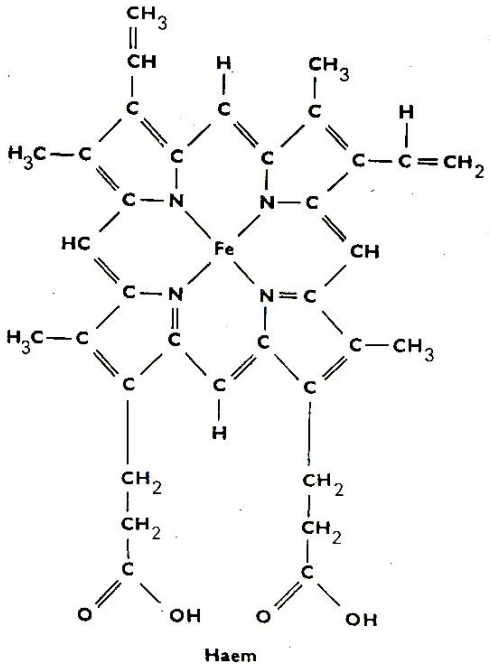
Hemerythin usually present in plasma solution but it occurs in cells i.e., in colomic corpuscles of sipunculus.

PIGMENT	COLOUR	SITE	ANIMAL	OXYGEN VOLUME PER CENT ML
Hemoglobin	Red	Corpuscles	Mammals Birds Reptiles Amphibions Fishes	15-30 20-25 7-12 3-10 4-20
		Plasma	Annelids Molluscs	1-10 1-6
Hemocyanin	Blue	Plasma	Molluscs Goshopods Cephalopods Crustaceans	1-3 3-5 1-4
Chlorocruonin	Green	Plasma	Annelids	9
Hemerythrin	Red	Corpuscles	Annelids	2

2.4.2. HEMOGLOBIN

Hemoglobin is the most familiar, the most widespread and the most efficient of the respiratory pigments. Hemoglobins combine with far greater amounts of oxygen than any of the other pigments. It is made up of an iron porphyrin compound Heme, is associated with a protein globin. Hence is a metalloporphyrin. It is composed of four pyrrole rings joined with methane groups to form a super-ring with an atom of ferrous iron in the centre attached to pyrrole nitrogens. The heme component of the molecule is constant feature of all the hemoglobins, but the globin portion varies in different species.

The atom of ferrous iron is associated with one molecule of oxygen to form oxyhemoglobin. The reaction is readily reversible. The unoxygerated compound is referred to as deoxyhemoglobin. These are not enzymatic reactions. Whether or not the heme unit combines with oxygen depends not only on the availability of oxygen but on the pH and ionic content of the solution as well as in construction of total hemoglobin molecule .



Fi . 2.1.3. Structural formula of heme.

The evolution of the highly efficient oxygen transport system of the higher vertebrates has involved changes related to both to the biochemistry of the hemoglobin molecule and the morphology of the cellular constituents. The most significant of the biochemical events have been.

1. The establishment of an oxygen combining depend on pH i.e., Bohr effect.

2. Change in the shape of oxygen equilibrium curve from the hyperbolic the sigmoid.

Increasing acidity, which in life follows the accumulation of CO_2 and other metabolites, brings about more ready release of oxygen. The equilibrium curve is shifted to right, a phenomenon which first described by the Danish Scientist C.Bohr and called after him, Bohr's effect. Most of the invertebrate hemoglobins have little or no Bohr's effect while the homeothermic vertebrates have a definite one. 2^{nd} is the biochemical evolution of hemoglobin is related to the formation of multiheme units and results in a sigmoid equilibrium curve. Bloods characterized by s-shaped equilibrium curves have a relatively low affinity for oxygen at the intermediate tensions. For a given fall in oxygen tension the sigmoid curve discharges more of its load than the hyperbolic one.

In Lamprey, the curve is hyperbolic and non heme-heme interaction; Hagfishes are also hyperbolic; the pacific genus, polistotrema has no Bohr effect / The atlantic genus, myxine is said to have heme-heme interaction.

Formation of Hemoglobin

The basic chemical steps in the formation of hemoglobin are

1. 2 Succinyl – COA + 2 glycine
2. 4 pyrrole $\longrightarrow$ Protoporphyrin 1x
3. Protoporphyrin 1x + Fe^{++} $\longrightarrow$ heme
4. heme + polypeptide $\longrightarrow$ hemoglobin chain (α or β)
5. 2α chains + 2β chains $\longrightarrow$ hemoglobin A

First succinate CO-A formed in the Kreb's cycle binds with glycine to form a pyrrole molecule. In turn, four pyrroles combine to form protoporphyrin 1x, which then combines with iron to form the heme molecule. Finally, each heme molecule combines with a long polypeptide chain, called a globin, synthesized by the ribosomes, forming a subunit of hemoglobin called a hemoglobin chain. Each of these chains has a molecular weight of about 60,000; four of them in turn bind together loosely to form the whole hemoglobin molecule.

There are several slight variations in different subunit hemoglobin chains, depending on the aminoacid composition of the poly peptide portion. The different types of chains are designated alpha chains, beta chains, gamma chains, and delta chains. The most common form is adult human being is hemoglobin A ($2\alpha + 2\beta$ chains).

Because each chain has a heme prosthetic group, there are 4 iron atoms in each hemoglobin molecule, each of these can bind with 1 molecule of oxygen, making a total of 4 molecules of oxygen or 8 oxygen atoms that can be transported by each hemoglobin molecule.

Basic structure of the hemoglobin molecule, showing one of the four heme chains that bind together to form the hemoglobin molecule.

Frog hemoglobin displays sigmoid curve, binds oxygen less tightly and delivers it most readily to tissues.

2.4.3. CHLOROCRUORIN

It is also a metalloporphyrin compound; closely allied to hemoglobin and the cytochromes. Chlorocruorin is never found in cells; but as a plasma chromo protein it has as great an oxygen-combining power as the comparable hemoglobins. Chlorocruorin is restricted to four families of

polychaetes. Various facts suggest that a genetic mutation, produced the chlorocruorin molecule in a world which already knew hemoglobin and that the mutation was, for some reason, preserve. The facts are as follows.

- → In serpula genus both the pigments are present in blood and the relative amounts vary with the age. Younger individuals have more of the hemoglobin while the other have more of the chlorocrourin.

- → In the sabellid, potamilla, chlorocruorin is the blood pigment. But in the part of muscle regions the respiratory pigment present is hemoglobin.

Thus hemoglobin and chlorocruorin have more Similarities. And the most common similarity is the presence of porphyrin nucleus in both hemoglobin and chlorocruorin.

2.4.4. HEMOCYANIN

Hemocyanin is of wide occurance and discharges those functions already discussed for hemoglobin. Hemerythrin is probably not concerned with the transport of oxygen but hemocyanin has a great role in transport of oxygen. Hemocyanin is the only one of the non-heme respiratory pigment which is abundant in animal kingdom. Hemocyanin occurs in many of the molluscs and Arthropods. However it is not considered to be a phylogenetically primitive pigment and some of the more lower members of these two phyla possess hemoglobin. Eg: the mollusc, Acra and the crustacean, daphnia. Two copper atoms are required to hold one oxygen molecule. When the blood is oxygenated the colour changes from colourless to blue.

→ In oxyhaemocyanin state, the copper ion is in cupric state. In deoxyhaemocyanin state, the copper ion is in cuprous state.

The quantity of pigment, hemocyanin can only be increased by forming giant molecules. The pigment clearly function in transport as well as function in storage.

Here the equilibrium curves are rather rectangular, but the shapes depend on pH and temperature.

2.4.5. HEMERYTHRIN

Hemeerythrin contains iron. Three atoms of iron are necessary to form combinations with an oxygen molecule.

→ In oxyhemeerythrin, the three iron atoms are in ferric state.

In deoxyhemeerythrin, the three iron atoms are in ferrous state.

The pigment was first discovered in ancient brachiopod, Lingula and has been found in only few other. It may occur in cells (Coclomic corpuscles of sipunculus) but is usually in plasma solution.

Unlike other respiratory pigments, Hemerythrin is not concerned with the transport of oxygen although the storage function is present. Hemerythrin is iron-containing protein, always in cells having norporphyrin structure. It is red in colour and present in all species of sipunculids.

2.4.6 REFERENCE

Hoar Comparative Animal Physiology

Schmidt – Neilson Comparative Animal Physiology.

2.4.7 EXPECTED QUESTIONS :

1. Give an account on role of blood pigments in transport of oxygen.
2. Describe the structure and functions of hemoglobin?
3. Write short notes on

(i) Hemerythrin (ii) Hemocyain (3) Chlorocruorin

Lesson – 3.1

COMPARATIVE ACCOUNT OF NERVOUS SYSTEM

Introduction

3.1.1 INTRODUCTION :

In all the multicellular animals above the level of sponges, the system meant to perceive stimuli detected by the receptors, to transmit these to various body parts, and to effect responses through effectors, is called nervous system. In vertebrates, it is highly specialized and plays at least 3 vital roles :

1. RESPONSE TO STIMULI

By responding to all sorts of stimuli, it acquaints the organism with them so that the organism may react and orient itself favourably in the surrounding environment.

2. COORDINATION

Along with endocrine system, the nervous system also serves to coordinate and integrate the activities of various parts of body so that they act harmoniously as a unit. This makes possible the integrated control of the internal body environment (homeostasis). However, the nervous system brings about rapid coordination by means of nerves, whereas the endocrine system does so gradually and slowly by screting hormones into blood.

3. LEARNING

By accumulating memories from past experiences, in higher vertebrates at least, the nervous system serves as a centre for learning.

The branch of medical science dealing with the structure (anatomy), functions (physiology) and diseases (pathology) of nervous system in called Neurology.

DIVISION OF NERVOUS SYSTEM

Nervous system is divided into 3 parts :

1. CENTRAL NERVOUS SYSTEM (OR) CNS

It consists of brain and spinal cord. It coordinates the impulses received from receptors and transmitted to the effectors for response.

2. PERIPHERAL NERVOUS SYSTEM

It is composed of 10 or 12 pairs of cranial nerves coming from brain and several pairs of spinal nerves from the spinal cord. It provides the connecting link of living lines of communication between the receptors, the central nervous system, and the effectors.

3. AUTONOMIC NERVOUS SYSTEM

It innervates smooth and cardiac muscles and glands. It is concerned with the involuntary or automate body activities, such as the peristalisis of alimentary canal and the beating of heart. Autonomic system is usually considered a part of peripheral system as the two are connected together.

3.1.2 ANATOMY OF NERVOUS SYSTEM

THE NEURON

The nervous system is composed of nerve cells or nerves surrounded by a delicate web of connective tissue called neroglia. Neuron is the structural as well as functional unit of nervous system. According to the "neuron theory", each neuron is a distinct anatomical unit having no protoplasmic continuity with other nerves. It is also physiologically distinct, so that damage or destruction of a neuron may not affect adjacent neurons. The neuron, rather than the nerve, transmits the nerve impulse.

As termed nycliated or medulated and appear white. Myelin substance is not continuous uniformly but becomes interrupted at intervals by circular constrictions termed nodes of Ranvier.

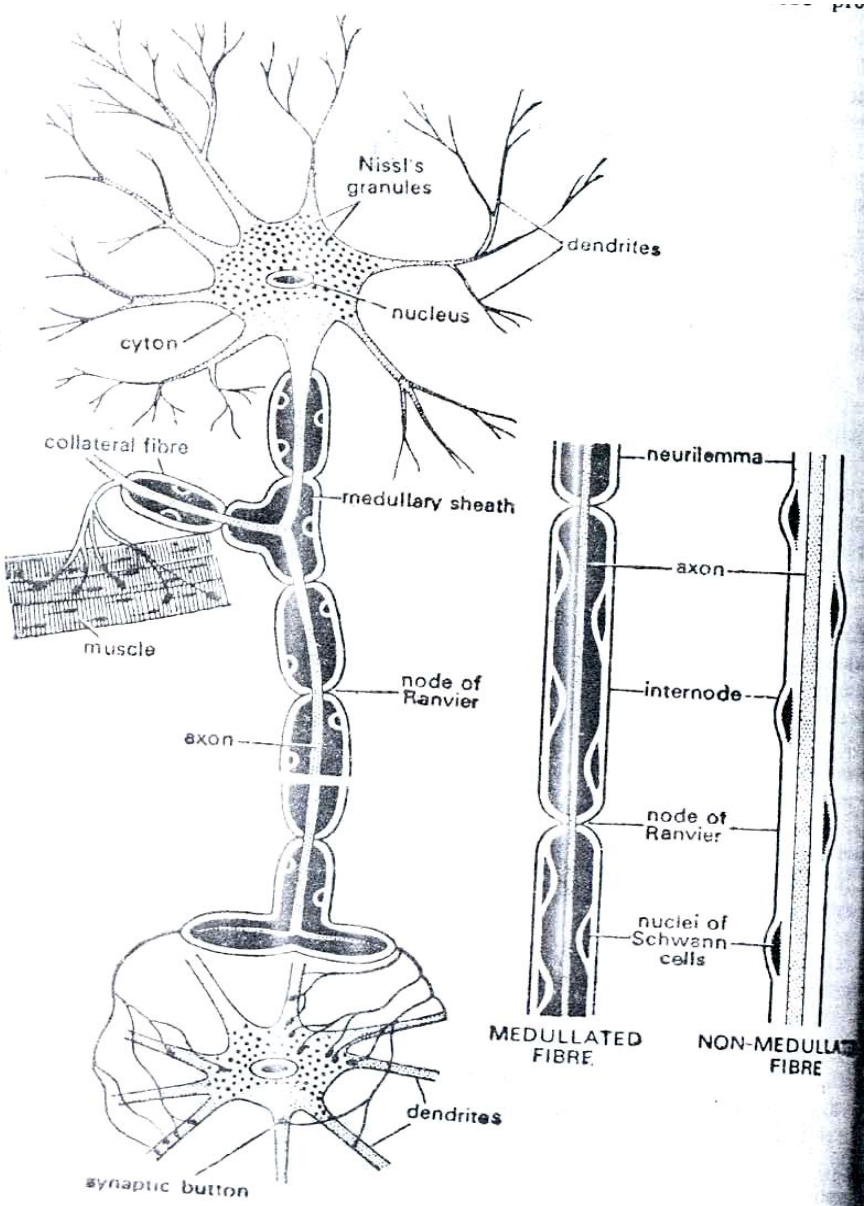


Fig.3.1.2 Generalized diagram of a vertebrate neuron.

1. STRUCTURE OF NEURON :

Neurons are of different shapes; but each consists of an irregular cytoplasmic cell body called cyton, with a number of branching cell processes or fibres.

(a) Cyton :

Cyton contains a nucleus and several small basophilic Nissl granules or tigeoid bodies that readily stain with methylene blue. These granules are made of RNA and take part in protein synthesis. Cytoplasm of cyton also contains a network of fine, thread-like neurofibrillae. A group or mass of cell bodies within the gray matter of brain or spinal card is called a nucleus, while outside the CNS is called a ganglion.

(b) Nerve Fibres :

Two types of fibres are differentiated on the basis of direction of nerve impulse conducted by them.

(i) Dentrites: These are shorter, usually several, much branched, with Nissl granules, and pass impulses towards or into the cell body.

(ii) Axon: It is longer, usually single, without branches and Nissl granules, and normally conducts impulses away from the cell body.

A nerve fibre consists of a central thin cytoplasmic stand, called axis cylinder, which is continuous with cell body. All nerve fibres outside brain & spinal cord, are covered by a thin delicate membrane, the schwann sheath or neurilemm. In most long nerve fibres, there is a layer of lipid or fatty material, called myelin a meduallary sheath, between axis cylinder and neurilemm. Such fibres part of nerve fibres between two adjacent nodes is called an inter node. Nerve fibres which lack the fatty sheath are called non-myelinated or non-medullated and are gray in appearance.

Just below neurilemma is a thin cytoplasmic layer with scattered flat nuclei, forming sheath cells or schwann cells. They secrete the myelin sheath and neurilemma each inter node is covered usually by a single schwann cell. Collateral branches may arise at right angles from long fibres or axons.

(C) Synapses

Neurons form pathways for conduction of nerve impulses, but cytoplasm of one of the neuron is not continuous with that of another. Electron microscrope has shown that branches of an axon end in terminal buttons full of mitochondria. These lie in close proximity but without actual organic connection with terminal branches of a dendrite of another neuron. The small gap thus left between the just aposed processes is called a synapse with the dendrites of another neuron. The whole nervous system in fact represents chains of neurons linked together by synapses in a complicated web.

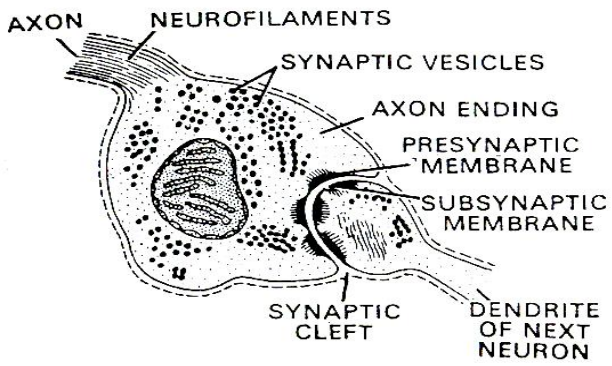


Fig. 3.1.4. Electron microscopic stucture of synapse.

3.1.3 Kinds of Neurons & Fibres

Nerve fibres and neurons are comparable to a "one-way-traffic" system, conducting nerve impulses in one direction only. Functionally, the following main types of nerve fibres and neurons are found:

The CNS to various effector organs.

(a) Afferent or sensory

These transmit and carry impulses from receptor to CNS.

(b) Efferent or motor

These transmit and carry impulses from CNS to various effector organs.

(c) Association or adjustor neurons

These lie within brain or spinal cord and link together through synopses the afferent and efferent neurons.

Structurally, 3 types of neurons occur depending on their protoplasmic process or fibres.

(a) Unipolar : Only two fibres arise close together

(b) Bipolar: Twofibres, one axon and one dendrite, arising from opposite poles of cell.

(c) Multipolar: Several processes arise.

Neurons include some of the longest cells in the body. While their cell bodies lie in the brain or spinal cord, their axons may reach the farthest body extremities, sometimes several meters away.

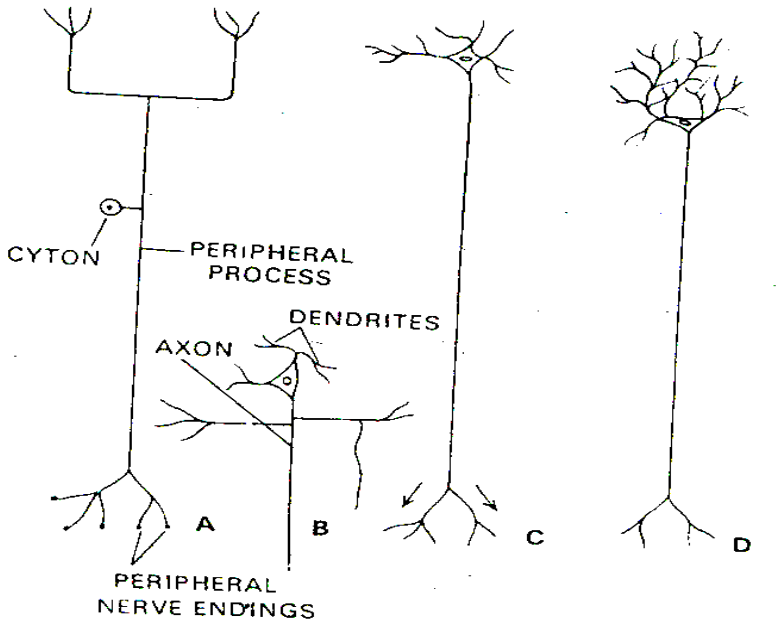


Fig.3.1.1. Diagram of different types of neurons and association between them

3. NERVE

A nerve consists of numerous nerve fibres (axons/dendrites), outside, the CNS, bound together in smaller bundles, like wires in a cable, by white connective tissue layers called perineurium. Surrounding tissue includes blood vessels to supply nutrients and oxygen. The external coat of fibres connective tissue of nerve is termed Epineurium.

3.1.4 Nature of Nerve impulse

The nature of nerve impulses passing along nerve fibre is partly physical and partly chemical. A wave of electric change or disturbance accompanies the nerve impulse. The electric charge, known as Action current, can be recorded with a galvanometer. While transmitting an impulse, the nerve consumes more O_2, produces more CO_2 and generates a minute but measurable amount of heat, than a resting nerve. These factors clearly indicate the physico-chemical nature of nerve impulse.

The synapse has a polarity, that is, like a "physiological value", it allows an impulse to travel in one direction only, from axon of one neuron to the dendrite of other. In fact, an impulse does not travel through a synapse, but a fresh impulse is induced

on its another side. On reaching the terminal button of an axon, the impulse induces them to produce a small amount of chemical neurohumour, usually acetyl choline, which sets up a fresh impulse in the next neuron. On the other hand, termination of sympathetic fibres release sympathin, a substance like adrenalin, and which is antagonistic to acetyl choline. These neuro-hormones may continue to stimulate the other neuron, but they are quickly inactivated by an enzyme, cholinesterase.

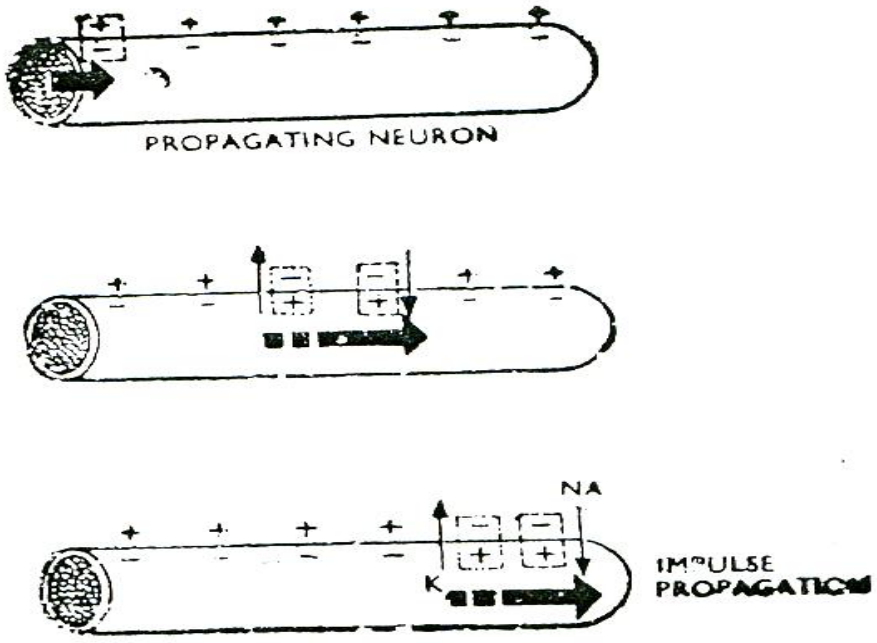


Fig.3.1.2. Propogation of nerve imdulse in a nerve fibre

A neuron is able to transmit an electric impulse very rapidly, at a speed of 100m/sec in man. Medullated fibres conduct impulses much faster than the non-medullated fibres. It travels at a uniform speed with the same intensity for a long time and does not spread to adjacent tissues due to insulation provided by mylin sheaths. A refractive period usually occurs when the depolarized nerve fibre cannot carry another stimulus. It is believed that the nerves are never tired. Impulses are conducted on the basis of "all or none" principle.

3.1.5 Nervous system in Invertebrates:

(i) In Protozoans & sponges nerve plexus is present in cytoplasm and no specialized nervous system is present.

AMOEBA FIGURE

No specialized nervous system is present in amoeba

PARAMOECIUM FIGURE

No specialized nervous system is present

This performs feeding & energy synthesis by photosynthesis.

(ii) In sponges no nervous system is present although large multicellular organelles are present.

(iii) In Hydra, a primitive or elementary nervous system is present. The nervous system is composed of individual cells which terminate in relation to other neurons and other cell types. The termination lack sempathtic vesicles. However, Epithelio muscular cell shows a neurosecretary cell neurite which shows great resemblance to synapse.

HYDRA FIGURE

The nerve plexus conducts without loss and without fatigue. According to Pantin(1956) the individual neuron may extend only 100y. The net plexue shows a slower conduction net & faster conduction net, the former conducts impulses at less than 0.5μm/sec., the later at 0.7 – 2.0m/sec.

Jelly fish: It is characterized by a series of nerve cells forming a network. Some of jelly fishes have specialized structure called `Rhophalium'. They have receptors.

(iv) Nervous system in platyhelminthes is ladder-like. Free-living animals have photoreceptors & ciliated pits as sense organs. Nervous system is reduced.

Ladder-like nervous system is connected by nerve cards. These are connected to cerebral ganglia located in vertical region. The CNS has been described as ladder like because of connecting nerve cards.

(v) Nervous system in Nemathelminthes, consists of a nerve ring, nerve cards & nerves.

Sense organs are poorly developed. They are tactile organs amphid, phasmids & eye spots etc.,

In the strobila of tapeworm there is a pair of lateral longitudinal nerves, 2 pairs of accessory lateral nerves and a pair of dorsal and a pair of ventral longitudinal nerves, making a

total of ten longitudinal trunks. The longitudinal trunks are connected in each proglottid by at least one sing commissure. Numerous branches are given off from longitudinal & ring commissure. In the scolex, the lateral nerves swell into a pair of ganglia connected by a transverse connissure. A nervous ring connects the outer end of these ganglia with the other longitudinal nerves.

(vi) In annelida, nervous system consists of Brain, nerve ganglia, ventral nerve cord.

In Earthworm, nervous system is segmented like body. Brain is located above the pharynx and it is connected to vertical ganglia.

(vii) In Arthropoda, nervous system consists of Brain, ganglia and ventral nerve cord.

(viii) In Mollusca, Nervous system is well developed. Paired ganglia are connected by commissures and connectives. Sense organs like eyes, tentacles, ospharadium, statocyst are well developed.

In snails, nervous system is characterized by presence of ganglia. They have ospharadium in mantle cavity useful to detect chemicals in air & water.

In Bivalves(clams) 3 pairs of ganglia(cerebeal, visceral & pedal) associated with oesophagus, muscles close to the shell & foot.

In Octopus, highest number of neurons 300,000,000 cornea, lens, setira, Iris, focus & Image are present with well developed central nervous control.

(ix) In Echinodermata, Brain is absent and nervous system is primitive. Sense organs are poorly developed. They include chemiosceptors, photoseceptors, tentacles & statocysts.

In Sea Star brain, and ganglia are absent. Nerve net surrounds mouth. Radial nerves extend to each arm. Eye spots are present at the tip of arm.

3.1.6 Central Nervous System

It includes brain and spinal cord. These are derived from a longitudinal mid-dorsal ectodermal thickening of embryo, called medullay or neural plate. This neural plate or neural groove is converted by fusion into a closed mid-dorsal longitudinal neural tube lying above the notochord. Histologically, the embryonic neural tube exhibits 3 zones of cells.

Development of Brain

The anterior end of embryonic neural tube is already enlarged forming the embryonic brain, called encephalon. But differential growth and 2 constricions, it is divided into a linear series of 3 primary cerebral vesicles, termed the fore brain, mid brain & hind brain. These give rise to 3 major divisions of adult brain-

1. Proscencephalon (fore brain)
2. Mesencephalon (Mid brain)
3. Rhonbencephalon (hind brain)

These further become subdivided into 5 subdivisions. The various parts of adult brain in different vertebrates are formed by modifications, that is, by thickening and foldings of these 5 subdivisions. The adult brain has a series of cavities, called ventricles, which are in continuation with the central canal of spinal card and filled with a cerebro-spinal fluid.

Subdivisions, parts and Associated structures of Vertebrate Brain

Divisions	Subdivisions	Parts	Cavity	Associated structurtes
PROSEN- CEPHALON (for Brain)	1.Telencephalon	Rinencephalon	I ventride (Rhinocoel)	Ofactory bulbs Ofactory tracts Ofactory lobes Paleuostes on pallium
		Cerebral hemisphere	II a lateral Ventricles (pavacoels) foramen of Monro	Corpora striala or basal ganglia copus callosum Neauorten on pallium paraphysis

	2.Diencephalon	Epithalamus (roof) Thalamus (sides) Hypothalamus (Floor)	III Ventricle Diacoel)	Habenulae parapineal or pineal apparatus pariatal Hypothalamic nuclei optic chiasma Median eninence Infurdibular stalk saccus vasculosus manillary todies anteriror chocoid pleasus
II MESEN CEPHALON (Mid brain)	-	Cruracerebri (floor)	Iter (or) Cerebral aqueduct	Optic loves Auditory lobes – Tectun Cerebral peduncles
III RHOMBEN CEPHALON (Hindbrain)	1.Metenceph-alon	Cerebellum		Trapesoid body pons
	2 Myclencep-halon	Medulla oblongata	IV Ventricle (Metacoel)	Restiform bodies pyramids

FIGURE: pattern of generalized vertebrate brain

Nerve cord or spinal cord is formed from neural tube behind the brain. The nerve cord is a cylindrical tube some what flattened dosoventrally, its anterior end is wide where it is continuous with medulla, the posterior end generally tapers to a fine thread, the filum terminale. The nerve cord has a thin central canal lined with ciliated epedymal cells. On its midventral side the nerve cord acquires a deep ventral fissure, mid-dorsally is a slight dorsal sulcus from which a donal septum extends into the interior. The dorsal septum and ventral fissure divide the nerve cord incompletely into 2 halves connected across the middle by commissures. There is an outer white matter with neurogonglia and nerve fibres, and an inner gray matter with neurogonglia and nerve fibres, non-medullated fibres, and neurogonglia.

Neural Crest

After the formation of neural tube, masses of ectoderm cells appear on each side between the neural tube and ectoderm, these cells are neural erests which extend on each side along the whole length of neural tube. The neural erests from segmental dorsal root ganglia of spinal nerve and ganglia of autonomic sympathetic nerves, they also form parts of ganglia and sensory cranial nerves. Some neural crest cells form those mesenchymal cells which give rise to visceral arches, while other neural crest cells form pia mater and arachnoid membrane of central nervous system: still other neural crest cells form chromotophores in lower vertebrates. Chromaffin cells of the medulla of adrenal glands arise from neural crest cells.

3.1.7 Comparative Account of CNS

Fishes

(a) Elasmobranchs

In Elasmobranch fishes(shark), olfactory organs are enormous so that olfactory lobes of brain are correspondingly large, attached to cerebrum by short but stout olfactory tracts or peduncle. Optic lobes and pallium are relatively moderate in size. Midbrain cavity (III ventride) is quite large and extends into optic lobes. A thin – walled vascular sensory organ, called saccus vasculosus, is attached to pituitary and connected by fibre tracts with cerebellum. Pineal apparatus is well developed. Topographical features of hind brain are least pronounced. Cerebellum is especially large due to active swimming habit. To assist cerebellum in the maintenance of equilibrium, suffle-like setiform bodies are present at the antero-lateral angles of medulla.

The nerve cord is a cylindrical rod running from the medulla to the end of tail passing through the neural cards of vertebrae, it has a narrow central canal. Running longitudinally is a slight dorsal sulcus or fissure but a ventral fissur is absent. There is a single meninx, the meninx primitiva applied closely to brain and spinal card. Between the vertebral column and meninx primitiva is a perimeningeal space have delicate stands of connective tissue and fat.

(b) Osteichthyes

In bony fishes, brain is more specialized than in Elasnobranches. In perch, olfactory lobes, cerebral hemispheres and diencephalons are smaller while optic lobes and cerebelleum larger than in shark. Some bony fishes have restiform bodies. In bottom-feeders, having scattered taste buds on body surface, the anterolateral sides of medulla show unusual bulgings or vagal lobes. Parapineal body is absent in modern teleosts .

The nerve cord is like that of Elasnobranches.

Amphibia

Brain of frog shows many differences from that of dog fish. Smaller olfactory lobes and larger optic lobes indicate a greater reliance on sight rather than small. Corpus striatum or paleostriatum (floor or cerebrum) receives greater number of sensory fibres projected forward from thalamus than in fishes. Two cerebral hemispheres show greater development in accordance with more complex activities of locomotion, hibernation, breeding etc; However, optic lobes are probably the dominant coordinating centers in amphibian brain. Poor development of cerebellum, a mere transverse band, shows relative decrease in muscule activity. Medulla is also small. A small penal body is present in all the modern amphibians.

The nerve cord is short ending in a film terminale lying in urostyle, at the level of limbs there are cervical and lumbar swellings. The nerve cord has an outer white matter and inner quadrangular gray matter with well marked dorsal and ventral horns or columns.

Reptilia

Reptilian brain shows advancement in size and proportions over that of amphibians because of complete terrestrial mode of life. Telencephalon increases to become the largest region of brain. 2 long olfactory lobes are connected to cerebral hemispheres which are longer than amphibians because of greater thickness and enlargement of carpora striata. Parapineal body, more often called parietal eye, is still found in sphenodon and in some lizards, but is vestigeal or absent in other reptiles. A pair of auditory lobes are found posterior to optic lobes which are not hallow. The III ventricle is reduced to a narrow cerebral aqueduct. Cerebellum is some what pear shaped and longer than in amphibians.

The nervecord extends the entire length of vertebral column, the gray matter is H-shaped in section with projecting poured dorsal & ventral horns as in other amniotes. Cervical and lumbar enlargements are present but they are absent in limbless lizards & snakes.

AVES:

Avian brain is proportionately larger than that of a reptile, and is short and broad. Olfactory lobes are small due to poor sense of smell. 2 Cerebral hemispheres are larger, smooth and project posteriorly over the diencephalons to meet the cerebellum. Pallium is thin but corpus stratum is greatly enlarged making lateral ventricle small and vertical. 3rd ventricle is also narrow

due to great development of thalami. Optic lobes on mid-brain are conspicuously developed in correlation with keen sight , but they are some what laterally displaced. The cerebellum is greatly enlorged with several superficial folds(flocculi) due to many activities involving muscular coordination and equilibrium such as flight and perching.

The nerve cord extends throughout the full length of vertebral column and it has no filum terminale, it has large branchial & lumbus enlargements. In the lumbas enlargement thedonal horns of the gray matter diverge outwards so that the central canal firms a wide diamond-shaped cavity called sinus shomboidalis.

Mammals

Parts of vertebrate brain in linear arrangement become progressively enlarged from fishes onwards until they reach their peak in mammals. Brain is proportionately larger than in other vertebrates. Cerebral hemispheres of prototheria are smaller and smooth, like those of reptiles. They are larger but smooth in metatheria, In most higher mammals(Eutherea), cerebral hemispheres become greatly enlarged and divided into lobes, with thick cerebral cortex of gray matter. In mammals such as rabbit, the surface of cerebral hemispheres is relatively smooth with few fissures. In others, such as man & sheep, surface is immensely convoluted with a number of elevations separated by furrows(sulci). This folding increases the surface cortex or gray matter containing nerve cells, resulting in greater intelligence without adding to size of brain. The 2. hemispheres are joined internally by a transverse band of fibres, the corpus callosum, not found in other vertebrates or even in prototheria & metatheria.

Olfactory lobes are relatively small but clearly defined and covered by the hemispheres. Diencephalons and mid brain are also completely covered by cerebral hemispheres. Characteristic of mammals are 4 almost solid optic lobes, called corpora quadrigemina, on the roof of mid brain. The III ventricle or its of mid brain is a laterally compressed vertical passage, called cerebral aqueduct.

Cerebellum is also large, conspicuously folded and may overlie both midbrain and medulla. Usual folds are a median vermis, two lateral flocculi and their mushroom-like projection, the paraflocculi. The other chief topographical features of mammalian hind brain include the pyramids carrying voluntary motor impulses from higher centers, cerebrum and cerebellum, and the trapezoid body of transverse fibres relaying impulses for sound. Hind brain contains centers for the regulation of digestion, respiration & circulation.

The nerve cord runs from the medulla to a point which does not reach the end of vertebral column, and it fails to extend into the tail. It is somewhat flat doso-ventrally with a dorsal sinus and a very deep ventral fissure, there are branchial and lumbar swellings behind which is a conus terminals from which a non-venous film terminale extends posteriorly. In section the nerve cord has an outer layer of white matter made of tracts of medullated nerve fibres, and an inner mass of gray matter and a central canal with ciliated epedimal cells. The gray matter contains nerve cell bodies, dendrites, and parts of axons terminating or beginning from cell bodies. The gray matter in section is H-shaped forming raised dorsal and ventral columns, the dorsal limbs of the H are dorsal columns or horns, and the ventral limbs are ventral horns, between these mammals have a

lateral column or horn on each side. The gray matter devides the white matter into pillar celled dorsal, lateral and ventral funiculi. The fibres of the dorsal funiculus are sensory, those of the exteral funiculus are both sensory and motor, and those of ventral funiculus are motor, these fibres are connected to brain.

3.1.8 Peripheral Nervous System

The peripheral nervous system consists of nerves connected to the central nervous system, it has cranial and spinal nerves. Cranial nerves are those which are joined to brain, they are all paired and emerge through foramina of skull. Except the 1st four pairs of cranial nerves, the rest arise from the medulla oblongat. There are 10 pairs of cranial nerves in anamnis & 12 pairs in amniota, besides which there is a paired nervous terminals or number zero nerve arising from cerebral hemisphere in all vertebrates except birds, it goes to organ of Jacobson. Cranial nerve shows dorsal & ventral roots but they never join. The cranial nerves are termed I to IX or I to XII from ancient times. III, IV & VI are motor ventral roots, V, VII, IX and X are mixed dorsal roots, the VIII is a sensory dorsal root. Cranial nerves I and II are different from the others. I,II & VIII are sensory nerves.

Cranial nerves (paired) of vertebrates

S.No	NAME	ORIGIN	DISTRIBUTION	NATURE	FUNCTIONS
I	Olfactory	Olfactory Lobe or Bulb	Olfactory epithelium in voral cavity	Sensory	Smell
II	Optic	Optic lobe on mid brain	Retina of eye	Sensory	Sight
III	Occulomotor	Floor of midbrain	Eye, 4 muscles of eye ball	Motor	Movements of cyeball, iris, lens elelid
IV	Trachlear	Floor of mid brain	Eye, Superior obligue muscles of eye ball	Motor	Rotation of eye ball
V	Trigemiral	Side of medulla	Head, face, Jaw, teeth	Sensory Motor	Fore head, scalp, upper eyelid, side of nose, teeth movement of tongus jaw muscles for chewing

VI	Abducens	Side of medulla	External rectus muscles of eye ball	Motor	Rotation of eye ball
VII	Facial	Side an floor of medulla	Amteria 2/3 tongue, muclas of face, neck & chewing	Sensory Motor	Taste, facial expression, chewing, movement of neck
VIII	Auditory (acoustic)	Side of medulla	Organ of corti in cochlea semicircular canals	Sensory	Hearing equilibrium
IX	Glosso Phayngeal	Side floor of medulla	Posterior 1/3 tongues, mucous membrane and murcles of phayme	Sensory Motor	Taste & touch movements(swallowin) of phynx
X	Vagus (pneumagatric)	Side floor of medulla	Muscles of pharepox, vocal cords,lungs, heart,oesophagus, stomach, interstine	Sensory Motor	Vocal cords, lungs, respiratory refluxes, peristaltic movements, speech, swallowing, secretion of gastric glands, inhibition of heart beat
XI	Spinal accessory	Floor of medulla	Muscles of pabte, larynx, vocal cords, neck, shoulder	Motor	Muscles of pharyse,larynex, neck, shoulder, movements
XII	Hypoglossal Spinal accessory	Floor of medulla	Muscles of tongue, neck	Motor	Movements of tongue

Note: Spinal accessory(XI) & hypoglossa(XII) are lacking in anamniotes(cyclotomes, fishes & amphibians)

Spinal nerves

There are 10 pairs of cranial nerves in Anamniota fishes, amphibions) & 12 pairs of cranial nerves in Amniota (Reptiles, Aves & Mammals)

3.1.9 Autonomic Nervous System

Cranial and spinal nerves (romatic nerves) mainly innervate the skeletal or voluntary fluxles and direct the adjustment of the vertebrate to its surroundings. On the other hand, autonomic nerves and ganglia innervate the involuntary or smooth muscles of viscera, heart and glands and control the internal body environment.

3.1.10 Expected Questions

1. Describe the nervous system in invertebrates
2. Give an account as Central Nervous System
3. Write in detail the peripheral nervous system
4. Write notes on nature of nerve impulse
5. Describe different kinds of neurons & fibres.

3.1.11 Reference Books

Comparative animal physiology – C.Ladd Professor

Animal Physiology – Schmidt – Nielson; KNUT.

Lesson 3.2

MECHANISM OF NERVE IMPULSE TRANSMISSION

Contents

3.2.1 INTRODUCTION

Animal life depends on an information processing system called the nervous system. Nerve cells or neurons, which are functional units of this system, generate, integrate and conduct excited states. While neuroid conduction depends on sheets of similar cells linked by cytoplasmic bridges, nervous conduction occurs in elongated cell process that may transfer information for long distances and which are usually chemically (not electrically) linked one to another.

Horridge suggested that neurons first appeared as neuro secretory or growth regulating cells, their elongated processes were later adapted to rapid conduction and chemical transmission by release of transmitter at their endings.

3.2.2 Organisation of Nervous System

Nervous system in sponges:

Sponges are devoid of nerve or sensory cells, so that the animal is unable to react to a stimulus as a unified whole. Instead, each cell is sensitive and reacts individually. In the absence of nervous system there are no coordinated actions of the whole body. However, they respond directly to certain stimuli. For example, the body may contract when taken out of water and the

feeding current may be stopped. The pores and oscula are surrounded by contractile cells, called myocytes, which are able to close these openings power of conductivity is very slight so that reactions to light, touch and chemical, etc, are very slow. Conductivity is best developed at the osculum. Some of collencytes acting as neurons, form a diffuse network connecting the choanocytes with pinacocytes and myocytes. The neurons are supposed to receive and conduct stimuli.

Cnidarian nerve nets

The nerve net represents the most primitive organization of neurons into a system for the integration of the behavior of an entire animal.

Morphological arrangement of neurons:

The cnidarian nervous system is basically a plexus of relatively short-fibered bipolar and multipolar nerve cells, together with neuritis from sensory cells. Most coelenterates, including Hydra, have at least two nets; a main plexus between the epidermis and the musculature, and a second less highly developed network associated with the gastrodermis and connected at various points with the epidermal plexus.

The cnidarians are highly successful and extremely diversified phylum of animals and it is not surprising that this basic pattern of the nervenet is considerably modified in the larger representatives with their complex reactions. In Hydra the neurons are only slightly more concentrated in the hypostome and the pedal disc where the plexus has a circular arrangement suggesting a nerve ring, but in the scyphozoans (jellyfishes) the neurons are concentrated and the fibers aligned to form a thick “through conducting” nerve ring at the margin of the bell. The long bipolar nerve cells form a trough conduction system for rapid transmission and are comparable to the giant fiber system of the higher vertebrates.

The primitive central nervous system of a flat worm

The nervous system of the platyhelminth has been linked to a coelenterate nervenet with a concentration of neurons in the head region. This is a misleading concept. Although the anatomical similarties in neuron arrangements are obvious, and significant phylogenetic step in integrative mechanisms was taken during the evolution of the primitive worms. The nervous system of planocera consists of a brain from which seven pairs of major nerve trunks pass peripherally and are interconnected to form a complex net.

A Central nervous system is absent in coelenterates and new dimension in neural organization appears at the level of the flat worms with separate sensory and motor pathways and co-ordinating interneurons. Nerve nets and pacemakers are also present in the flatworms and remain important components of the nervous organization of the most advanced animals, but the appearance of ganglia forms a new element and marks a first step in the march toward the integrating systems of higher forms.

3.2.3 Evolution of nerve trunks and brain

The trend in phylogeny has been toward the development of a single, longitudinal nerve trunk conducting messages to and from different parts of the body, with a massive anterior concentration of neurons concerned with sensory reception, integration, and the control of activity. The evolution is clearly associated with the appearance of bilateral symmetry and a dominant head with its battery of sense organs.

Longitudinal nerve trunks are foreshadowed in planocera with two major conducting routes in the posterior body. Some of the other flatworms have several longitudinal nerve tracts with cross connections instead of the reticular net. Invertebrate nerve trunks might seem the logical forerunners of the vertebrate spinal cord. In both major groups , a median longitudinal tract conduct impulses and integrates the activities of a greatly elongated animal body, more over neurons appear to operate in much the same way at all levels in phylogeny.

Invertebrate ganglia. The clustering of neuron somas into discrete masses(ganglia) parallels the evolution of longitudinal transmission lines, the nerve trunks. From the simple nervous systems of flatworms, there is a progressive concentration of nerve cells into ganglia, with a further consolidation of the ganglia in the head to form a massive nerve center, the BRAIN. In lower forms, scattered gaglia regulate processes in specific body area. Thus, each metamere contains a ganglion in segmental animals like the annelids and arthoropods with a ladder-type nervous system, while separate pedal, pleural and visceral ganglia are characteristic of many molluscs.

3.2.4 The vertebrate brain and a hierarchy of nerve centers

The vertebrate musculature is innervated by a segmental series of paired spinal nerves and several pairs of the cranial nerves. With the exception of some of the cranial components that have been modified during development, these nerves have two roots a dorsal root which is entirely sensory(afferent) with the cell bodies located in a ganglion, and a ventral root which is motor(efferent) with neuron somas in the ventral portion of the central nervous system

Functional anatomy of nerve cells

The vertebrate motor neuron from the ventral horn of the spinal cord is most often selected to illustrate a typical nerve cell. This is a multipolar cell with numerous short fibers(dendrites) associated with the input or reception, and one long fiber(axon) which transmits to the muscle. Characteristically, the soma or cell body contains a central spherical nucleus with prominent nucleolus and fine chromatin granules while the cytoplasm is filled with prominent granules, flakes, or clumps of chromidial material, the nissil bodies. These are composed of ribose nucleoproteins and are thought to be responsible for the synthesis of proteins-possibly the enzymes concerned with acetylcholine synthesis

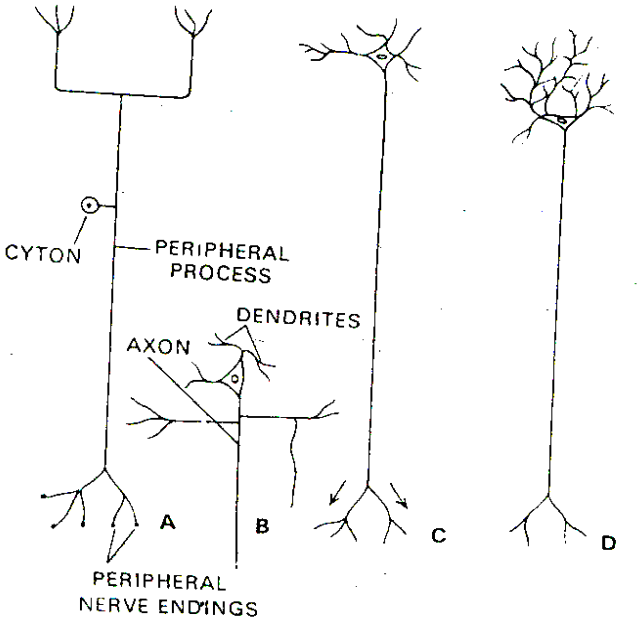


Fig.3.1.1. Diagram of different types of neurons and association between them

with appropriate techniques, fine neurofibrils can be shown to course through the cytoplasm and to extend into the dendrites and axon. Neurons of all animals, from hydra and jelly fishes to chickadees and men, show common staining reactions based on the presence of similar cytological elements.

3.2.5 Origin and propagation of nerve impulse

Pioneer physiologists also recognized conduction(the progressive spread of excitation)as a fundamental property of living cells and one which is inseparably connected with irritability and conduction are found in nervous and muscular tissues, these properties can be readily demonstrated in many other types of cells.

Nerve impulse is the sum total of chemical and physical events in the propagation of a wave of physiological activity along a nerve fiber. It is a wave of electrical depolarization and repolarization sweeping along a nerve fiber.

1.Propagation in a non-myelinated fibre

When a nerve fibre is at rest i.e. when it is not carrying an impulse, the outside of the fibre (surrounded by Na+) is positively charged in relation to the inside. The inside of the fibre is negatively charged even though it contain K+, because of the presence of cl- and a variety of large organic anions (resulting from metabolism). Sucha as acetate, pyruvate, lactate and aminoacids – that are too large to diffuse easily through the axon membrane.

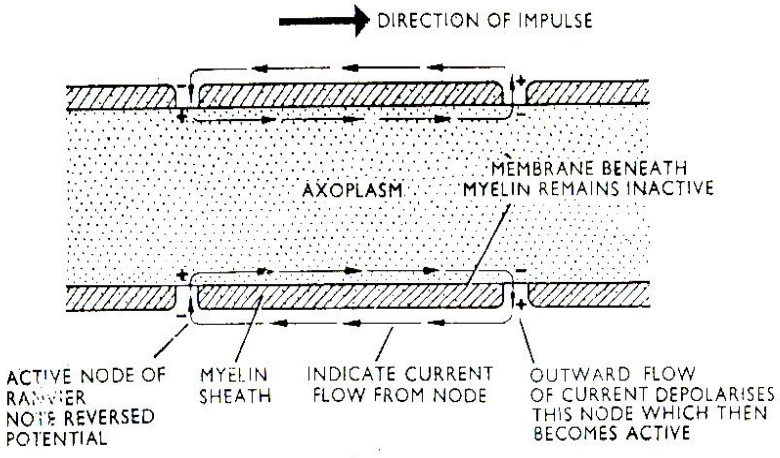


Fig. 3.1.3. Saltatory conduction through myelinated nerve fibre.

3.2.6 Origin of resting potential

As long as a cell is alive, its surface membrane separates solutions of different chemical composition. The osmolarity of the external solution equals that of the internal solution, but the ionic species are very different, it is this difference which produces the resting membrane potential. At the plasma membrane, where the internal and external fluids would tend to mix by diffusion, there are localized accumulations of positive and negative charges separated by this bimolecular layer. This is a purely localized phenomenon, in most cells ionic diffusion fronts of K+ press toward the outside while Na+ presses toward the inside. Exchanges of ions between the cell and its surroundings are restricted but not entirely prevented by the permeability properties of the cell membrane, the balance is maintained by cellular processes of active ionic transport . Thus, electrical neutrality is preserved both in the extra and the intracellular fluids, but the diffusion fronts result in sufficient separation of ions to create the transmembrane bioelectric potential.

Physiological evidence, based primarily on studies of squid axons, vertebrate muscles, and certain algalcells, points to K+ as the principal source of the resting potential. For more than half a century it has been realized that cell membranes behave as though they are freely permeable to K+ but relatively impermeable to Na+. Hodgkin and Katz(1949) estimate that the resting membrane of the squid axon is 25 times more permeable to K+ than to Na+. Because of this difference in free movement of cat ions (+) through the cell membrane, the passive diffusion of potassium toward the outside will be much greater than the passive diffusion of sodium toward the inside.

3.2.7 Depolarization

First, the membrane is usually not simply depolarized during excitation, the potential is often substantially reversed (40 to 50 with the inside positive in nerve) moreover, there are many cases where membranes are actually hyper polarized on stimulation. Second the use of radioactive

isotopes has clearly shown that the membrane is permeable to sodium and chloride as well as to potassium.

Repolarization

K+Ion with their positive charge, now begin to flow out faster than the Na+ flows in. When these positive charges are moved to outside of the cell, they initiate the process of repolarization (return to the resting stage) and inside of the cell again becomes negative.

Metabolic pump

Two types of ion pump have been considered:

1. An electrically neutral pump that transfers equal numbers of like charges in different directions across the membrane.

2. An electrogenic pump that transfers more ions in one direction than the other and thus contribute to the potential. The linked sodium-potassium pump of the squid axon was once thought to be electrically neutral, but current evidence shows that it transports three Na+ for every two K+ and hence is electrogenic. The chloride, calcium and magnesium pumps are(located) electrogenic in nature. Ion pumps are important in maintaining the resting potential and cells every where seem to have the capacity to develop active transfer systems appropriate to their requirements for intracellular ion regulation.

3.2.8 The Action Potential

Sodium ions have been found to play key role in initiating the action potential of squid axons and vertebrate muscle fibres. Modern micro analytical methods applied to single cells show that the briskly rising spike is associated with a rush of Na+ into the cell. In resting cells, Na+ valves appear to be mainly closed while the K+ and cl- valves are open only in sufficient number to balance the electrochemical forces and establish the resting potential.

A stimulus opens the sodium gates and permits rapid influx of Na+, which decreases and then reverses the transmembrane potential, the sodium valves are only momentarily open, as they close, there is rapid loss of K+ associated with the opening of the K values.

3.2.9 Propagated action potentials and the spread of excitation

A spike discharge at any point on an electrically excitable membrane will disturb the delicate balance of ions in neighboring regions and create a flow of electric current between the resting and active areas. This flow of current is the basis of nerve impulse, muscle excitation, and conduction found in several different types of cells.

Propagation of the nerve impulse along the axon

The first point to be emphasized is the reversal of membrane charge. The local circuit current thus established reduces the membrane potential just ahead of it sufficiently to activate the adjoining region. Thus, there is a progressive reversal of charge that extends from the point of stimulation as though an electrode were moving along the membrane at the rate of conduction. The second important feature of membrane conduction is the explosive nature of the all-or-none action potential which occurs when the threshold or firing level is reached, in the squid axon, the threshold charge may be amplified by a factor of 5.

3.2.10 Pace maker potentials

Some cells generate action potential spontaneously in the absence of obvious external or internal triggering, their membranes gradually depolarize to threshold. This spontaneous electrical activity was first recognized in vertebrate cardiac and smooth muscle cells, but comparable oscillations occur at all levels in animal phylogeny.

The progressive and spontaneous depolarization to threshold, which follows each spike, is termed the pacemaker potential or the pre potential. Repolarization is followed by a slow depolarization to threshold, this initiates another spike, to be followed by a gradual depolarization. The frequency of the oscillations is characteristic of different types of cells. The pacemaker potential in vertebrate smooth and cardiac muscle cells is attributed to a gradual decrease in potassium conductance or permeability, increasing sodium and / or calcium conductance would have the same effect and this may be responsible for the pre potential or contribute to it in some pacemakers.

3.2.11 Myelinated nerves

Although the velocity of the nerve impulse increases with the size of the conducting fiber, the most rapidly conducting nerves are not giant axons but the much smaller fibres of vertebrates. Some mammalian nerves conduct at rates of 80-100 m/sec while the median axon of the earthworm Lumbricus, one of the most rapidly conducting giant axons of invertebrates, transmits at about 30m/sec.

Seen with the ordinary light microscope, the myelin sheath of a vertebrate myelivated nerve is a homogeneous osmophilic layer closely surrounding the axoplasm and neatly covered with the cytoplasm of schwann cells. Outside this again are the connective tissues which will be omitted from further discussion. Deep construction in the myelin sheath occur at intervals of about 1mm. At these points the nyelin in interrupted, and the axoplam is covered only by the neighboring schwann cells.

3.2.12 Interneuronal transmission

Sir Charles Sherrington(1861-1954); who spent a long and productive life studying the integrative action of the nervous system, first applied the term “synapses” to the point of contact between two nerve cells.

Any specialized relationship where one neuron affects another may be termed as synapse. Two functional types are recognized.

1. Electrical synapses, through which excitation passes electrotonically from one neuron to another.

2. Chemical synapses, where a presynaptic fiber releases transmitter which excites a post synaptic fiber.

Electrical synapses

Low- resistance electrical pathways are now recognized in many nervous systems, including the central nervous system of the higher vertebrates. Structurally, these pathways are specialized gap junctions. Where the space between the two cell membrances is extremely narrow or nonexistent. Ultra structural studies show that this narrow gap is bridged by cytoplasmic channels or tubes through which exchange of low-molecular-weight substances and electrical current can flow between the two sinaptic fibres. Thus, the actual synaptic space is a network of polygonal channels continuous with the extra cellular spaces of the tissue, while minute tubes formed by protein molecules bridge the gap and provide low resistance electrical pathways.

In principle, electrical or ephaptic transmission is the same as impulse propagation in an axon. The septa are regions of low resistance, the action current generated on one side flows to the adjacent segment and excites it to produce a spike potential.

3.2.13 Chemical synapses

At chemical junctions, a fluid filled space about 20mm wide separates the pre synaptic and post synamptic elements. This space prevents the direct electronic spread of excitation from one nerve to the other. Instead, a chemical(transmitter) is secreted by the pre synaptic neuron, diffuses across the space, and creates electrogenesis by altering the permeability of the post synaptic membrane to specific ions. Several different transmitters are now well known and will be described. Some of them lead to excitation and some to inhibition. The best known excitatory transmitters operate by simultaneously increasing the permeability to Na+ and K+, while the permeability to K+ and cl- is increased at the inhibitory ones. Depolarizing potentials, associated with excitation, are termed excitatory post synaptic potentials while the hyperpolarizing potentials, characteristic of inhibition, are called inhibitory post synaptic potentials.

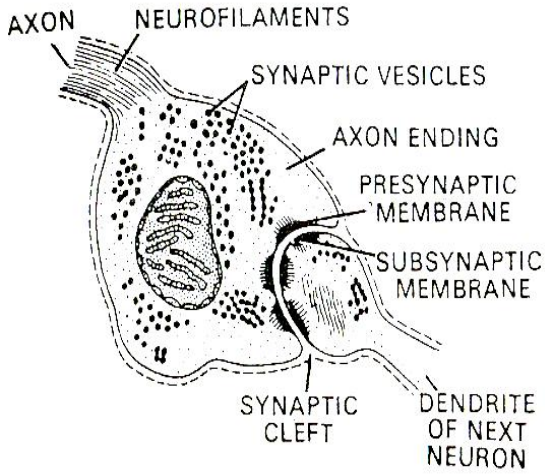


Fig. 3.1.4. Electron microscopic stucture of synapse.

3.2.14 REFERENCE BOOKS :

General and Comparative Physiology - William S. Hoar

Comparative Physiology – C.L.Processor

3.2.15 EXPECTED QUESTIONS :

1. Give an account on vertebrate brain and a hierarchy of nerve centers.
2. Write notes on evolution of nerve trunks and brain.
3. Explain the process of interneuronal transmission.
4. Write short notes on :
    (a) Chemical synapses
    (b) Myelinated nerves
    (c) Depolarisation
    (d) Pacemaker potential

Lesson 3.3

CHEMO, MECHANO AND PHOTORECEPTORS IN ANIMALS

3.3.1 Introduction

It is inevitable for the animals to know their surroundings. They respond to the environmental changes and adjust accordingly. This response and adjustment of animals are possible only because of the presence of a communication system. This communication system includes signal receivers or receptors, conducting pathways or nerves, a interpreting means or brain and a responding organ, the muscles or glands. A receptor is a specialized structure which reconceives stimulus. A stimulus is an environmental change. The world is made to known to us by our senses.

A receptor may be a specialized single cell or a group of cells. When it is in the form of single cell it is called a sensory cell. When it is in the form of a group of cells, it is called a `sensory organ'.

The most common receptors are those connected with the familiar five senses, namely sight, - hearing, touch, smell and taste. These are only a few of the many senses. The important receptors include eye, ear, nose, tongue, skin etc…

Types of receptors

Based on the type of stimulus received the receptors are classified into four types. They are as follows:

1. Chemoreceptors

When a receptor responds to a chemical stimulus, the receptor is called a chemoreceptor. Sensory organs of smell and taste are chemoreceptors.

Eg: tongue and nose.

2. Photoreceptor

When a receptor is stimulated by light, it is called a photoreceptor.

Eg: eyes.

3. Mechanoreceptor

When a receptor responds to a mechanical stimuls, it is called a mechanoreceptor. The mechanical stimuls includes sound, touch, pressure, displacement of the body etc. Ear, skin, antenna, lateral line sensory organ Ampulla of Lorenzini, etc…

4. **Thermoreceptor**

When a receptor is stimulated by temperature, it is called a thermoreceptor.

3.3.2. Chemoreceptors

The chemoreceptors respond to chemical stimuli. They find out the smell and taste of the substances. The important chemoreceptors are taste buds, olfactory sacs etc.

Classification of chemoreceptors

Chemoreceptors are clossified into two groups, namely gustatoreceptors and olfactoreceptors.

1. Gustatoreceptors

These are the organs of taste. They are concerned with the detection of chemicals in liquids. The important gustatoreceptors in vertebrates are taste buds.

Taste buds

The taste buds are located on the surface of the tongue. Each taste bud is formed of a group of cells. There are two types in each taste bud. They are supporting cells and neurosensory cells. The supporting cells from the outer covering and the neurosensory cells – occupy the interior of the taste bud. Each neurosensory cell is long and narrow with a taste hair at the free end and nerve fibre at its base. The taste hairs project into a depression called taste hair.

Mechanism of sensation of taste: when liquid substances enter the taste pore, the taste hairs are stimulated. The stimulus is converted into the impulse and is carried by the nerve fibers.

2. Olfactoreceptors

Olfactoreceptors are the organs of smell. They detect the chemicals in gas phase. The important olfacto receptors are the following.

a. Olfactory pit

b. Olfactory sacs

c. Jacobson's organs

d. Nasal passages

a. Olfactory pit

It is a ciliated depression present in the head of Amphioxus.

b. Olfactory sacs

These are present in cyclostomes and fishes. There are two sacs in each fish. They open to the exterior by external nostril. Each olfactory sac is formed of olfactory epithelium. It is produced into a series of folds called – schneiderian folds. These folds are connected dorsally by a median raphe. Water entry the sac through inhalent siphon and it comes out through exholent siphon.

c. Jacobson's organ

These are paired chambers present in amphibians, sphenodon, lizards, snakes, monotremes, marsupials, insectivores and rodents. But in turtles, crocodiles birds, and many mammals they are found only in the embryo and are absent in the adults.

These are sac-like chambers lying below the nasal cavities but above the buccal cavity. Each sac opens by a short duct into the buccal cavity. Each sac is lined with olfactory epithetium.

d. Nasal passages

In mammals the lining of the nasal passages serve as olfactory organs. It is formed of membrane having neurosensory cells and supporting cells. The free end of the neurosensory cells are provided with six to eight sensory hairs and the base is connected to a nerve fibre.

3.3.3. Photoreceptors

These receptors receive light stimulus. The eyes are important photoreceptors.

Eye

Eye is a photoreceptor. The human eye is a tender ball, the eye ball. It is about 1 inch in diameter, It is protected in a socket of the skull. The eye ball has three concentric coats, namely an outer sclerotic coat or sclera, a middle charoid coat and an inner retina. The sclera is a tough fibrous capsule. It forms the white of the eye. The eye muscles are attached to the outside of the sclera. The front of the sclera facing outside is protectly transparent and is called cornea.

The chorid coat is the middle layer. It is formed of blood vessels and non-reflecting pigment. The pigment acts as a light shield preventing the light from scatteing. The front portion of the choroids is interruptedby a small opening called pupil. The region of the choroids visible through the cornea and surrounding the pupil as a coloured band is called iris.

The iris functions as a diaphragm. When the light is dim, the diaphragm expands and thus the size of the pupil enlarges; as a result more light is allowed inside. When the light is bright, the diaphragm contracts and thus size of the pupil decreases, as a result less light is allowed inside. The expansion and contraction of iris is brought about by two sets of muscles called circular and radial muscles. The iris is connected with the ciliary body.

The pupil is occupied by a lens. The lens is an elastic transparent rubber balloon filled crystal clear jelly. The lens is held in position by suspensory – ligments attached to the ciliary body which encircles the lens.

The retina is the inner most layer of the eye ball. It is about the thickness of a postage stamp and not much thicker. It lines the two thirds of the back of the choroids. It ends just behind the ciliary body in a serrated border called oraserrata. Retina contains special photosensitive cells called rods and cones. The rods are cylindrical in shape and the cones are pyramidal in shape. Each eye contains about 100 million rods and 7 million cones. The rods contain a pigment called rhodopsin, the cones contain another pigment called rhodopsin. The cones are responsible for bright-light (day light) vision, colour vision and acuity of vision; the rods are responsible for dim light-vision.

The rods and cones are arranged perpendicularly on the retina. They have an outer segment (facing choroids) and an inner segment (facing vitreous humour). The inner segment is connected to a nerve fibre. Each cone has a separate nerve fibre, but many rods are connected to a single nerve fibre. All the nerve fibres converge towards the posterior side of the eye where they leave the eye as an optic nerve. Thus the nerve fibres of the rods and cones are directed towards the light, but the free end of the rods and cones are directed away from the light. As a result the retina is referred to as inverted retina.

The place where optic nerve leaves the eye is marked by creamy white disc called optic disc. In this area rods and cones are absent. So no vision is effected in this area. Hence this area is called blind spot.

The space lying between the cornea and the iris is called anterior chamber. It is filled with a lymph like watery fluid called aqueous humour. The space lying between the iris and the lens is called posterior chamber. It is also filled with aqueous humour.

The eye is protected in front on its outer surface by a thin transparent layer of epidermal cells called conjunction. The outer skin above and below forms folds called eyelids. The eyelids are provided with hairs called eyelashes. Above the upper eyelid is a ridge called eyebrow provided with hair. The eyelashes and eyebrows help to prevent dust, sweat and so on from reaching the sensitive moist surface of eyes. The eye is kept moist by the tears a watery secretion

of two specaial lacrimal glands. Excess of tears are drained from the eye into the nasal sinuses by the lacrimal duct, opening from the inner corner of the lower eyelid.

Vision

The ability to see objects is called vision. Vision effected only in the presence of light. Vision is the result of a photochemical reaction occurring in the rods and cones.

Defects in vision

Vision is affected by abnormal refractions, deficiency of vitamins, diseases of eyes etc. A few defects are as fallows.

1. Hypermetropia or long sight

It is a defective vision caused by errors of refractions. It is a condition in which parallel rays of light are bought to a focus behind the retina. This is caused in two ways. (1) Eyeball is short (2) The refracting power of the lens is below the normal. It can be corrected by wearing convex glasses to bring the focus on the retina.

2. Myopia or short sight

It is another defect caused by errors of defraction. Here parallel rays of light come to a focus in front a retina resulting in a blurred image. It is also caused by two factors. (1) Long eye ball and (2) The refraction by the lens may be too high. It can be corrected by wearing concave lens to bring the parallel rays focused on the retina.

3. Presbyopia

It is defined as the recession or "near point". The near point is closer to the eye at the age of 8 and then recedes gradually until about the 45^{th} year, when a much more rapid recession occurs. It is due to the plasticity of the lens. As age advances, the plasticity becomes verymuch reduced. As a result at the age of 40, he is not able to read at the usual distance i.e. near point recedes. It can be corrected by convex glasses.

4. Astigmatism

In this defect parallel rays are not brought to a single point, but in a number of different points. It may be inherited or acquired. It is caused by the development of cataract of the lens, ulceration of cornea, injury to the refracting surfaces, diseases etc. Astigmatism can be corrected by wearing lenses with cylindrical surface on one side and spherical surface on the other side.

5. Anisometropia

In this case there is difference between the refraction of the two eyes. One eye becomes dominant, the image in the other eye being suppressed. After a period, the disused eye loses its capacity of sight. Treatment consist in correcting each eye separately.

6. Night blindness

This is caused by abnormal photochemical reactions. When vitamin A is deficient, the photosensitive – pigments present in the rods and cones cannot be resynthesized or the synthesis is delayed. As a result the person cannot see in dimlight.

7. Colour blindness

Colour blindness means lack of appreciation of one or more colours. This disease is more common among males (8%) then among females (0.5%). Most cases are inherited as sex-linked recessive characters, but colour blindness can also be acquired as a result of disease of the retina or nervous system.

The colour blind person may not discriminate one or more or none colours. When the colour blind person cannot distinguish red colour the defect is called protanopia; when green is not discriminated the defect is called deuteranopia and when blue colour is not distinguished, the defect is called tritanopia.

3.3.4. Mechanoreceptors

The sense organs receving mechanical stimuli are called mechanoreceptors. The mechanical stimuli may be in the form of touch. On the nature of the mechanical stimuli the mechanoreceptors are classified into three types. They are the following.

1.Tangoreceptors
2. Phono receptors and

3. Rheoreceptors

1. Tangoreceptors

The trangoreceptors are the sense organs of touch. They are also referred to as the tactile sense organs. Tangoreceptors are located in the barbells of catfishes, in the antenna of insects, in the knee, feet and palm of man etc. The important tangoreceptors are following.

1. Nerve endings
2. Merkel’s corpuscles
3. End bulbs of Krause

4. Pacinian corpucles
5. Meissner's corpucles
6. Grandry's corpucles and
7. Herbst corpucles

2. Phonoreceptor

Phonoreceptor receive sound vibrations. Ears are the important phonoraceptor.

Ear

Ear is the seat of two senses, namely hearing and equilibrium. Human ear has three divisions, namely external ear, middle ear and inner ear. External ear has pinna and external auditory meatus. External ear is separated from the middle ear by a membrane called tympanic membrane (or) ear drum. The middle ear enclose a cavity called tympanic cavity. In communicates to the pharynx through an Eustachian tube. The tympanic cavity contains three ear ossicles arranged in a series from tympanic membrane towards inner ear in the order of malleus (hammer) incus (anvil) and stapes (stirrup). The middle ear communicate with the inner ear through two openings namely fenestra ovalis and fenestra rotunda, both of them are guarded by membrane. The inner ear is called membranous labyrinth protected by bony labyrinth. It contains the following structures: utricle, sacculus, spirally coiled cochlea and 3 semicircular canals. The membranous labyrinth is filled with a fluid called endolymph and the space between membranous and bony labyrinth is filled with perilymph.

3. Rheoreceptors

Rheoreceptors detect water- current and water pressure. They are strictly confined to aquatic animals like cyclostomes, fishes and amphibians. The important rheoreceptors are the following.

1. Lateral line sense organ
2. Ampulla of Lorenzini
3. Pit organs and
4. Vesicles of Savi

3.3.5 Thermoreceptors

When a receptor is stimulated by temperature, it is called a thermoreceptor. Eg: skin.

Based on the position of receptor, they are classified into three types. They are as follows.

1. Exteroceptors

When a receptor is located on the surface of the body or stimulated by external stimulus, the receptor is called an extero- receptor.

2. Intero ceptors

When the receptor is located inside the body or stimulated by internal stimulus, the receptor is called an interoceptor.

3. Proprioceptors

The receptors specifically concerned with equilibrium and co-ordinated locomotion are called proprioceptors.

Eg: Free nerve endings, Muscle spindles, golgi receptors, statocysts etc.

Thermoreceptors are stimulated by temperature. They are situated on the skin. There are two types of thermoreceptors, namely cold sensitive receptors and heat sensitive receptors.

1. Cold sensitive receptors

These receptors are stimulated by lower temperature. They are also called end bulbs of Krause.

2. Heat sensitive receptors

These receptors are stimulated by higher temperature. They are also called end organs of Ruffini.

Expected Questions

1. Explain the role of receptors in animals
2. Give an account on photoreceptors
3. Write notes on chemo receptors
4. Write in detail on thermoreceptors in animals

Reference books

1. Canparitive Physiology – W.S. Hoar
2. Animal Physiology - Nielson

Lesson – 3.4

THERMOREGULATION IN ANIMALS HOMEOTHERMS AND POIKILOTHERMS

CONTENTS

3.4.I. INTRODUCTION

Active animal life is limited to a narrow range of temperatures, from a few degrees below the free going point of pure water (O^OC) to approximately + $50^{O+}C$. We are now concerned with the temperature of the organism itself not the surroundings. In polar regions numerous fish and inverter brates live in water at – 1.8^OC. At the other extreme, in hot springs a few animals can live at about 50^OC. Some blue green algae live above 70^OC and a few thermophilic bacteria survive above the boiling point of water.

Most animals, among them all aquatic invertebrates, have nearly the same temperature as their surrounding. Birds and mammals, in contrast, usually maintain their body temperature nearly constant and independent of the environment. However some other animals both vertebrates and vertebrates, can at times maintain a substantial difference between their own temperature and that of the surrounds.

Each and every activity of living organism is the result of the biochemical processes that take place in their body. All such processes are so much temperature sensitive that even a slight change in temperature alters the rate of these reactions. Therefore, a situation arises a need for maintenance of a specific body temperature for the life of an animal to be carried on in a perfect

order. The way in which the organisms maintain their body temperature within a certain limited range is termed as `thermo regulation'.

3.4.2 CONFUSING TERMINOLOGY

There is no simple and easy way to classify the various responses to the thermal environment. Birds and mammals usually maintain their body temperature above that of the environment and have traditionally been called warm blooded. This term is so well established that it is convenient to use it. It is how ever in accurate and may be quite misleading.

A cold blooded animal is not necessarily cold; a tropical fish (or) a desert lizard (or) an insect sitting in the sun may have higher body temperature than a mammal. Furthermore, quite a few mammals and some birds undergo periods of torpor (or) hibernation during which their temperature may decrease to near the freezing point of water, with no harm to the animal. In that state it seems odd to call them warm blooded. The corresponding scientific terms, poikilothermic for cold blooded and homeothermic for warm blooded, are also imprecise.

(Poikkilothermic (Greek : Poikilos = changeable)

Homeothermic (Homoios = similar)

The following are some other terms that are used to classify various other responses to the thermal environment.

Heterotherms

Animals that at times have high and well-regulated body temperature, but at other times are more like cold–blooded animals, are often called Heterothermic (Greek heteros = different).

Endothermic Animals

These animals are able to maintain a high body temperature by internal heat production.

Ectothermic animals

These animals depend on external heat sources, primarily solar radiation.

The choice of terminology is primarly a matter of convenience. The question is not weather a certain terminology is right (or) wrong, but how useful it is for a given purpose.

3.4.3 Effect of Temperature on Metabolism

As stated earlier, the physiological processes are highly temperature sensitive. Environmental temperature weatherring' (or) falling manipulates, the rate of metabolic processes accordingly. The fact has been studied by various authors vant Hoff describes this generalization in the following way. For every few degrees rise in temperature, the rate of bio-chemical reactions becomes almost double. This is known as Q_{10} law and is expressed as

$$Q_{10} = \frac{(Kt + 10)}{Kt}$$

Where Kv is the velocity constant at temperature "t" and Kt + 10 is the velocity constant at temperature "t" and Kt + 10 s the velocity constant at temperature (t + 10).

In case of poikilothermic animals, with the change in environmental temperature the rates of metabolic processes changes. But when find homeothermic animals the change in external temperature has no (or) very little effect on body temperature which remains almost constant. Also we see that the poikilotherms having low body temperatures are lower grade of animals as compared to birds and mammals having higher body temperature. Thus it can be said that higher body temperature favours more complex form of life.

3.4.4 EFFECT OF LOW TEMPERATURE :

Varied kinds of responses are shown by animals to cold conditions. A few of them migrate to avoid the cold conditions, while the others who face such low temperatures either mould themselves accordingly (or) sure to be effected adversely. Lethal temperature for different animals varies according to the degree of exposure to temperature.

There are number of theories explaining the cause of death because of cold but there is no general agreement and none of thero are universally accepted.

3.4.5 EFFECT OF HIGH TEMPERATURE :

The effect of life of animals due to high temperatures are much more severe than those of low temperature. Aquatic animals face less variations in temperature because of high specific heat of water (H_2O) and thus their lethal temperatures are lower as compared to those of tand animals. It is evident that the higher temperatures are lowerer as compared to those of lind animals.

After certain limit, if the temperature rises the body activities cease down and the animals finally die. Protoplasm constituting the animals contains proteins and enzymes will coagulate and get denatured at high temperatures. Thus effect the body activities in general and finally result in death. The excess of heat also leads to an increased viscosity of cellular fluid. With the result of which only vacuolation also takes place. This leads to the release of Ca^{++} ions within the cells and the Ca^{++} ions so released have a disruptive influence on the cell by affecting the permeability of plasma membrane. All these factors combindly (or) alone affect the organisms adversely.

3.4.6 MECHANISM OF HEAT REGULATION IN POIKILOTHERMS

The body temperature of poikilotherms changes according to that of the environment which they do not have any control on it. This is so because they lack the temperature regulating mechanisms. Still to a very small degree a regulation of temperature is run in these animals and this is by their behavioural and metabolic activities.

Many reptiles (Snakes and Lizards) are often found to bath in sun light. This practice may increase their body temperature by even $20^{O}C$. This is because of absorption of solar radiation and conduction by the substrate. By fluttering of wing's also some insects manage to rise the temperature of their flight muscles to the extent to make the flight possible. This method of `generating' metabolic heat is also very efficient as in bees and can raise the temperature by 10-$12^{O}C$. Generally in fish and other aquatic poikilotherms there is no appreciable difference between their temperature and that of the surrounding water. The heat produced as a result of muscular activity during moving is exchanged and equilibrium in temperature with that of surrounding water is maintained.

Besides these, these are certain special methods also which are in practice to overcome the handicaps of being poikilotherms such as larvae of butterfly, venessa group together in cold weather. This group as a whole is able to maintain a temperature of 1.5 to $2.0^{O}C$ higher than that of the surrounding air. Workers of polites (A social wasp) fan with their wings to produce a cooling effect. In extreme hot weather they put water on their combs. Its evoporation produces cooling effects.

In this way it is seen that inspite of lack of heat regulatory mechanisms, poikilotherms do have adopted different ways to adapt themselves to the hot (or) cold condition.

3.4.7 THERMO REGULATION IN HOMEOTHERMS

Homeotherms, in contrast to the poikilotherms definitely maintain a constant body temperature (which may, however, vary to a very small extent within a certain limited range).

The reptiles are the first animals to show some kind of thermo-regulatory device though they are at a very primary level. Birds and mammals are the groups that possess highly developed thermo-regulatory centers, situated in the hypothalamms and are quite efficient.

Homeotherms regulates their body temperature in the following manner. Weather heat produced (or) lost it is adjusted against the environmental temperature by physical processes and the production is regulated by altering the metabolic rates (or) chemical regulation according to the body requirements.

In cold, the heat is lost from the body by radiation. This loss is reduced by lowering the temperature of body surface so as to lower down the heat gradient between the animal and its atmosphere. As a result the heat given to the surroundings gets lowered and is conserved in the body of the animal itself. The loss of heat occurs by the process of conduction is quite much in homeotherms because of their higher metabolic rate. This may be reduced by the presence an insulating layer between the body surface and the tissue. Blood circulation in skin and the presence of layer of fact below the skin which works as an insulating layer in combination with the four (or) feathers in homeotherms are the mechanism to combat the loss of heat by both of these probabilities.

The loss of water from the body in the form of swetting is also a method of controlling temperature. More and more water is given out as the temperature rises. For this these are present

the sweat glands in the skin of mammals. However birds and marsupials etc. lack these glands and therefore have to use some other methods for evaporation of water. Animals inhabiting the polar regions (or) Arctic regions have to live in a permanently cold environment and accordingly possess a very thick coat of furr. Ex: polar bear just opposite to it is the case of desert animals they have to live almost permanently to hot climate. As a consequence their dermal fat is aggregated to a limited peace in the body, so that the heat loss may take place through rest of the surface easily. Ex: Camel (Dermal fat concentrated in hump region).

3.4.8 HOMEOTHERMIC ANIMALS

In aquatic homeotherms eg. Seals, whales etc., body is so thickly insulated that the inside temperature is quite different from the body surface temperature, which is only slightly different from the body surface temperature, of surrounding water. The extremeties of body are not found to be insulated in this way and to compensate this there is formed a thick net work of arteries and veins so that the heat gets transferred to venous blood from arterial one and does not get lost. Homeothermic animals are further assisted by few chemical mechanisms in addition to these physical methods in regulating their body temperature increased activity of thyroid gland and of adrenal cortex increase metabolic activity in a few tissues as muscles, liver etc., leading to the increased heat production.

3.4.9 CONTROL OF HOMEOTHERMY

Control of homeothermy by the central nervous system is mainly carried out by hypothalamus in the brain. There is one centre for heat and three centers for cold stimulation. As soon as stimulus for heat is received the immediate response given to the skin is dilation of nessels and wetting. Similarly the cold centers respond by constriction of blood, vessles, muscular contraction, shivering, retardation and finally cessation of sweatting i.e. all the means of retaining head in the body.

Pituitary gland controls the process by its hormonal secretary and nereous effects are brought about in addition by the motor neurons of spinal cord in case shivering and autonomic nervous system in sweating and blood vessel constriction.

3.4.10 Heterotherms

Some low grade mammals like Echidna, opossum, ornithorhynchus etc., are not very much efficient in maintaining a constant body temperature and large fluctuations of temperature is observed in them. They may have a temperature that is little bit lower than that of the environment.

Similarly a few birds and smaller mammals (endotherms) show diurnal variations in their body temperature and this is correlated with their changed metabolic activity during day and night.

3.4.11 HIBERNATION

In cold climatic conditions the food is scarce and also the food requirement to conduct normal metabolism becomes very high. Both these lead to many deaths because of starvation.

To prevent deaths from such situation many animals pass their winter in lethargic states. It is a pattern of adaptive hypothermia found in small animals like rodents, insectivores, bats, etc. Because of low body temperatures the heat losses get minimized and thus only a small amount of food is required by animal. Consequently the metabolic rate reduces down. Most of the body activities come to a very minimum level however, vital activities such as heart beat, respiration etc., continue. During hibernation the animal lives entirely on reserve foods and because they perform very less activities, they are said to be in a sleeping state.

Generally the hibernating animals undergo this stage till winter lasts but there are a few in which the pheromenon is known to take place at other time also. For example in bats diurnal changes and they sleep at day times, with a little search for food at night. Thus they behave as hibernators everyday and the long winter sleep found in them may be considered as an extension of this daily hibernation.

The arousal from hibernation is a slow and complex process. Slowly and slowly the animal comes to its original metabolic rate and body temperature, the cause of this is thought to be shivering and non shivering thermogenesis.

Hibernation, in homeotherms, there is a mode of temperature regulation against the cold conditions and the animals behave like poikilotherms to some extent. If the environmental temperature goes below zero the animal regains its own body temperature rather than lowering so much and starts all its metabolic reactions. Thus it is a well regulated process by virtue of which hibernators tide over the most adverse climate and thus is biologically important as it preserves the species.

3.4.12 AESTIVATION

Hibernation is a phenomenon adopted during hypothermic conditions and aestivation just opposite to it, used to tackle hyperthermic conditions. Many small animals as amoeba, molluses, even fish are found to enter a state of protection. This follows a state of high ambient temperature. Along with this the decreased water quantity around them, induces conditions of hyperthermia. These protective coverings assit to avoid the conditions of tissue dehydration, enzyme loss, turn off metabolic mechanisms etc.

3.4.13 ACCLIMATIZATION

It is a phenomenon correlating the climatic and metabolic changes. Earlier this term was used to include the metabolic changes associated with the change in temperature and humidity of climate but now it includes all the metabolic changes, because of changed O_2 content of water, salinity food etc., with the climatic changes, the overall behaviour of animals also changes.

Salinity, humidity and other climatic factors change at every place and no animal has a constant environment. Thus to define the process, the ecological factors of a particular place are to be taken as constant.

Discontinuous distribution of animals all over the world and the migratory changes show that the animals oppose the changed climatic conditions and which do not move, either die (or) have to change themselves accordingly.

3.4.14 HOMEOSTASIS

Animals have evolved in such a way that there is more control and less variability in internal environment with respect to changed temperature, concentration of different nutrients, pH, O_2 content, degree of hydration and other factors and this control is termed Homeostasis.

3.4.15 EXPECTED QUESTIONS :

1. Describe the mechanism of thermoregulation in a Homeotherm animal.
2. Describe the tomer vertebrates undergo minter sleep mention the changes brought about by the during hibernation?
3. Write in detail the process of thermoregulation in Homeotherms and poikilotherms?

3.4.16 REFERENCE BOOKS :

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Lesson 4.1

IONIC AND OSMOTIC BALANCE IN ANIMALS

CONTENTS :

4.1.1 INTRODUCTION

More than two thirds (71%) of the earths surface is covered with water. Most of this is ocean. The total fresh water in lakes and rivers makes up less than 1% of the area and 0.01% of the volume of sea water (Sver drup et al. 1942, Tutehinson 1967). On land, life exists in a thin film on just below and just above the surface, in water, organisms not only live along the solid

bottom but extend throughout the water masses to the greatest depths of ocean, in excess of 10,000 meters.

4.1.2 WATER BALANCE : GAINS AND LOSSES

For an organism to remain in water all loss of water must, over period of time, be balanced by an equal gain of water. The components in the water balance are :

i Water loss

Evoporation from body surface,

from respiratory organs

Feces

Urine

Other specialized sections

ii Water gain

Drinking

Uptake via body surface

From water

From air

Water in food

Oxidation water (metabolic water)

The problem of maintaining balance may work either way. There may be an excess of water (or) a shortage of water and the physiological mechanisms must therefore be able to cope with both situations.

For example, a fresh water insect may swallow on large amounts of water with its food and also be subject to osmotic inflow of water. The excess water must be eliminated, a task normally carried out by the renal organ (or) kidney, which then must produce a large volume of dilute urine. A terrestrial insect living in a dry habitat, on the other hand, has a very limited water intake, and all losses must be reduced to such a level that their sum in the long run does not exceed the total gain.

Any organism can tolerate a certain variation in its water content and some are more tolerant than others. Mammals, for example, can usually withstand losing 10% of their body

water, although they are then in rather poor condition; a loss of 15 to 20% is probably fatal to most. Many lower organisms can withstand greater losses some frogs, for example, can withstand the loss of 40% of their body water, but very few animals can tolerate losing half of their body water.

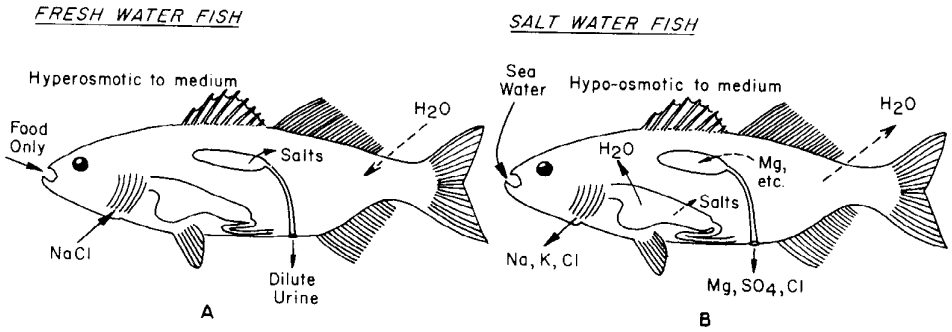

Figure 4.1.1 Schematic representation of main paths of ion and water movement in osmoregulation of freshwa bony fish, *A*, and marine bony fish, *B*. Solid arrows indicate active transport; broken arrows show passive transpo

iii Water loss : Evaporation

Evoporation takes place both from the respiratory organs and from the general body surface, but it is often experimentally difficult to determine these two variables separately.

The respiratory organs of insects and vertebrates differ profoundly in structure and function. The lining of the vertebrate lung is always moist. The respiratory air is saturated with water vapor, and the water loss from the respiratory tract is substantial. The respiratory organs of insects, however consist of tubes lined with chitin, and only the finest branches of these are relatively permeable to water. Nevertheless, for insects the water loss from the respiratory system is important.

Morshy fly larvae (Bibio) - 900

Cockroach (Peri planeta) - 49

Desert locust (schistocerca) - 22

Tsetse fly (Gtossina) - 13

Meal worm (Tenebrio) - 6

Flour mite (Acarus) - 2

Tick (Derma centor) - 0.8

All data refer to micrograms of water evaporated per hour from 1 cm^2 body surface at a vapour pressure difference of 1 mm Hg (0.13 kpa) (Schmidt – Nielsen 1969).

An insect that lines in very dry surroundings (example : a mealworm) with draws water from the rectal contents until the fecal pellets are extremely dry. This withdrawl of water has the appearance of an active transport of water moved from a high osmotic concentration in the rectum of lower concentration in the blood.

iv Water gain : drinking

Most obvious form of water intake is drinking free water. Such water is of course, available to all fresh water insects, such as when there is dew (or) rain.

For most insects however, free water is available only intermiently and at irregular intervals and many live in dry habitats where no free water is available.

v Water in food

Insects that eat plants may obtain – large amounts of water in the food, for fresh vegetable material has a high water content. Succulent fruits, leanes, and so on may contain over 90% water but even the deriest plant material contains some free water. Dry grains and seeds, flour, wool and other seemingly completely dry substances on which insects are able to subsist, grow and reproduce may contain about 5 to 10% free water.

When water is plentiful in the food, the problem is to eliminate the excess. This is the normal function of kidney, which then produces dilute urine large quantities under dry conditions, in contrast, the goal is to eliminate the excretory products with a minimum of water and produce a urine as concentrated as the renal mechanism is able to achieve.

vi Oxidation Water

For animals living under dry conditions, the most significant water gain is from water formed in the oxidation of organic material we can properly call it oxidation water but the term metabolic water is also common.

Everybody knows that water is formed when organic materials burn.

$(61 + 12\ 06 + 60_2 \rightarrow 6\ CO_2 + 61 + 20\ (180\ g) + (192\ g) \rightarrow (26\ 4g) + 108\ g)$

Food Sturf	Water formed ($g\ 1+20\ g^{-1}$ food)	Metabolic energy value		Water formed	
		($Kcal\ g^{-1}$)	($K\ g^{-1}$)	($g\ H_2O\ Kcal^{-1}$)	($g\ 1+2\text{-}kl^{-1}$)

Starch	0.56	4.2	17.6	0.13	0.32
Fat	1.07	4.4	39.3	0.11	0.027
Protein	0.39	4.3	18.0	0.09	0.21
Protein	0.50	4.4	18.4	0.11	0.027

- Amounts of water formed in the oxidation of various food stuffs (Schmidt – Nielsen, 1964)

4.1.3 TERRESTRIAL VERTEBRATES

Reptiles

There are four major orders of living reptiles, of these, the crocodiles are always associated with water. The other three – snakes, lizards and tortoises are considered well adapted to dry habitats, but they also have some representatives that are aquatic (or) semiaquatic. All the aquatic reptiles have lungs and are air breathers, and are obviously descended from terrestrial stock.

The skin of a reptile is dry and scaly and has been assumed to be impermeable to water. Let us therefore examine evoporation from the skin in a number of reptiles. We can see that cutaneous evoporation in a dry habitat reptile is only a small fraction of that in an aquatic reptile, and that even the aquatic reptile (when kept in air) evoporation. One magnitude lower than in most – skinned animals such as frogs. When the water snake matrix is kept in air the skin contributes nearly 90% of the total evoporation.

There is a close correlation between evoporation and habitat. The drier the normal habitat, the lower the rate of evoporation. The total evoporation, combining body surface and respiratory evoporation from a desent rattle snake is less than 0.5% of its body weight and snake could probably survive for 2 to 3 months at this rate. It remains in an underground burrow (or) tunnel where the humidity is higher, it could undoubtedly last even longer.

In addition to water loss through evoporation, water is also needed for unique formation. Reptiles excrete mainly uric acid as an end product of protein metabolism, and this compound is highly insoluble, it requires only small amount of water for excretion.

Marine reptiles have a special problem because the water they live in and much of their food contain large amounts of salt.

The gain in water that is necessary to balance the losses must be derived from the same sources as for other animals, drinking, food and oxidation water. There is no indication that

reptiles have the ability to obtain water by absorption from the atmosphere, as some insects can therefore, when drinking water is unavailable, their total water intake must be derived from food and from oxidation water.

Birds and Mammals

Until now we have discussed water balance without considering problems of temperature regulation, but some animals, in particular birds and mammals, use water to keep cool in hot surroundings. Humans and some other mammals sweat; dogs and many other mammals and birds pant; and the increased evoporation cools the animal.

A Kangaroo rat is not an exceptionally "dry" animal; its body contains as much water as other mammals. Even when a Kangaroo rat has lined on a diet of only dry barely for weeks (or) months, its water content remains the same. It maintains its body weight (or) may even gain in weight. This shows that the animal remain in water balance on the dry food and does not depend on some kind of water storage, in other words, water loss does not exceed water gain.

Evoporation from respiratory tract

The amount of evoporation from the respiratory tract depends on how much air is brought into the hugs (the ventilation volume) and on the fact that the exhaled air is saturated with water vapor. The amount of water already present in inhaled air determines how much additional water is needed to saturate the air.

Kangaroo rats in dry air, exhale air at temperatures below the inhaled air; birds; although they do not cool the air appreciably have higher exhaled air temperatures. Humans with their much widen nasal passages, have very incomplete heat exchange, and the exhaled air is commonly only a few degrees below body temperature. In humans, therefore, heat exchange in the note and the associated water conservation are lesses importance and larger amounts of water are lost in the exhaled air.

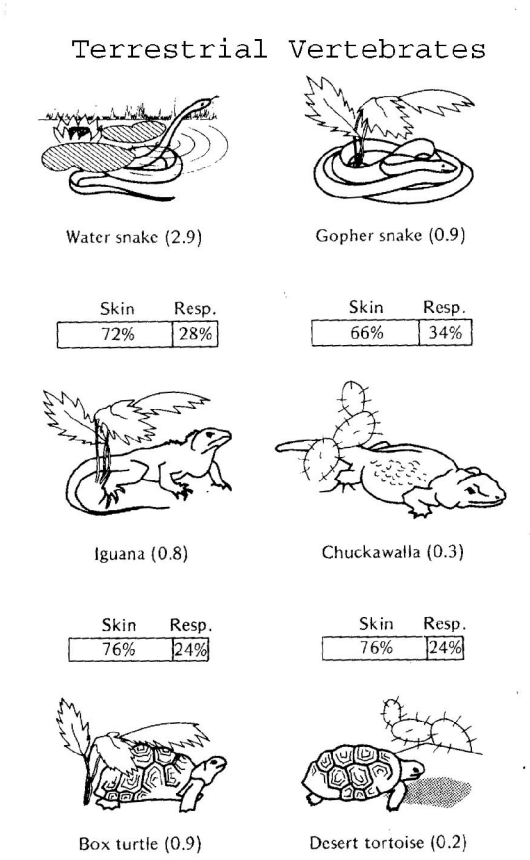

Fig. 4.1.2 Osmotic regulation

4.1.4 MARINE AIR BREATHING

Vertebrates

The higher vertebrates reptiles, birds and mammals are typically terrestrial and as we have seen, some are at home in the moist arid deserts of the world. However, several lives of terrestrial vertebrates have secondarily invaded the sea but have remained air breathers.

In regard to problems of water and salt they are essentially terrestrial animals, and compared with fish, they are physiologically isolated from the surrounding sea water. In contrast to fish, which have gills that are relatively permeable to water, the higher marine vertebrates have lungs and thus escape the osmotic problem of an intimate contact with the sea water over a large gill surface the higher marine vertebrates differ physiologically from their terrestrial relatives primarily in that they have only sea water to drink and much of their food has a high salt content. If a vertebrate drinks sea water the salts are absorbed and the concentration of salt in the body in the body fluids increases. Unless the salts are eliminated with a smaller volume than that which was taken in there can be no net gain of water. In other words the salts must be excreted in a

solution at least as concentrated as sea water, otherwise the body will become more and more dehydrated.

The reptilian kidney cannot produce urine that is more concentrated than the body fluids, and the bird, kidney can usually produce urine, no more than twice as concentrated as the blood. The kidney therefore does not have surficient concentrating ability to permit these animals to drink sea water (or) eat food with a high salt content, and if they do they must have other mechanisms for salt excretion.

Marine reptiles

Three orders of reptiles; turtles, lizards and snakes have marine representatives the fourth living order of reptiles the crocodiles has no truly marine representative.

The excretion of excess slat, which the reptelian kidney is mable to handle, in carried out by g' 1 and s produce a highly concentrated fluid that contain primarily sodium and cloridein in concentrations substantially higher than in sea water.

Marine Birds

Many birds are marine, but most of them live on and above, rather than in the ocean. Many are coastal, but some are turnly relagic. The young albatrons that is hatened on a pacific island spends 3 (or) 4 years over the open ocean before it returns to the breeding grounds.

Pengunins, the most highly adapted marine bizds, have lost their power of flight. They are excellent suimerers and are well advanced in their evolution toward a fully aquatic life. Nevertheless, in the physiological sense they have remained essentially terrestrial air breathing animals that reproduce onland.

In birds that are fed a diet high in salt (or) receive salt solutions to drink, the glands increase in size and become even larger than normal (Schmidt – Nielsen and Kin, 1964).

The slat glands usually remain inactive and start secreting only in response to an aquatic stress. Otherwise the glands remain arrest, and in this respect they differ from the kidneys, which produce urine continuously.

Marine Mammals

Three orders of mammals – seals, whales and sea cows are exclusively marine in the sea that they spend practically their entire life in the sea. Seals return briefly to land to bear and nurse their young but whales and sea cows (Manatee and dugong) even bear their young in water. Do marine mammals have some physiological mechanism that corresponds to the salt – secreting glands or birds and reptiles? There is still inadequate information about whether seals and whales ingest any appreciable amounts of sea water, either by drinking (or) incidentally with the feed. There is good evidence, that seals do not have to resort to drinking sea water.

Mammals have in their water balance an item that does not apply to birds and reptiles. The female nurse her young and large quantities of water are required for production of milk. One way of reducing this loss of water would be to produce a more concentrated milk. It has long been known that seal and whole milk has a very high fat content and higher protein content than cow milk. The high fat content of seal milk can also be viewed in light of limited water resources of the mother.

Osmotic regulation over and over again seen is important and the organs of excretion are for the maintaince of the relative constancy (or) steady state, of internal concentrations and water content of living organism.

4.1.4 EXPECTED QUESTIONS

1. Write an essay on osmotic balance in animals.
2. What is ionic balance, give a detailed account of it in animals.
3. What are adaptation in terrestrial animals or water conservation?
4. How does the aquatic organisms cope with the ionic and osmotic balance.
5. Give a detailed account on osmo regulation in animals?

4.1.5 REFERENCES

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Lesson 4.2

Excretion in Animals

CONTENTS

4.2.1 INTRODUCTION

As a result of metabolic activities certain waste products are formed. The major waste products are carbon dioxide, water and nitrogenous compounds. These wastes, if retained in the body, will have harmful effects. Hence their removal becomes necessary. Removal of these wastes from the tissues of the body to the outside is called excretion.

4.2.2 ORGANS OF EXCRETION

The organs or the tissues responsible for the elimination of waste products are called excretory organs. These organs eliminate the wastes in one of the following ways:

1. By elilminating nitrogenous wastes.
2. By adjusting water balance of the body.
3. By maintaining ionic composition of the extracellular fluids.

Major organs of the body which help in the excretion process are: integument, gills, liver, intestine, lungs and kidneys. In certain lower animal groups such as protozoa and prorifera, excretion of wastes takes place directly through the cellular memebranes. In such cases simple mechanisms like osmosis and diffusion may be found very effective. In certain species, however, excretion is done through contractile vacuoles as in *Amoeba* and *Paramecium.* In higher invertebrates and

vertebrates, definite excretory organs are found which do the specialized job of excretion. Integument of the skin helps in the elimination of urea through the sweat glands. Along with the urea, certain inorganic salts are also removed by the skin. The gills and the lungs are helpful in removing gaseous products like carbon dioxide. Liver is one of the most important glands in the body of vertebrates which helps in the removal of cholesterol, bile salts and excess of calcium and iron salts. These are generally eliminated by the intestine along with the faecal matter. The intestinal epithelium also excretes some inorganic salts which are in excess. Rubidium, potassium, calcium and magnesium, etc., are excreted in parat through the intestinal wall. Kidneys are the major excretory organs in all vertebrate groups and also in some invertebrates which eliminate urea, exces of water, salts and other nitrogenous wastes. The renal mechanisms are responsible for maintaining ionic regulation or fluid balance in majority of animals.

4.2.3 TYPES OF EXCRETORY PRODUCTS

The end-products of metabolism fall under two major categories:

1. Carbondioxide; and
2. Compunds containing nitrogen. Besides these products, water forms an important product which requires to be eliminated if found in excess, and also it forms a vehicle for the transport of waste products to the exterior. Here we shall give our attention mainly to the production of nitrogenous wastes and their elimination.

4.2.4 NITROGENOUS WASTES

In living organisms nitrogen is never eliminated in the form of free nitrogen but results in the formation of nitrogenous end-products. Proteins are the main nitrogen containing compounds which are metabolized to form end-products like ammonia, urea and uric acid. These end-products are derived from the degradation of proteins, amino acids, pyrimidines and purines.

Proteins are important dietary constituents needed for the building, jgrowth and repair work of the body. Proteins are broken down to smaller protein molecules (peptides and dipeptides) upon hydrolysis. These subunits can be further hydrolyzed to yield amino acids which are metabolized to yield ammonia and urea as nitrogenous end-products.

Normally, adults are said to be in a state of nitrogen balance when the nitrogen loss equals to the nitrogen intake. If the nitrogen balance is disturbed in an animal, it experiences a new situation and tries to adjust itself to a new nitrogen level. This new level can be achieved by an adjustment between increase or decrease of nitrogen excretion. Nitrogen excretion losses from the body are generally measured by an analysis of the urine and faeces.

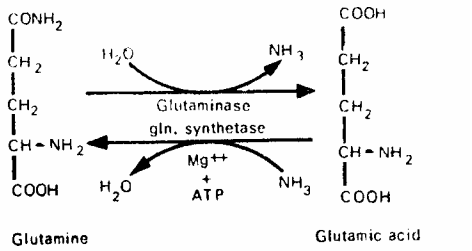
Ammonia

Ammonia is the chief breakdown product of amino acids nd is removed by oxidative deamination process. Deamination chiefly occurs in the liver, but kidney also helps in the process. Ammonia is a toxic substance, and is constantly being produced in the tissues by deamination of amino acids.

1. Amination of keto acids,
2. amidation of glutamic acid.
3. formation of urea in the liver.

The rapidity with which ammonia is removed from the body ensures a very low concentration of it in the blood of most animals. Mammals cannot withstand ammonia in their blood in concentrations more than 0.0001 to 0.0003 mg/100 ml. however, the blood of amphibians, reptiles and fishes can withstand a higher concentration of ammonia (less than 0.1/100 ml). many invertebrates show a higher tolerance for ammonia.

Ammonia is highly soluble in water and in majority of aquatic animals it is lost by diffusion in the surrounding water. In a number of animals ammonia does notform the excretory waste, but helps in maintaining acid-base balance in mammals, ammonia is obtained chiefly by deamination of glutamine of blood by glutaminase. This happens in kidney where amino-nitrogen is increased, which reacts with hydrogen ions so that more ammonium ions (NH_4+) are secreted. This aspect of acid-base balance will be treated in more details while discussion the role of kidney. Ammonia is also formed from urea by the action of urease.



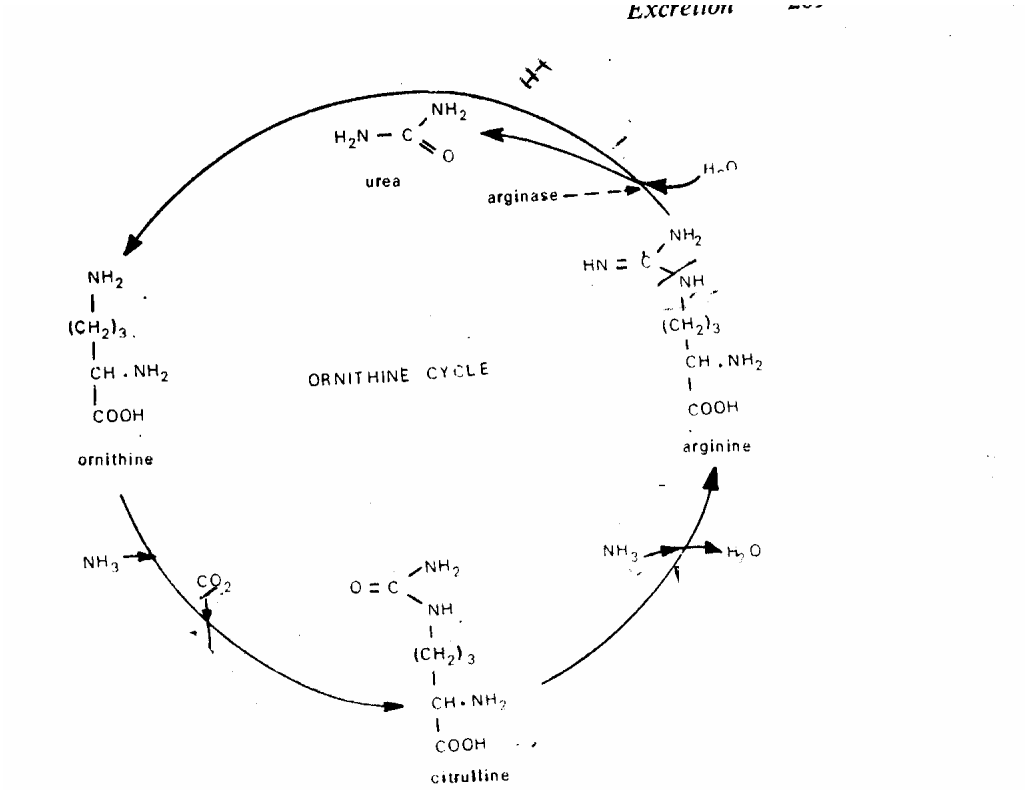
Deamination of glutamine results in the production of NH_3. Glutamine is synthesized from glutamic acid by glutamine synthetase.

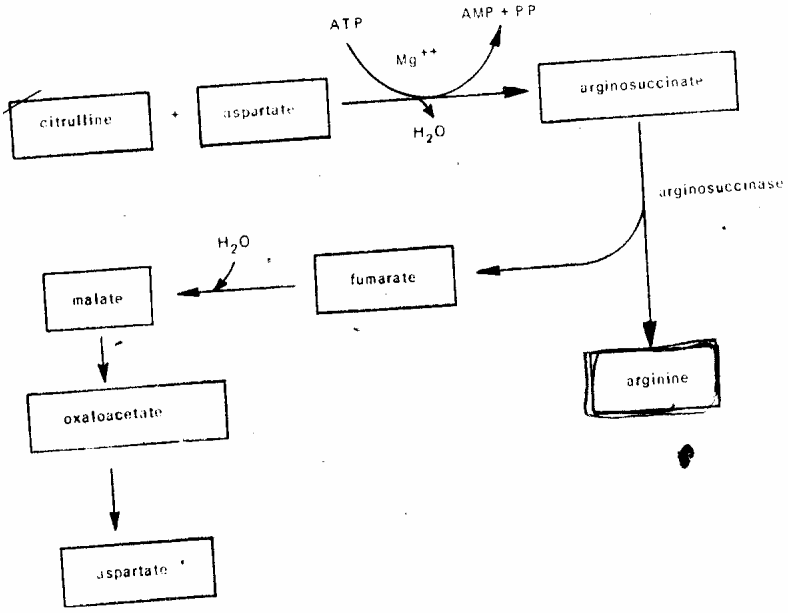
Urea

Urea is derived from organic compounds like amino acids and purines. And liver is believed to be the chief organ capable of making it. It is highly soluble in water and less toxic than ammonia. The human blood normally contains 18 to 38 mg of urea per 100 ml. however, higher concentrations of urea can be tolerated by man which. Of course. Indicates uremic condition in man.

Urea formation in liver has beenstudied by Krebs and Hanseleit and has been explained in a series of reactions.

Ornithine, citrulline and arginine are the three amino acids which participate in the formation of urea. Liver contains an enzyme arginase





Which hydrolyzes arginine to ornithine and urea is formed as a byproduct this is also known as *ornithine cycle.*

The ornithine cycle has been studied mostly in the mammalian liver. In manhy vertebraesw which lack arginase, urea is not formed and instead uric acid is the chief end-product of nitrogen metabolism.

The steps involved in urea formation are as follows:

1. Citrulline is formed by the addition of CO_2 and ammonia to ornithine. This CO_2 and ammonia come from *Carbamyl phosphate.*
2. Citrulline gives rise to arginine in two intermediate steps. In the first step, citrulline and aspartate form arginosuccinate in the presence of ATP and magnesium ion. It is a reversible reaction. In the second step, arginine is formed from arginosuccinate by splitting of fumarate. The fumarate is later converted to malate and oxaloacetate in citric acid cycle. And gives rise to aspirate .

Uric acid

Uric acid is the most important nitrogenous waste in the urine of birds, reptiles, some snails and insects. It is formed ammonia and contains less hydrogen than any other nitrogenous waste. Uric acid is less toxic and being insoluble in water, may be stored or excreted in crystalline form. Formation of uric acid is an adaptation for the conservation of water since its elimination requires very little water.

Uric acid is formed in the liver of birds, and in insects it is made in the Malpighian tubes. Uric acid is formed either as an end-product of purine metabolism or as a product of waste nitrogen derived from the protein. In man, uric acid is the end-product of purine metabolism. In subprimate mammals. As also in a number of insects, uric acid is further oxidized to allantioin. Thus allantion is the main end-product of purine metabolism in such animals.

4.2.5 OTHER NITROGENOUS CONSTITUENTS

The excretory nitrogenous products come' from nucleic acid meta. bolism. There are purine compounds, viz. adenine and guanine. Pyrimidine nitrogen is excreted as urea or ammonia. Traces of pyrimidine may be excreted as such also.

(a) *Guanine:* Guanine is the main nitrogenous excretory product in some arthropods spiders, but is conspicuously absent in insects. It is faintly. soluble in water and its mode of formation is rather unknown.

(b) *Xanthine and hypoxanthine:* In a number of insects *(Melophagus, Galleria* and *Pieris,* etc.) xanthine and hypoxanthine are excreted.

(c) *Trimethylamine oxide:* Marine teleost fishes, which have a diet rich in trimethylamine, excrete trimethylamine oxide.

(d) *Hippuric acid and ornithuric acid:* Hippuric acid is formed in mam. mals. The diet of mammals contains traces of benzoic acid which is a toxic substance. This benzoic acid combines with amino acid glycine to form a less toxic substance hippuric acid. In case of birds, dietary benzoic acid cQmbines with ornithine and is excreted in the form of ornithuric acid.

(e) *Creatine and creatinine:* Creatine is present in the muscle, brain and blood in the free state as weB as combined state (as phosphocreatine). Traces are present in the urine also. Three amin_ acids-glycine; arginine, and methionine are involved in the synthesis of creatine. Some of the crea. tine is converted into creatinine which is _n anhydride of cre.atine. It is form_d largely in muscles and occurs in the blood and urine in free state.

(f) *Pterydines:* Pterydines are also regarded as excretory products which are important pigments in insects. The synthesis of pterydines reo sembles that of uric acid. In some insects *(Qncopeltus)* traces of pterydines are excreted in the faeces, whereas in butterflies *(Pieris brassicae)* pterydines are deposited in the wings, fat body, etc. Only traces are excreted ill the .urine.

4.2.6 PATTERNS OF EXCRETION

We have seen that diverse types of nitrogenous excretory products are formed in animals, and more than one type of such products may be excreted in an individual. The dietary proteins are digested in the stomach and the intestine by way_of enzymatic hydrolysis which liberates amino acids. Most of the amino acids are absorbed as such, while some may be lost by way of excretion. Thus the loss of amino acids from the body may prove injurious to the health of tht organism. Amino acids are required as the Duilding blocks for the synthesis of the blood and tissue proteins. Due to transamination reactions nitrogen is formed which m!!y be eliminated in leveral forms (urea, ammonia, etc.) as described above. Based upon the type of nitrogenous compound excreted, animals have been classified into leveral broad categories.

Ammonotelic animals

Animals in which ammonia is the chief metabolic waste are called ammonotelic. Ammonia is highly soluble in water and diffuses rapidly from Ihe body surface into the surrounding aquatic medium. Aquatic vertebrates excrete large amounts of ammonia which is formed by hydrolysis of urea present in the blood. The presence of ammonia in blood is toxic, hence requires plenty of waterfor rapid elimination. The amount of ammonia liberated in the body varies with the diet and the species of the animal. Certain protozoans like *Tetrahymena* and *Paramecium* excrete. large quantilies of ammonia. Sea anemones excrete about 52.7 percent ammonia in the form of nitrogenous waste. Echinoderms and polychaetes are also ammonolelic. Cephalopods and pelecypods, both freshwater as well as marine forms, exc:(ete large quantities of ammonia.

The crustaceans excrete ammonia predominantly although they form amino acid nitrogen also. In aquatic insects also ammonotelic behaviour is found. In *Sialis* larvae, for example, about 90 percent of nitrogen in the form of ammonia is liberated. Aquatic habitat of animals appears to be an important requirement for ammonotelic behaviour and may be said to be an aquatic. adaptation. An interesting behaviour in earthworms has been described by Bahl (1947). It was experimentally demonstrated that earthworms kept in natural moist surroundings produce more urea than ammonia. However, if the earthworms are kept immersed in water they start excreting ammonia (Delaunay, 1934).Freshwater fishes! let out more ammonia than urea, a major proportion of which diffuses out through the gills. The amount of nitrogen excreted out through urine is comparatively less.

Ureotelic animals

Ureotelic animals excrete most of their nitrogen in the form of j,lrea. It is the predominant organic substance present in the urine of animals. The problem of water conservation in adult mammals has necessitated reabsorption of water in the kidney tubules, thus excreting urea in a concentrated form. In df-sert animals, low water intake has resulted in active tubular secretion of urea. In ruminants, urea excretion is greatly reduced and is retained in the rumen which 'acts as a protein source. It has been suggested that low protein diet leads to a marked decrease in urea output, whereas a high protein diet increases urea production.

Amphibians are predominantly ureotelic, as also the elasinobranch fishes. The synthesis of urea in frogs takes place in the liver, and in elasmo. branchs all tissues except brain and blood are capable of synthesizing it by the same cycle as occurring in m_mmals.

Uricotelic animals

Terrestrial animals like insects, lizards, snakes and birds excrete their nitrogen in the form of uric acid. As already described, uric acid is formed by deamination and oxidation of purine bases (guanine and adenine). Uric acid production is also related to the problem of water conservation in these animals.

In insects uric acid is the most important nitrogenous constituent of urine. When plenty of water is available to insects, uric acid remains in solution in the Malpighian tubules. However, during scarcity of water, uric acid crystallizes in the form of crystalline spheres. In *Rhodnius* the urine is dried and consists of about 64-84 percent of uric acid (Brown, 1937). In lizards, snakes and birds, the urine is in the form of a solid or a semi-solid mass and contains large quantities of uric acid.

Guanotelic animals

In some arthropods such as spiders, guanine is a predominant excretory product elaborated by the Malpighian tubules and cloacal sacs. The farmation of guanine from protein nitrogen is still not adequately known.

Trimethylamine oxide

Marine teleosts excrete trimethylamine oxide as the major nitrogenous product which is soluble in water and nontoxic in nature. It is, however, absent in marine elasmobranchi while marine teleosts are faced with the problem of maintaining osmotic balance while retaining water in the body which is aided by trimethylamine oxide. This compound is present in small quantities in the muscle, and blood of the marine fish which diffuses outthrough the membrane. This compound has a foul smell and is probably derived from the breakdown products of lipoproteins. Considerable quantities of trimethylamine oxide are formed in 'octopus, squids, crabs and barnacles. It occurs in traces in the urine of certain animals like echinoderms, oysters, gastropods and tunicates. Its 'presence in marine teleosts is, however, related to the maintenance of concentration in the body.

4.2.7 CHANGES IN NITROGEN EXCRETION

Principal wastes come from the metabolism of purin.es, pyrimidines and amino acids. .It is a known fact that the production of nitrogenous wastes may vary during the development and adult life; variations may be due to environment and diet also. In amphibians, for ex:ample, urea is a predominant waste in the adults, whereas larval amphibians are ammonotelic.

Environmental influcnce is perhaps more important in shifting the' production of nitrogenous substances. If animals producing ammonia are transferred to a medium containing more salt, their capacity of urea production is enhanced. Higher concentrations of urea are helpful in maintaining osmoregulatory functions.

Embryonic history of animals reveals that the patterns of metabolism change with the differentiation of organ systems. The metabolic machinery of the individual is geared to suit the individual to its environment. In case of the tadpole of *Bufo*, 80 percent of nitrogen is excreted as ammonia which gradually declines to 15 percent until the adult stage is reached. Needham has proposed existence of recapitulation in patterns of nitrogen excetion on the basIs of excretory pattern in the chick. In a three-day old chick embryo, ammonia is the chief excretory product. The percentage of ammonia gradually declines. On the fifth day, ammonia declines considerably and the percentage of urea increases to a maximum until the eighth day. After this"urea also starts declining and uric acid increases rapidly. About the eleventh day uric acid concentration in the urine is maximum with a concomittant drop in urea. The cycle o(events in the embryonic life of the chick shows that up to four days the chick was ammonotelic, later on it became ureotelic, and about the eleventh day it became uricotelic and'continued to be so throughout its adult life.

4.2.8 DIETARY INFLUENCE ON NITROGEN EXCRETION

Diet influences the pattern of excretion to a great extent. Insects provide the best examples to demonstrate this fact. In a reduvid bug *Rhodnius,* immediately following a blood meal, considerable quantity of urea is excreted in the urine which contains excess of water and salts. After a few hours urine becomes rich in uric acid. In the meat eating larvae of *Calliphora* and *Lucilia* (blowfly) the excreta is rich in ammonia. However, in the pupal stage excretion of ammonia is replaced by uric acid. :rhus the excretion depends on the substances present in excess in the diet and also on the production of waste substances in metabolism.

Earthworms furnish yet another example where'the excretory wastes depend on the nutritional state. In a normal well-fed *Lumbricus,* urea appears in small quantities, i.e. 8-15 percent of the total excretory nitrogen, while ammonia is predominant. During the state of starvation urea increases up to 85 percent and oercentage of ammonia declines considerably.

4.2.9 EXCRETORY DEVICES IN INVERTEBRATES

Excretory devices met with in the organisms are essentially the adaptive capabilities evolved in relation to their habitat. Animals may reside in one of .the following surroundings: freshwater, marine and land. Diverse exeretory devices have been developed in animals in order to ensure ionic regulation of the body fluids.

Protozoans

Although protozoa do not have specializecr-:excretory organs, the wastes are discharged through cellular memb_ Several mechanisms like osmosis, diffusion, etc., are responsible for waste elimination through the membranes. However, in a number of species, contractile vacu91es serve as excretory organelles. The function of ;fontractile vacuoles has been extensively studied in *Paramecium.* The vacuoles are membrane bound vesicles formed temporarily, wiiich collect excess amount of water and discharge on the surface of the organism. These vacuoles may be of wandering type and may foIl ow a definite path for elimination. Only freshwater protozoans possess such vacuolar mechanisms for waste regulation.

Coelenterates

Coelenterates also do not possess specialized excretory organs and-, processes like diffusion osmosis and active transport to regulate the fluids in the body. The need for organs of excretion in coelenterates is greatly restricted.

Platyhelminthes

The animals of this phylum are characterized by having a specialized *flame cell system.* The flame cell is a large cell blinded at one end and bearing many cyloplasmic

processes. There are series of such cells' which open in an excretory duct. The nucleus is displaced generally towards the blind end side and the cytoplasm bears many secretory droplets. A bunch of cilia arises in the hollowed out cytoplasmic region which keep on moving to produce a directed flow of fluids. The excretory products enter the flame cells in a fluid state from the parenchymatous cells by diffusion. Excess of water along with metabolic wastes are thus discharged by the flame cells.

Annelida

The excretory organs are in the form of tubular and coiled structures called *nephridia* which are metamerically arranged. These ne,}1)hridia are open. at both ends, hence known as metanephridia. In _ome annelids, ,protonephridia are present in place of metanephridia, which are brancHed and open blindly in the coelom: A metanephridium 'differs f_om a protonephridium in having a ciliated funnel or nephrostome. These nephridia receive fluid waste from the blood and the coelomic fluid and elim! urine rich in urea and ammonia.

Mollusca

In molluscs the excretory organs are in the form of *kidneys* and [*cardia! gland.* The kidneys are mesodermal organs which communi, with the coelom, whereas the epitheiiallining of the pericardium contain glandular tissue serves as pericardia I gland. In cephalopods, the nitrogen! wastes are eliminated in the form of guanin, while uric acid and ,urea case of opisthobranchs and bivalves respectively.

Arthropoda

Excretory organs in arthropods are of several types and include nepl ridia, coxal gland, green gland, shell gland and Malpighian tubules, et! Except Malpighian tubules, these organs are derived from coelomoduct: In the present context we shall deal with the mechanism of excretion b Malpighian tubules as they have proved to be the most efficient organs 0 excretion in terrestrial arthropods. These tubules open into the lumen 0: the intenstine through their proximal end and their distal blind end reo mains suspended within the haemocoelomic spaces". The excretory products pass out through the alimentary canal.

The Malpighian tubules collect and transport solutions from the haemolymph into the hindgut where water and some physiologically important compounds are absorbed by the hindgut epithelium. These tubules are characteristic organs. of insects which help in removing wastes and sometimes to conserve water. T!Ie physiology of these tubules has been excellently described in mosquito larvae by Ramsay (1953) and in *Rhodnius* by Wigglesworth (1965). The tubules are bathed in the haemolymph from where they absorb potassium ions. The absorption of potassium ions takes place by active transport mechanism which also helps in the diffusion of water and substances of low molecular weight' such as inorganic salts, glucose and urea into the tubules. A continuous flow of such substances from the haemolymph into the hindgut takes place via these tubules. In the hindgut, recovery of essential compounds" an9tl:water takes place by reabsorption

and thus only wastes are' eliminated. The rectal glands of insects are responsible for conservation of water. Generally the malpighian tubules lie freely in the body cavity, but in certain insects the terminal portions are the intimately attached to the wall of the rectum. This condition is found in lepidopterous larvae, coleoptera and some tenthredinid larvae and is associated with the conservation of water in dry habitats.

In *Rhodnius,* a cIearcut regional distinction has been found in the mlalpghian tubules. Wigglesworth (1942) found that the upper portion is conerned with the secretion and the lower portion with reabsorption. For this reason the lower portion contains uric acid granules and the upper portion contains clear fluid.

4.2.10 EXCRETORY DEVICES IN VERTEBRATES

Kidneys are the chief organs for excretion of wastes in vertebrates and, therefore, deserve special attention. Besides their excretory function, kidneys function in a significant manner in the maintenance of internal environment of the body.
The structural and functional details of vertebrates kidney was discussed in detail in the next lesson.

4.2.11 EXPECTED QUESTIONS

1. Describe the different excretory devices in animals
2. Describe different excretory products of animals
3. Give an account on ornithine cycle

4.2.12 REFERENCE BOOKS

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Lesson 4.3

ULTRAFILTRATION IN KIDNEY

CONTENTS

4.3.1 INTRODUCTION

Kidneys are the chief organs for excretion of wastes in vertebrates and, therefore, deserve special attention. Besides their excretory function, kidneys function in a significant manner in the maintenance of internal environment of the body.

4.3.2 STRUCTURE OF KIDNEY

Structure of Kidney mammalian kidney could be taken as an example to explain the structure and function of a typical vertebrate kidney. The kidneys are paired organs which are generally bean-shaped structures. When seen in a sagittal section, it shows two main divisions. The outer portion is called the cortex, and the inner region forming the main mass of the kidney is called the medulla. The dedulla is composed of malpighian bodies and convoluted tubules.

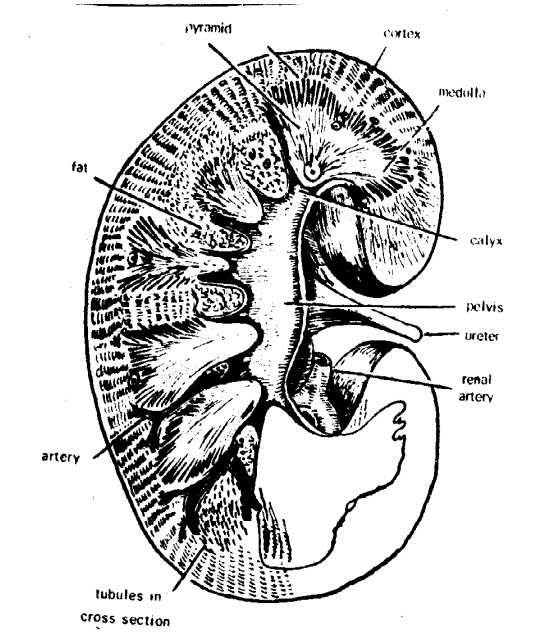

Figure 4.3.1 *L.S. of vertebrate kidney.*

Histological examination of kidney shows that it is made up of a large number of secreting units,called nephrons.Each nephron is composed of a spherical structure known as the Malphegian body and a convoluted tubule.Malpighian bosies have a double-walled capsule enclosing a network of capillaries called glomerulus. The capsule opens into a long tuble through a narrow neck and takes a rather tortuous course in the cortex,and later desends down in the mesullary region.Hence it makes a loop of Henle and through ascending and descending loops terminates into a colleting tuble. The tubules are surrounded by a network of blood capillaries which helps in the exchang of materials between the blood and the cells of the tubules.The capsule has very thin layer of endothelial cells,while the ascending and descending loops are lined with cuboidal cells. The lumen of the tubules is very narrow.

Blood supply: Kidney receives a very rich supply of blood.An adult kidney receives about 1.3 liters of blood per minute. The blood supply of kidney comes from a short renal artery which arises from the abdominal aorta.After entering the kidney,the renal artery divides into a number of arterioles-*afferent arteriole.* The afferent arterioles further branch into capillaries and enter into each glomerulus.These capillaries then join into form another arterioles called *efferent arterioles* which further opens into another set of capillaries,called *peritubular capillaries* surrounding the proximal tubuleof the same nephron.Having taken this tortuous course.This capillary opens into a venule which joins with other venules of form finally the renal vein.The renal vein opens into the inferior vena cava. At this stage it would be interesting to know as to how the pressure for blood flow is maintained through afferent and efferent arterioles, and peritubular capillaries.

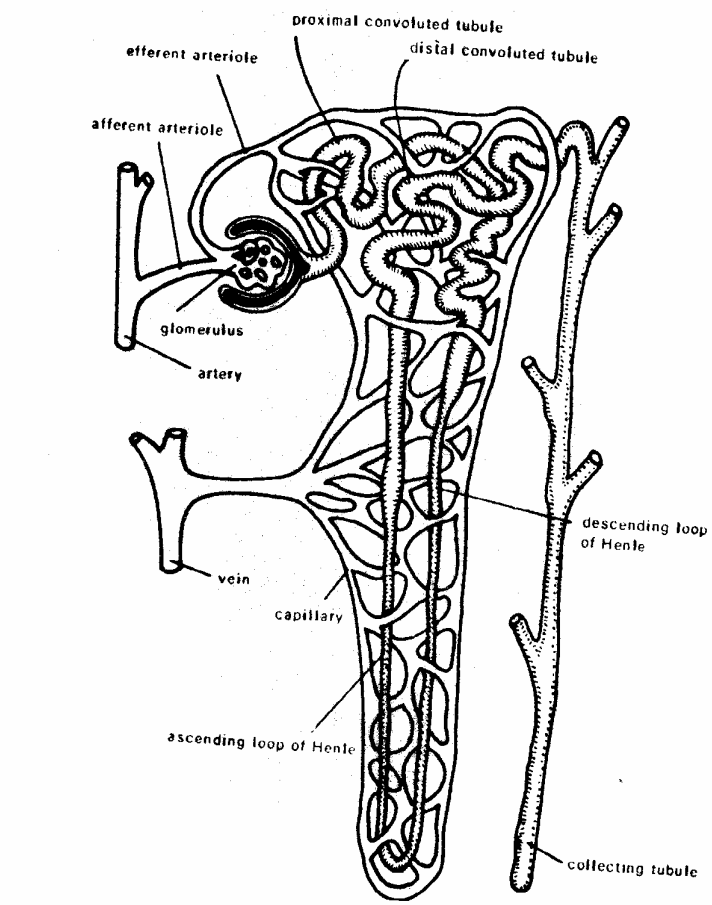

Figure 4.3.2 *Structure of a nephron.*

The renal artery is thick and short and thus the pressure drop in reaching the blood to the kidney is small. The afferent sure drop in reaching the blood to the kidney is small. The afferent arterioles which are larger than other arterioles in the body lower the pressure to some extent to about 60 mm Hg which is close to hydrostatic pressure in the glomeruli. The efferent arterioles bring the pressure further down to about 15 mm Hg. This causes further decrease in the hydrostatic pressure in the peritubular capillaries and allows movement of fluid into the capillaries. Further, the afferent and efferent arterioles are subjected to vasomotor changes to after the blood pressure in the glomeruli. Constriction of the afferent arterioles decreases the pressure within the capillaries and allows less blood flow through them. Efferent arterioles, upon contraction, raise the blood pressure in the glomerulus capillaries and consequently decrease the blood flow.

Functions of kidney: The principal functions of kidney are:

(1) To eliminate certain nonvolatile waste products of the body like urea, sulphates, etc.
(2) To regulate hydrogen-ion concentration of blood by eliminating any excess of nonvolatile acids and bases.
(3) To remove excess of certain nutrients such as sugar and amino acids when their concentration increases in the blood.
(4) To remove foreign or injurious substances from the blood, such as, iodides, pigments, drugs and bacteria, etc.
(5) Maintenance of osmotic pressure of the blood by regulation of the excretion of water and inorganic salts, thus keeping constant the volume of circulating blood.
(6) Kidneys regulate the arterial blood pressure by secreting the hormone renin.

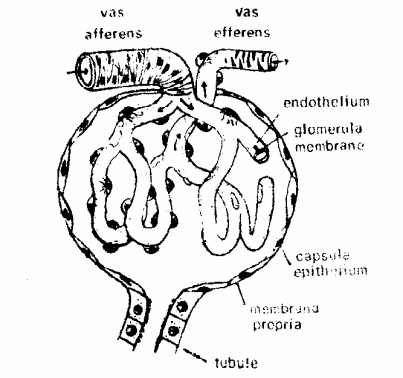

Figure 4 . 3 . 4*Structure of a Bowman's capsule.*

4.3.3 URINE FORMATION

In mammalsl each kidney is composed of tens of thousands of uriniferous tubules which form the urine. Urine is formed from the blood circulating in the glomerulus. Thus urine is a filtrate of the blood which goes into the tubules as a dilute fluid resembling the plasma deficient in colloids. This dilute fluid is concentrated in the tubular region by reabsorption of the excess portion of the fluid and certain salts and thus replaced in the blood stream. Besides, certain substances may also be secreted by the tubular epithelium into the urine. Formation of urine by the kidneys is considered to be due to three types of activity—glomerular filtration, selective secretion and tubular reabsorption.

4.3.4 FUNCTION OF THE GLOMERULUS

In the middle of the nineteenth Century, Ludwig proposed a theory of physical filtration and diffusion. According to him noncolloidal constituents of blood were removed by the thin membranes of the glomerulus by filtration and only clear dilute filtrate was allowed to enter the tubules where excess amount of water were reabsorbed making the urine concentrated. Later, Cushny in 1914 proposed a partial modification of Ludwig's theory and suggested that along with water, the noncolloidal constituents of the plasma filter through the glomerulus. As the liquid

passes through the tubular region, some of the water, salts, glucose, amino acids and certain other constituents useful for the body are reabsorbed by the tubular epithelium and sent back to the blood.

We shall now consider the process of filtration in the light of the current ideas. The structure of the glomerulus suggests that it is best suited for the purpose of filtration which would depend on three conditions: (1) semipermeable nature of the glomerular membranes; (2) osmotic pressure exerted by the contents on either side of the membrane and: (3) blood pressure in the glomeruli.

4.3.5 FILTRATION

The semipermeable nature of glomerular membrane would allow to pass through it proteins of low molecular weights. Egg albumin (MW: 35,000), gelatin (MW: 35,000) and haemoglobin (MW: 64,500) and substances around these molecular weights can be expelled through it. Proteins of high molecular weight such as casein (200,000), serum globulin (160,000) and serum albumin (72,000) are not excreted. Such membranes excert osmotic pressure to effect filtration. The colloids of the blood exert an osmotic pressure against filtration and may cause diffusion of water into the blood. However, the hydrostatic pressure of blood would try to force the water from the blood into the tubules. This suggests that blood pressure is higher than the osmotic pressure to cause filteration and the energy of filtration is derived from the hydrostatic pressure. The hydrostatic pressure of blood in the afferent glomerular artery is bout 75mm Hg, whereas the osmotic pressure exerted by the plasma proteins is about 20 to 30 mm Hg. The interstitial pressure acting on the capillaries is 10 mm Hg. Therefore the final pressure or the actual driving force is 25-30 mm Hg which may be expressed as follows:

Pb-po-pc = pf

Where

Pb = hydrostatic pressure of the blood,

Po = osmotic pressure of proteins,

Pc = total of interstitial pressure and movement pressure, and

Pf = final driving force.

Glomerular filtration rate (GFR): About 1 litre of blood is filtered per minute by both the kidneys. When the net filtration pressure is about 25 mm Hg, about 120 ml of glomerular filtrate is formed at the Bowman's capsule. Therefore GFR is about 120 ml per minute, which is actually the volume of plasma filtered per minute. It may be expressed as:

GFR = UV/P

Where

U = mg of the filtered substance per ml urine,

V = ml of urine per minute, and

P = mg of filtered substance per ml of plasma.

4.3.6 FUNCTION OF THE TUBULE

The composition of urine is quite different from the glomerular filtrate. The glomerular filtrate contains some essential substances like water, glucose, amino acids, chlorides, sodium and other wastes like urea, creatinine, and uric acid. The essential substances are retained to carry on carry on normal metabolism, and this selective function is carried out by the tubules of the kidney. Thus by secretion and reabsorption the glomerular filtrate is transformed into urine.

4.3.7 TUBULAR REABSORPTION

Certain substances which appear in normal quantities are reabsorbed completely, but appear in the urine when normal levels are exceeded. Such substances are known as threshold substances. Amino acids and glucose are such threshold substances which are efficiently reabsorbed by the tubular cells. Reabsorption of glucose: In a normal adult, when the GFR is 120 ml/minute, about 120 mg of glucose are transferred into the filtrate per minute. Normally, except only a few mg, the entire quantity of glucose is reabsorbed. The absorption takes place in the proximal part of the tubule by active transport mechanism associated with phosphorylation. In men the maximum rate at which glucose can be reabsorbed by the tubule is 350 mg/minute. This is known as the tubular maximum for glucose (TmG). In women TmG is about 300 gm/minute. Sometimes considerable amounts of glucose are found in the urine, a condition known as glycosuria. Glycosuria can be artificially caused by administering Phlorizin which inhibits phosphorylation. Reabsorption of water: The osmotic pressure of the plasma remains more or less unchanged and is due to the presence of inorganic salts which act as electrolytes. If large quantities of water are taken, this might cause dilution of the plasma. This causes reduction in the osmotic pressure which results in the excretion of larger amounts of water in the urine. Thus the kidney defends the osmolarity of the plasma by excreting excess amount of water. Increased rate of urine secretion is known as diuresis and the substances which produce this effect are called diuretics. Urea has a diuretic effect. Certain salts such as NaCl and Na_2SO_4 also have diuretic effects.

Normally 150 to 180 litres of glomerular filtrate is produced every day, and out of this approximately 80 percent of the filtrate is reabsorbed in the proximal part of the tubule. This is called obligatory reabsorption.

Reabsorption of inorganic salts: Soidium, chloride and bicarbonate ions are selectively reabsorbed in proximal tubular portion. Along with the reabsorption of Na^+ there is parallel reabsorption of it so that regaining of NaCl helps in the return of water. Reabsorption of Na^+ is aided by the adrenal cortical hormone.

Potassium is also present in small quantities in the glomerular filtrate. Normally all the potassium filtered is reabsorbed by the proximal tubule. However, if any potassium appears in the urine, it originates as a tubular secretion from the distal tubule which is responsible for acid-base equilibrium. The secretion and reabsorption of sodium and potassium are controlled by a hormone, *aldosterone,* which is secreted from the adrenal cortex. Sodium reabsorption is lowered

during osmotic diuresis and glucoco;ricoids (costisol and coricosterone) increase the tubular reabsorption of Na^+ in exchange of H^+ and also reabsorption of Na^+ with Cl^-.

Diuresis: When the rate of urine secretion is increased the condition is called diuresis and the substances which cause this are known as diuretics. Glucose and urea have marked diuretic effects. Besides these, other compounds like caffeine and deoxycorticosterone acetate also act as diuretics.

Increased water content in the blood results in duresis. The solutes of the glomerular filtrate which are not absorbed in the proximal tubule exert an osmotic pressure so that more water passes out of the tubules thereby increasing the concentration of solutes in the blood. Such is the state when glucose and urea are present in higher concentrations in the blood. If sufficient water is available to the organisms, the excretion of water runs parallel with that of urea. Animals consuming a high protein diet will form more urea in the body and would require larger volumes of intake of water, otherwise a mild diuresis occurs. Diabetic patients also excrete larger volumes of urine so that the filtered load of glucose exceeds TmG resulting in a condition known as polyuria.

In some cases, diuretics bring about an increased blood flow through the kidney which is mainly the function of vasomotor nerves. Although no direct nervous control of the kidney has been demonstrated, yet sometimes under emotional stress, diuresis or decrease in urine excretion are observed. This may be caused by vasomotor nerves which bring about vasoconstriction or dilation of renal arteries and arterioles, thus altering the kidney secretion.

Clearance: The maximum amount of the blood plasma that can be cleared by the kidney in one minute is called the clearance.

Clearance tests are done with reference to the plasma. Mathematically, calculation of plasma clearance of any substance can be represented as:

$$C = \frac{UV}{P}$$

Where

C = plasma clearance in ml per minute,
U = concentration of the substance in urine in gm/100 ml,
V = volume of urine passed in ml/minute, and
P = concentration of the substance in the plasma in gm/100 ml.

To take a specific example, if the plasma contains 0.05 gm of inulin per 100 ml, the urine 6.25 gm inulin lper 100 ml, and the rate of urine excretion is 1 ml per minute, then inulin clearance rate would be

$$\frac{6.25X1}{0.05} = 125 \text{ ml/minute}$$

4.3.8 HOMEOSTASIS

life is an extension of non-living processes. The physico-chemical laws which are applicable to the non-living systems are applicable to the living systems as well in many ways, a living process can be considere as a kind of super-chemistry and is an example of interactions between matter and energy to produce a highly complicated and well organized self-duplicating automatic system. Thus living system is not a closed system but an open system with matter and energy that flow into the system being in a steady state with the matter and energy that flow out of the system. Living organisms create and maintain their essential orderliness at the expense of their environment and this tendency to maintain themselves in a steady state condition is known as homeostasis.

In the nineteenth century, physiologist Claude Bernard developed an idea that the cells and tissues of the body which are bathed in an internal fluid constitute the internal environment or milieu interior, whereas the external environment of the whole organisms constitutes milieu exterior. The internal environment is maintained at a constant, irrespective of the organism's external environment. In animals a number of homeostatic mechanisms are at work which serve to maintain internal environment such as osmotic and ionic regulation, temperature regulation, buffer mechanisms, active transport and excretion. The details of these homeostatic mechanisms have been described in appropriate places of this book.

4.3.9 EXPECTED QUESTIONS

1. Describe in detail the structure of kidney
2. Explain the structural details of Bowmans capsule
3. Tubular filtration in kidneys

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Lesson 4.4

OSMOREGULATION IN ANIMALS

CONTENTS:

4.4.1 INTRODUCTION

When two aqueous solutions of different concentrations are separated by a membrane permeable to water but impermeable to solute molecules, the water diffuses through the membrane from the solution of low concentration (Hypotonic) to that of high solute concentration (Hypertonic) until the molecular concentrations on either side are the same. This process of solvent movement is called osmosis

OR

When two different concentrated solutions are separated by a semipermeable membrane or plasma membrane, the lower concentrated solution (Hypotonic) passes through the membrane into the higher concentrated solution (Hypertonic) till the two concentrations are made equal (Isotonic). This process is called osmosis.

All living organisms maintain a proper amount of water and salts in their bodies, with the help of social structures, such a regulator of the water and salt contents of the body is termed as osmoregulation. HOBER first coined the term osmoregulation to the collective activity of the variety of meachanisms used by organisms to control water movement and water volumes. It is not sufficient if the water volume is regulated. The Internal ionic or molecular concentration is

also to be regulated as large differences exist in the internal ionic concentration as well as the ionic concentration in the different parts of the body of the animals. The various processes that are involved in maintaining the internal ionic concentration is called ionic regulation. The maintenance of external ionic concentration is called ionic regulation. The maintenance of external ionic concentration and internal ionic concentration of the body are inseparable and the term osmoregulation is used to the two processes. Osmoregulation is also closely related to the homoeostatic function like P^H and temperature regulation in which body water and ionic concentrations are involved.

4.4.2 ISOTONIC, HYPOTONIC, AND HYPERTONIC ANIMALS

Depending upon the osmoregulatory mechanism animals are classified as

1. Isotonic (or) Isosmatic

The concentration of body fluids is as that of their surrounding medium and such animals never face the problem of osmoregulation as long as they live in such medium.

2. Hypotonic (or) Hyposmatic:

Most marine animals are isotonic since the concentration of their body fluids resembles the concentration of sea water

3. Hypotonic (or) Hyposmatic:

Animal which live in a medium of lower salt concentration face the difficulty of hydration hence the water from outside continuously enter into the body and dilute their body fluids. Such animals evolved special mechanisms to get rid off the excess of water that enters the body.

Fresh water protozoans and crustaceans are hypotonic and eliminate the excess of water by their contractile or pulsating vacuoles and also through the excretory organs.

4. Hypertonic (or) Hyperosmatic:

Animals which live in a medium of higher salt concentration have to evolve regulatory mechanisms by which excess of water from the body is prevented.

Teleost fishes living in sea water are in constant danger of dehydration. To compensate the loss of water they drive surrounding water.

4.4.3 ANIMALS RESPONSE TO OSMOTIC CONDITIONS OF THE MEDIUM

Animals exhibit two patterns of response to osmotic conditions of environment for their survival.

a) animals may be osmotically dependent and their body fluid concentration change according to the medium. Such animals are called as osmocon formers or poikilosmotic. These animals can tolerate wider variation in their internal osmotic concentration.

b) Animals which are osmotically stable or independent i.e. when concentration of the medium changes, the internal concentration of the bodyfluid remain unchanged. Such animals are called as osmoregulators or homeosmotic. These animals can withstand a wider environment range.

4.4.4 POIKILOSMOTIC AND HOMEOSMOTIC ANIMALS

Most of the aquatic invertebrate animals are evolved with tissues which tolerate dilutions of their body fluids and can adjust their internal medium to that of the external medium. Such Osmolabile or osmotically variable animals are called poikilosmotic.

a) Stenohaline:

Poikilosmotic animals that can tolerate only slight changes in salinity are known as stenohaline. For example the marine spider crab, Maia, when transferred to 80% sea water, puts up weight up to an certain extent due to quick entry of water into its body. Although the excretory organs of the crab work actively to eliminate the excess water in the form of a dilute urine, the crab loses large quantities of salts also along with the urine making the body fluid more dilute. Since the crab is not able to replenish the salts, it dies within 18 hours. Arenicola is another example of stenohaline condition.

b) Euryhaline:

Poikilosmotic animals which can tolerate and withstand wide ranges in salinity are known as euryhaline. They are found in estuaries or river mouths or near sea shores where the salinity may fluctuate to a great extent. For example the sea mussel, Mytilus can tolerate the dilution of sea water upto 4% and lives unaffected. Siponculid worms such as phascolosoma. Aurelia and Aplusia are also euryhaline.

2. Homeosmotic Animals

These are osmostable i.e they can regulate and maintain the osmotic concentration of their body fluid irrespective of the out side concentration.

Homeosmotic animals living in fresh water adopt different methods for osmoregulation which are as follow:

1. Presence of an impermeable cuticle

2. Restriction of semipermeable surfaces to relatively small areas of respiratory and digestive system.

3. Development of Excretory organs to produce hypotonic Urine.

4. Possession of special cells to absorb salts from the surrounding fluid to make good the salt loss through urine.

5. tolerance of dilute body fluids to minimise the expenditure of metabolic energy.

4.4.5 MECHANISM OF OSMOREGULATION

1.Osmoregulation in fresh water Animals:

Osmoregulation in fresh water animals is effected by pumping out of excess water from their bodies. The salt loss through the excretion of water is made good by salt absorbing gills, skih, and various parts of the alimentary canal.

1. Protozoa:

In fresh water protozoans such as Amoeba Euglena and Paramecium, which live in a hypotonic medium, outside water enters into the body and dilutes the body fluid. This excess water is eliminated by the rhythmic pulsation of the contractile vacuole. Parasitic and urine protozoa do not posses a contractile vacuole.

2. Crustacea:

The blood of fresh water crustaceans like Palaemon is hyper tonic to the surrounding water. The later, therefore, continuously diffuse into the blood through highly permeable gills. The excess water is excreted in urine by the antennary or green glands. Salt loss through urine is made good by the active uptake of chloride, sodium and potassium from the surrounding medium by the chloride cells of gills even if the concentration of salts in the medium is extremely low.

3. Mollusca:

Fresh water mussels like unio and Anodonta carry on osmoregulation through kidneys. Osmotic pressure of these animals is higher than the surrounding aqueous medium and as such water diffuses into the tissues. This water is eliminated by the kidneys during excretion.

4. Fresh water Teleosts:

These are hyperosmotic to the surrounding medium i.e their blood is more concentrated than the external medium. As a result, outside water enters through the thin permeable skin, the smooth surface of the gills and lining of oral and pharyngeal cavities. This water is quickly transported to the well developed glomerular kidneys which reabsorb desirable solutes and secrete a dilute urine. Thus the blood concentration is restored. However along with the urine, some salts also pass out. The salt loss is made good by chloride cells present on the gill

epithelium. These cells are capable of absorbing the small quantities of salts present in the fresh water.

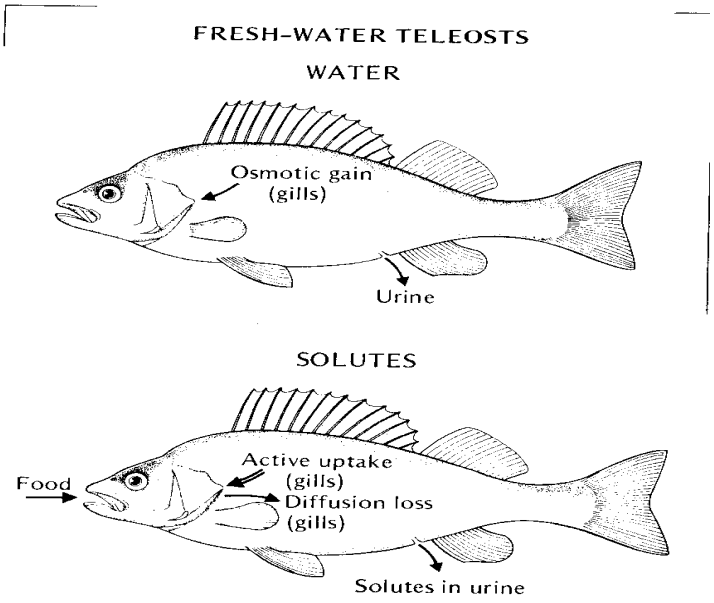

Fig. 4.4.1 Osmotic regulation

Kidney of fresh water fishes serves primarily as filter and reabsorber of solutes.

5. Fresh water Elasmobranchs: (Cartilaginous fishes)

Pristis and charcharias giaganticus, which often enter the large reivers and other fresh water habitats, have a tendency to retain some urea in their blood and tissues. As a result, large quantity of water enters the body by osmosis. This water is eliminated by the large glomerular kidneys.

6. Amphibia:

Fresh water which contains a small percentage of salts diffuses into the body through smooth skin of amphibians. The well developed glomerular kidneys serve to remove the excess water which is excreted as dilute urine. The salt losses through the urine are replenished by reabsorption of ions from the urine.

4.4.7 OSMOREGULATION IN MARINE ANIMALS

1. Hagfish:

A few marine animals such as the hagfish, Myxine, maintain body fluids about as salty as the sea waters of the surrounding ocean and so do not tend to lose water by osmosis. However, the glomerular kidney of the hagfish is an ion-regulating structure, it removes Ca^{++}, Mg^{++} and So_{4+} and reabsorbs K^{+} and Cl^{-}.

2. Marine Teleosts:

In the marine bony fishes E. Opsanus and cophius, the body fluids are hypotonic to the marine environment, having a solute concentration only about 1/3 that of sea water consequently, they lose water through the smooth surfaces of the body like gills and oral epithelia. Thus they are constantly in danger of losing so much water to their environment that the solutes in their body fluids may become extremely concentrated and the fish may die of osmotic dessication. Therefore, to compensate for their osmotic water loss, they drink sea water. This restores their water content but leads to a new problem. How to eliminate the excess salt ingested. This problem has been solved by the evolution of special.

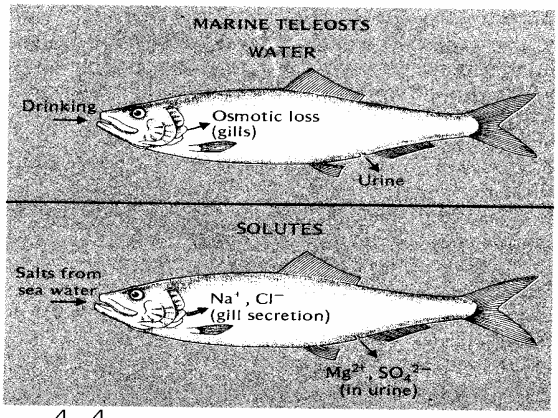

Figure 4.4 A marine teleost is osmotically more dilute than the water in which it lives. Because of the higher osmotic concentration in the medium, the fish constantly loses water (top diagram), primarily across the thin gill membranes. Additional water is lost in the urine. To compensate for the water loss, the marine teleost drinks substantial amounts of sea water. Of the ingested salts, sodium and chloride are absorbed in the intestine and eliminated via the gills by active transport (bold arrow, bottom diagram); magnesium and sulfate are excreted by the kidney.

"Chloride secreting cells" in the gills that excrete excess salt. Hence, these fish can take in salt water and still remain hypotonic. Water loss through urine is minimized by the development of aglomerular kidneys. Further, the distal convoluted tobule of the nephron is also absent consequently, urine flow in opsanus is only 255ml/Kg per day as compared to 300ml/Kg per day in a fresh water teleost.

3. Marine Elasmobranchs:

Marine cavitilaginous fish such as scoliodon and stegostoma have body fluids isotonic with sea water. They achieve their isotonicity in a different way. Because they have unusual tolerance for urea, instead of constantly, pumping this waste out, as do all other fish, sharks retain a higher concentration of it in their blood equal to that of sea-water. Though the osmotic imbalance is removed in this way, the ionic concentration of the body fluids and the surrounding sea-water remains different. The marine elasmobranchs achieve their ionic regulation by actively removing the excess salts with the help of a rectal gland. They do not have chloride secreting cells in their gills.

4. Migratory fishes:

Catadromous fishes like the eel, Anguilla bengalensis migrate from fresh water to sea, while anadramous fishes like salmon, salmo fario, migrate from the sea to fresh-water for spawning. Such fishes have to regulate their blood tonicity in two contrasting media. It has been observed that the cold blood concentration of eel is hypertonic when it lives in the fresh-water and it shows the same pattern of osmoregulation as fresh-water teleosts. On the other hand, blood concentration of the spawning eel in the marine medium is hypotonic to the sea-water. Therefore, it maintains itself against an osmotic dessication.

a) by drinking sea-water

b) eliminating the excess salts by the chloride secreting cells of the gills.

5. Marine Reptiles:

Some reptiles like turtles, sea-snakes and the iguana are able to maintain the osmotic and ionic concentration of their body fluids by the same mechanisms as met within marine teleosts. They drink sea-water and consume salty prey. Thus they are able to absorb the water but eliminate the salt through special `Salt glands'.

Turtles have special glands in their heads that can cxcrete NaCl at a concentration about twice that of sea water. Since ancient times, turtle have these great armored reptiles come ashore, with tears in their eyes, to lay their eggs, but it is only recently that biologists have learned that this not caused by an excess of sentiment – as is the case with Lewis Carroll's mock turtle- but is rather a useful solution to the problem of excess salt from ingestion of sea water.

6. Marine Birds:

Sea birds such as petrels, cormorants, penguins and herring gulls eliminate their excess salts, chiefly NaCl in the form of a salty fluid through their nostrils. The salt glands are located in their nasal chambers. In the herring the concentration of NaCl thus got rid off is about 5 times its concentration in the blood.

7. Marine Mammals

Whales, Dolphins, Porpoises and seals do not drink water, hence, they depend upon food for their water requirement. These mammals never sweat and in this way avoid loss of water by preservation from their skin.

4.4.7 OSMOREGULATION IN TERRESTRIAL ANIMALS

Since terrestrial animals do not always have automatic access to either fresh or salt water, they must regulate water content in other way, balancing of gains and losses. Terrestrial animals gain water by drinking fluids by eating water-containing foods and as an end product of the oxidative processes that take place in the mitochondria. when 1gm of glucose is oxidized, o.6gm of water formed. When 1 gm of protein is oxidized, only about 0.3gm of water is produced. Oxidation of fat, however, produces 1.1gm of water because of the highly hydrogen content of fat.

The main problem of terrestrial animals is the loss of body water content. It is solved by a combination of some of the following adaptations.

1. Presence of a highly impermeable cuticle or skin covered with scales, feathers or fur and deposited with wax or keratin. Such a water proof cover prevents loss of water by evaporation.

2. Elimination of nitrogenous wastes, as urea or uric acid with little or no loss of water. In reptiles and birds loss of water is restricted due to uricotelism. They excrete a semisolid urine in the form of uric acid crystals. Reabsorption of water from faces by the rectal glands and cloacal wall further minimizes water loss.

   In mammals and in some birds there is a water absorbing column called Henle's loop in the urinferous tubule of the kidney which minimize the water loss through urine.

3. Ability of water absorption through the body surface of the desert lizard. Moloch horridus absorb water like a blotting paper when the atmosphere is humid or the animal is drenched in rain.

4. Production of metabolic water by the oxidation of food stuffs. Particularly the fat. Some animals living in extremely dry habitats depend upon metabolic water for their vital activities. The Kangaroo rat, Dipodomys of the American desert for example, may spend its entire life without drinking water. It is not surprising that it prefers a diet of fatty seeds, which yield a large amount of water on oxidation. Analysis shows that the Kangaroo rat is highly conservative in its water expenditures. It has no sweat glands, and being nocturnal, it searches for food only when the external temperature is relatively cool. Its faces have a very low water content, and its urine is highly concentrated. Its major water loss is through respiration, and even this loss is reduced by the animals of long nose in which some cooling of the expired air takes place, with condensation of water from it.

If the Kangaroo rat is fed high-protein seeds such as soybeans- the oxidation of which produces a large amount of nitrogenous waste and a relatively small amount of water –it will die of dehydration unless some other source of water available.

On the average, a human takes in about 2,300 milliliters of water a day in food and drink, and gains an additional 200 milliliters a day by oxidation of nutrient molecules. Water is lost from the lungs in the form of moist exhaled air, is eliminated in the faeces, is lost by evaporation from the skin, and is removed from the blood and excreted as urine. The latter is usually the major route of water loss. In a normal human adult, the rate of water excretion in urine average 1,500 milliliters a day but the actual amount produced may vary from 500 to 2,300 milliliters.

The cleidoic eggs of reptiles and birds provided with a large amount of yolk and enclosed by a hard shell. The eggs are laid on land. The developing embryo has limited supply of water, chiefly metabolic in nature. The nitro genous wastes are converted into non-toxic uric acid crystals which are stored in an allantoic sac to be excreted at a later stage.

5. Tolerence of dehydration and fluctuation in internal temperature. The camel, `Ship of the desert' can tolerate the loss of more than 25% of their body weight in water, going with out drinking for as long as an entire week in the summer months, 3 weeks in the winter. Besides, the camel can tolerate a fluctuation in internal temperature of 5^{O} to 6^{O} C. It is estimated that the camel saves as much as 5 litres of water a day as a result of these internal temperature fluctuations. Its body temperature can vary from 34^{O} to 45.5^{O}C with out taxing its regulatory machinery like sweat glands. The camel never sweats till the body temperature rises to 41^{O}C. Therefore, much water loss is saved by this method moreover, the camel excretes a much more concentrated urine, in other words. It does not need to use so much water to dissolve its waste products.

6. Behavioral adaptations tending to confine the animals to regions of high humidity and to burrow into the soil.

7. Restriction of activity to those periods when the temperature is not severe.

8. Regulatory mechanisms to check water loss through nervous and chemical co-ordination. ADH increases the reabsorption of water from kidney tubules where as aldosterone is concerned with ionic balance. In mammals, aldosterone increases the reabsorption of sodium and promotes the renal excretion of potassium.

4.4.8 EXPECTED QUESTIONS

1. Describe the mechanism of Osmoregulation in animals.
2. Write in detail the process of osmoregulation in marine animals
3. Give an account an osmoregulation in terrestrial animals
4. Differentiate the osmotic regulatory mechanisms of poikilosmatic & Homeosmotic animals.

4.4.9 REFERENCE BOOKS

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Lesson 5.1

MUSCLE SYSTEM : FUNCTIONS AND TYPES OF MUSCLES

CONTENTS

5.1.1 Introduction

The way muscle is used by various animals differs a great deal (depending primarily on the function of the particular muscle). The demands on the flight muscles of an insect, which contract several hundred times per second, and on the muscle that closes the shells of a clam and remains contracted perhaps for several hours, are very different indeed. The best way to describe how muscle can serve different purposes is to examine some characteristic types of muscles and how they are modified to meet specific demands.

Muscles may be differentiated into smooth and striated types though in strict sense these terms are very narrow to accommodate all the different varieties of muscles that exist.

5.1.2 Vertebrate fast and slow muscles

Vertebrate striated muscle is compared of muscle fibers that fall into two (more) distinct classes that are frequently referred to as fast and slow fibers. This terminology can easily lead to confusion, and it is now common to designate the fast fibers as twitch fibers and flower as tonic

fibers. Usually there is a difference in the amount of myoglobin present in two kinds of fibers. The twitch fibers which have a lower myoglobin content have been known as pale (or) white; the tonic fibers, with a higher myoglobin content as red any one muscle may consist of only twich fibers, only tonic fibers (or) a mixture of both.

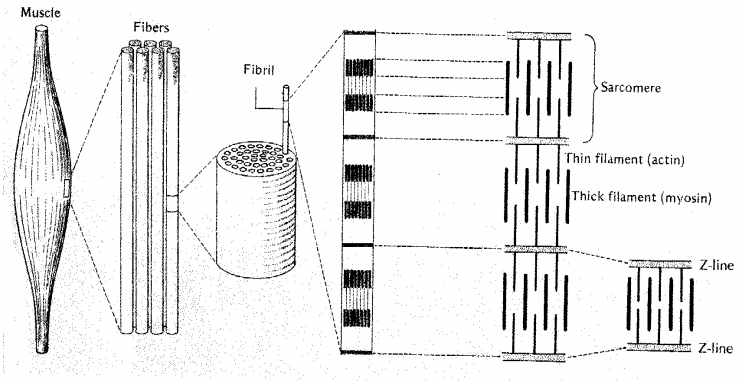
The distinction between twich (fast) and tonic (slow) muscle fibers was first made for frog muscles. The main functional difference is that twitch fibers are used for rapid movements and tonic fibers are used to maintain low – force prolonged contractions.

5.1.3 Striped (or) Striated Muscles

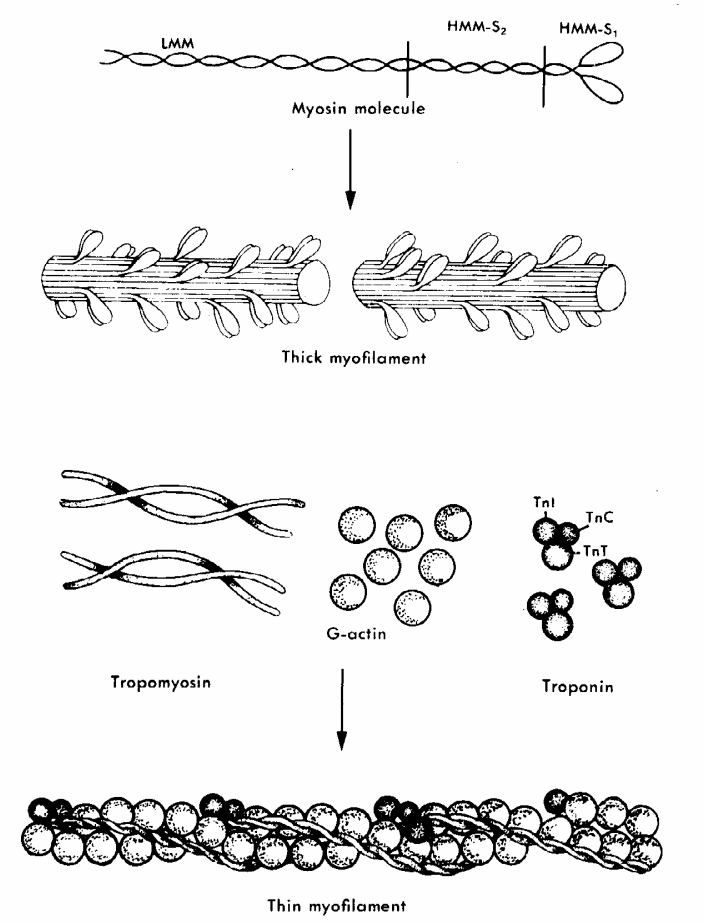
The striated muscles exhibit an alternating arrangement of dark and light bands crossed by thin dark line under the polarizing microscope, the dark bands are found to be doubly refracting and the light bands are singly refracting (Wei'sman, 1913) under the high power of a light microscope the striated pattern is seen as a regular alternation isotropic "I" bands (or) light bands, through which light passes equally in all directions and anisotropic "A" bands (or) dark bands, possessing different directions. The length of a A band of vertebrate fibril is usually about 1.5 microus and that of an I band is 0.8 micron. In the "Z" line, designed from the term Zwischen schelibe which liserts the I-band.

In the middle of the A band is another zone which takes a light stain known as the "H" band (or) "H" zone desined from the German name "Hensens" line. The portion of the muscle fibre from one Z-line to that of adjacent I - band is termed as the Sareomere.

Examination under electron microscope reveals that the myofibril is made up of two kinds of small filaments one twice as thick as the other the dense A band consists of the overlapping thick and thin filaments the lighter I band consists of thin filaments, while the H - band consists of the thick filaments only. The thin filaments about in the middle of their length pass through a narrow zone of dense material, the "Z" line. The thicker filaments are about 100 A^O in diameter and 1.5 microns long and the thinner ones are 50 A^O in diameter and 2 microns long. Each thin filament lies in between 3 thick ones. A myofibril of 1 micron diameter contains about 5,000 filaments in each cross section of an A – band.



Schematic diagram of a vertebrate striated . The whole muscle is composed of fibers, which in t microscope appear cross-striated. The fibers of fibrils, which have lighter and darker bands. The electron microscope reveals that these bands result from a repeating pattern in the regular arrangement of thick and thin filaments.



5.1.4 Smooth Muscle

In constast to striated in vertebrates this type of muscle occurs in the stomach, intestine bladder, useters, uterns, branchi blod vesses and so on. Contraction of smooth muscle depends on filaments of the same proteins as in striated muscle, actin and myosin and a supply of energy from ATP smooth muscles lack the situations charestic of skeletal muscle because the arrangement of actin and myorin is less.

The fibers are only a fraction of a milli meter long and often such in many different direction smooth muscle is not a discrete organ like a skeletal muscle, it is usually an integral part of the time of some other organ.

Contraction of smooth muscles depends on filaments of same proteins situated muscle, actin and myosin and a supply of energy from ATP. However, the actin filaments are

predominantly oriented parallel to the long axis of the cell, so this is the direction of the force of contraction.

Contraction in smooth muscle is triggerd by a different mechanism from that in skeletal muscle. Like skeletal muscle, stimulation of smooth muscle causes a rise in the contraction of calcium ions, but the ions diffuse into the cell from the extracellular fluid. While this would be too slow for skeletal muscle contraction, diffusion across the cell membrane is sufficiently fast for smooth muscles because smooth muscle cells have a large surface area relative to their volume, and they activate slowly contraction of smooth muscle in blood mussel regulated by compounds released by endothelial cells lining the mussel.

Electrical depolarization also causes smooth muscles to contract. When a small number of muscle cells in a smooth muscle are electrically stimulated, the contraction spreads to neighbouring cells through gap junctions, which permit the flow of ions between cells. As with condiac muscle, the presence of gap junctions permits adjacent cells to commnicate, coordinating their activities.

Contraction in smooth muscle is very different from skeletal muscle the degree of shortening is variable, with smooth muscle being able to adjust its length over a wide range. Both the activation and the velocity of contraction are slower. Additionally smooth muscle can maintain contraction of prolonged periods with such lower energy expenditure than would occur in skeletal muscle.

5.1.5 Cardiac Muscle

The muscle of the heart contains actin and myosin filament and cross striations identical to those in skeletal muscle, but the mitochondria are much more abundant. This is understandable in view of the constant demand on cardiac muscle for continued work throughout the life time of the organism.

One important contrast to skeletal muscle is that when a contraction starts in the heart. It rapidly spreads to the entire muscle. The heart muscle consis of a large number of branching cells that are connected end to end by specialized inter calated dises. As the fibers branch, they connect to adjacent fibers and form a complex three dimensional network. The intercalated dises serve to maintain cell to cell cohesion; at irregular intervals along the disc these are gap junctions which are important because they form areas of low electric resistance that permit the rapid spread excitation from one fiber to the next throughout the heart. The other important aspect of cardiac muscle related to the electric phenonena that occur during muscle contraction. During contraction the cell membrane of the cardiac muscle fibers, like other muscle fibers, undergoes electric changes, known as action potentials. The peculiarity of the heart muscle is that the cell membrane, after completion of an action potential, remains in a retractory state for a given period of time, long enough to allow the muscle to relax after each action potential. Because of this retractory period, the candiac muscle cannot go into a sustained confraction (a tetonus). The refractory period is the essential for synthetic alternation between contraction and relaxation of the heart.

The contraction of heart orginates in the pace maker cells. These are specialized muscle cells, and because the repetitive contractions originate in muscular tissue, we speak about the vertebrate heart as being myogenic. The heats of some invertebrates in contrast are called neurogenic because the contractions are insitiated by impulses from the nervous system The myogenic nature of the vertebrate heart does not mean, however, that there is no influence from the mervous system one is the vagon name, which contains para sympathetic nerve fibers that release acetyl choline, cousing slowing of the beart rats. Stimulation from sympathetic nerves causes the release of noradrenaline and an increase in rate and more powerful contractions of the heart muscles.

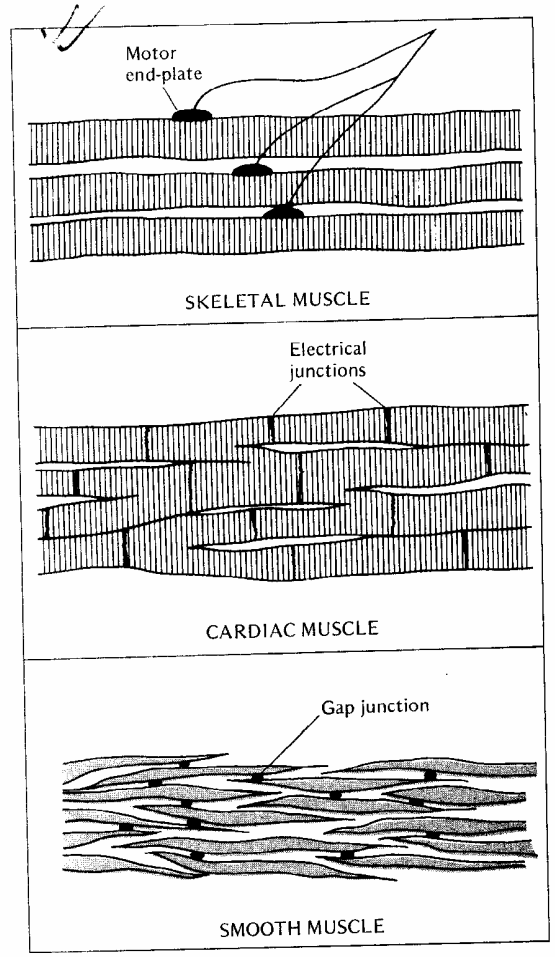


Figure . The main structural characteristics of the three major types of vertebrate muscle.

5.1.6 Functions of the Muscle

Muscles convert chemical energy into mechanical energy and perform work. The nerve impulse initiate the above process by depolarizing the membrane of the muscle fiber. Under activation, the fibre structure in the muscles is changed and their length diminishes. The energy for this purpose is derived from exotheric energy yielding reactions. The complete work done by the contractile elements of the muscle is not applied on the load. Part of it is spent on pulling and stretching the non contract parts of the muscles, namely the sarcoplasm, sarcolemma and the connective tissue. The shorteing of the contractile elements is known as contraction of muscles. After contraction the muscle filaments return to their normal position, known as the relaxation state. However the relaxation state is not a passive state as energy is consumed from the starting of contraction to until nearly the end of relaxation. This period is referred to as active state. Accordingly the active state is designed the load there a muscle can just been lengthening.

Isotonic and Isometric Contractions

The muscle is said to be in an isotonic condition, when it contracts with a constant load that it can lift. During this phase, the muscle maintains an equal tonus (or) tension. On the other hand, when a muscle contracts against a weight that it cannot lift, it is said to give an iso metric contraction, since it maintains, inform length. Another muscles, during iso toniccontraction, there is a change in the shape of the muscle, while there is no such change of shape in isometric contraction.

Muscle twitch : (Simple contraction)

The response of a muscle to a single brief stimulus, such as an electric shock, is known as twitch. A twitch can be devided into two portions (or) phases.

1. Latent Period

A latent period is the period in which the length of the muscle remains constant.

2. Contraction Period

It is the period, during which muscle shortens.

3. A relaxation Period

In this period the length of the muscle and its tension reach the normal level.

TETANUS

If a muscle fiber is stimulated before it relaxes for a record time, it can contract again. Therefore, a muscle can be maintained in a continuously contracted phase if stimulated frequently within a given time. A continuous contraction of this type is known as “Tetanus”.

SUMMATION

When the pre synaptic portion of a nerve is stimulated more than two times, it tends to have an additive effect on the post synaptic portion. In the case of muscles, the effects may either be mechanical (or) electrical; accordingly summation (or) addition take place in the electric behaviour of the membrane of the muscle fiber and in the contractile elements. However, as the electric membrane responses are of short duration. It is essential that the stimulations should be at short intervals. In muscles a series of stimuli causes contraction, which gradually increase and the resulting final contraction is greater than a simple contraction, excited by a stimules of greater intensity and excites all the fibers of a muscle. The additive effect of repeated contraction is known as summation.

FACILITATION

In contrast to summation, facilitation, refers to the sevier of contraction resulting from repeated stimulations. Facilitation is not a single phenomenon which takes place within a definite period of time and does not proceed indefinitely. If the stimulation are repeated for a longer time than the optimal value, contractions gradually decrease and may altogether stop.

FATIGUE

The failure of a muscle to contract is called fatigue. Fatigue may be observed if individual twitches are induced continually by electricity. During fatigue the muscle contraction capacity decreases gradually and the individual muscle fiber fail to contract.

Even though the exact reason for fatigue is not known, various explanations have been made.

(i) The expansion of the metabolic sources of energy.

(ii) accumulation of waste products.

(iii) Loss of potassium ions from the post – synaptic cell and the accumulation of the same in the extra cellular space.

(iv) Increase in the concentration of sodium ions in the post synaptic cell.

(v) Expansion of the stored transmitter substances in the pre-synaptic cells.

Experiments have shown that removal of the waste products, formed during contraction by repeatedly washing the muscle in a balanced salt solution, delays fatigue.

5.1.11 EXPECTED QUESTIONS

1. Write about the different types of muscles.
2. Write short notes on
   (i) Muscle fatigue
   (ii) Tertoms
   (iii) Sumation
3. Give in detail the function of muscles.

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Lesson 5.2

MUSCLE CONTRACTION THEORIES

Contents

5.2.1 INTRODUCTION

A purposeful locomotory movement certainly occurs in all animals. Among unicellular animals this is involved in the movement of the cell itself or in that of special structures of the cell such as the cilia, flagella, etc., but with the cellular differentiation in the multicellular animals this property of the movements gets restricted to the special muscle cells. These muscle cells are long and variously organized, the connective tissue binds them together. A general speciality of all muscle cells is their capacity to shorten in length, i.e., to contract. Sometimes the muscles do not shorten even on contraction such as when they are joind to the fixed structures or while maintaining a particular position due to the actin of the antagonistic muscles; but here to, the production of heat in these muscles indicates that they are expending energy in an attempt to contract.

5.2.2 Types of Muscle

Muscle is generally devided into three types. Skeletal, Cardiac, and Smooth, though smooth muscle is not a homogenous single category, skeletal muscle makes up the great mass of the somatic musculature. It has well – developed cross – striations, does not normally contract in the absence of nervous stimulation. Lacks anatomic and functional connections between individual muscle fibers, and is generally under voluntary control. Cardiac muscle also has cross – striations, but it is functionally syncytial and contracts rhythmically in the absence of external innervation owing to the presence in the myocardium of pacemaker cells that discharge spontaneously, smooth muscle lacks cross – striations. The type found is most hollow visera is functionally syncytial and contains pacemakers that discharge irregularly. The type found in the eye and in some other locations is not spontaneously, active and resembles skeletal muscle.

5.2.3 Structure of Muscle

The striped muscles are concerned with the skeleton. Their fibres are long and multinucleated. Each fibre contains a thin membrane sarcolemma on its surface. The inner substance of the fibres consists of two main parts – the liquid part sarcoplasm, and the cross striated myofibrils arranged in it. The muscle fibres of this kind of structure occur in bundles which constitute the entire muscle.

Sarcolemma is the outer covering formed of connective tissue, it is elastic and is continued with the tendinous material which forms the origin and insertion of the muscle immediately below the plasma membrane.

Myofibrils are the microscopic filaments extending length wise which are arranged in bundles. When viewed through a light microscope, the myofibrillar bundles appear striated. A definite pattern or design occurs in this striated arrangement which becomes quite obvious through an electron microscope. The larger structural blocks of the myofibrils are called the sarcomeres, upon maceration the muscle fibre breaks up into sarcomeres. In an Intact muscle one can see thin Z – bands at the margins of these sarcomeres. In the middle of the sarcomere is seen a broad darker band called the `A-band', on either side of which occurs a contractive I-band. At times a lighter coloured H-hand is visible in the middle of the A-band.

The liquid sarcoplasm occurs in between the myofibrils and also at the periphery of the muscle fibre. It contains a system of interconnecting tubules scatterd throughout, which are called the sarcoplasmic reticulum, this reticulum is arranged length wise in between the myofibrils. A number of nuclei (on the surface only) and mitochondria are scattered in the liquid sarcoplasm.

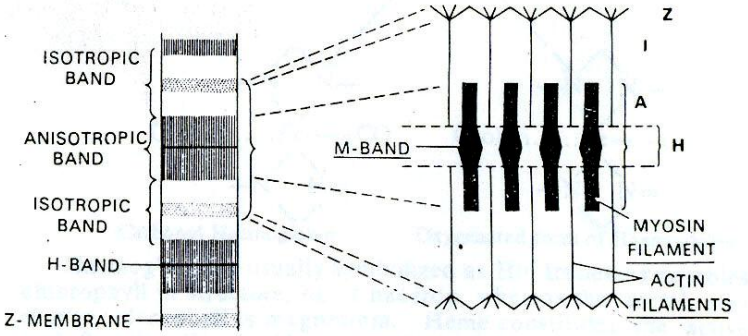

Fig. 5.1.2 A—A portion of single myofibril as seen under high magnification of light microscope.
B—A sarcomere showing the arrangement of actin and myosin myofilaments.

It has been possible to examine the detailed structure of the individual myofibrils with the help of an electron microscope. Each myofibril is made up of two types of strands – thick strands of nearly 10 mμ and thin ones of nearly 5 mμ. Chemical analysis of the myofibrils has revealed

that thick strands are composed of the protein myosin and the thin strands of another protein actin. In the enlarged protein of the thick dark strands are of myosin and the thinner ones are of actin.

The thick and thin strands along a myofibril do not continue throughout its full length but are in the form of overlapping pieces, this is the reason why the myofibrils present the special striated appearance. It is obvious that wherever there is greater overlapping of the thick and thin strands the colour will be darker, and where ever they are less over lapping it will be lighter.

5.2.4 Chemical Constitution of the Skeletal Muscle

The muscle fibres are composed mainly of proteins about 20% of chemical constituents of this tissue is protein. 75% is water and the remaining 50% is composed of inorganic material carbohydrates (glycogen and its derivatives) and certain other organic substances.

`The Proteins in Muscle'

Muscle proteins are characterized by their elasticity, which confers contractile power on this tissue. As mentioned earlier, thick myofilaments consist primarly of myosin whereas thin of proteins, namely actin, tropomyosin and troponin.

Myosin :

Myosin is the most aboundant muscle protein which is a globulin. It has three important biological activities.

1. Myosin molecules spontaneously assemble into filaments in solutions of physiologic ionic strength and pH. Infact, the thick filaments consist mainly of myosin molecules.

2. Myosin is an enzyme Vhadimir Englechardt and Militsa Lyubimova discoved in 1939 that myosin is an ATP ase.

$$ATP + H_2O = ADP + ip - H$$

This reactin is immediate source of the free energy that drives muscle contraction.

3. Myosin binds to the polymerized form of actin, the major constitute of the thin filaments.

Mysin has a very large molecular weight 500,000. It contains two identical major chains and four light chains. Electron micrographs show that myosin consists of a double headed globular region joined to a rod the rod is double headed α - helical cable that is 1340 along, and the globular regions have a diameter of about 90A.

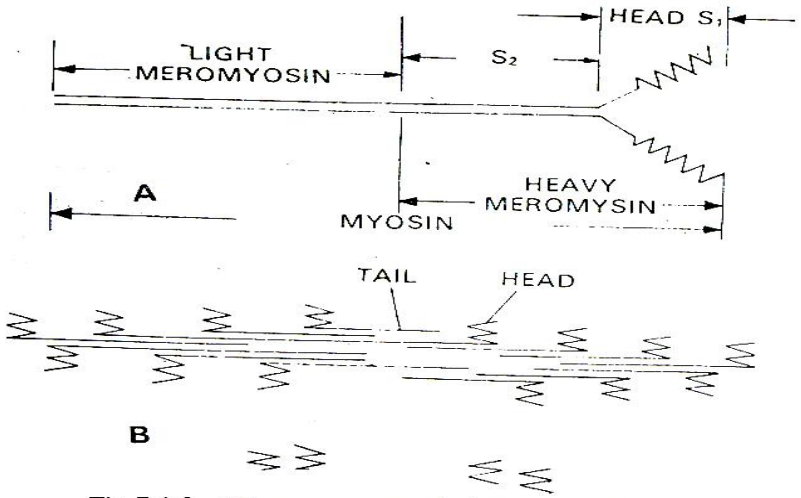

Fig.5.1.3 Minute structure of myosin filament.

Actin :

Actin is the major constituent of thin filaments. In solutions of low ionic strength, actin in composed of G-actin monomer which is an end-to-end aggregation of numerous globular subunits. As the Ionic strength is increased to the physiologic level. G-actin polymerizes into a fibrous form called F-actin which closely resembles the thin filaments. An F actin fibre looks in electron micrographs like two strings of beads wound around each other. It may be concluded. Therefore, that F-actin is a double stranded helix of actin monomers.

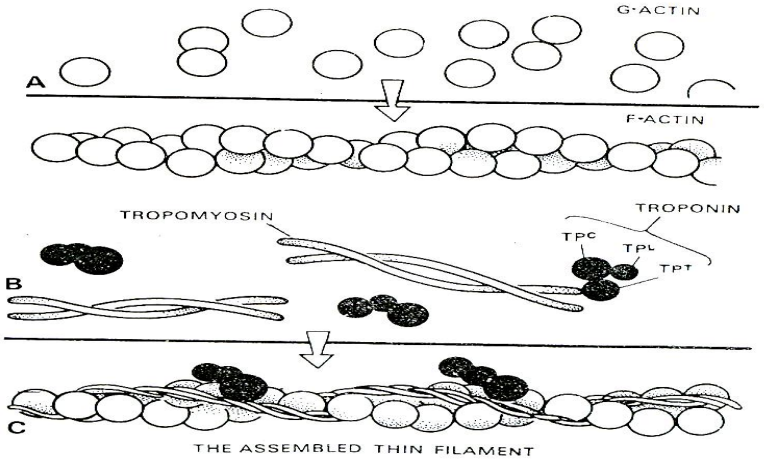

Fig. 5.1.4 Minute structure of action filament.

Figure Schematic representation of a thin fibre. Figure shows the spatial configuration of three protein components: actin, tropomyosin, and troponin of the thin filament.

Tropomyosin :

Tropomyosin is a two – stranded α-helical rod which is located in the groove between the two helical strands of actin. A troponin complex is attached to the tropomyosin at intervals of about $385A^{O}$.

Troponin :

Troponin is a complex of 3 polypeptide chains designated TPC (calcium binding subunit) TPI (inhibitory subunit) and TPT (tropomyosin binding subunit). Troponin is an important control protein, in as much as it prevents the interactin between actin and myosin unless combined with Ca^{+2} ions. TPC binds with Ca^{+2} and turns on contraction where as TPI bind to actin, turning of 4 to 7 actin monomers. TPT binds to tropomyosin and restores $Ca+^{2}$ sensitively, thus regulating the actin activity, depending on the Ca^{+2} level.

5.2.5 The sliding Filament Theory of Muscle Contraction

The siding filament mechanism of muscle contraction was discovered by two bio-physicists Hugh Huxley of University College, London and F.A.Huxley (1965) of Cambridge. The shortening of the sarcomere during contraction s due to the sliding of thin filments into A and H bands. The sliding theory of muscle contraction postulates that the thin actin filaments are displaced with respect to the thick myosin filaments during each cycle of contraction and relaxation.

I. The Contractile Process

When a muscle is in the resting state, it remains extended because actin and myosin component of the actomyosin – ATP complex carry similar electric charges, and, therefore, repel each other. A series of events take place during the contraction phase:

Step-1

When a nerve impulse arrives at the junction between the nerve ending and the muscle, the sarcolemma of a muscle fibre is depolarized, subsequently, the deplorization of sareolemma is transmitted to the interior of the muscle fibre by a plexus of channels the sarcoplasmic reticulum. Calcium ions are maintained in this sarcoplasmic reticulum when a muscle is in the resting state. This is accomplished by an energy-requiring active transport system for calcium ions.

Step-2

Excitation of a motor nerve to the muscle brings about release of calcium ions from the sarcolemma.

Step-3

The released calcium binds to the T_p C subunit of the troponin complex. Producing conformational charges which are transmitted to tropomyosin and then to actin proteins of the thin filaments. This permits actin to interact with myosin with resultant musclar contraction.

Step-4

Intact myosin has the activity of the enzyme adenosine triphosphatase (ATPase) which hydrolyzes ATP and ADP, releasing the energy required for activity. The thick and thin filaments interact by cross-bridges emerging at intervals along the thick myosin filaments; the contractile force of the muscle (ATP) is generated at the sites of the cross-bridges. These bridges act like hooks or leaves, exerting tension on the neighbouring actin filaments. The `ratchet' like actin of cross-bridges slides the neighbouring actin filament lengthwise along the myosin filament.

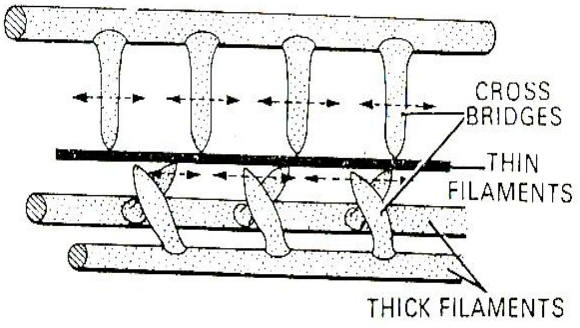

Fig. 5.1.5. Position of cross bridges between myosin and actin filaments during sliding

"Arrangement of cross bridges". The cross bridges enable the thick filaments to pull the thin filaments by a kind of ratchet actin. In this schematic drawing, one thin filament lies among three thick once each bridge is a part of a thick filament, but it is able to hook onto a thin filament at an active site (dot) presembly. The bridges are able to bend back and forth (arrows), A single might thus hook on to anactive site pull the filament ashort distance, then release it and hook into the next active site.

II. Relaxation

With cessation of nervous stimulation, contraction ceases and muscle fibrils return to the resting state. Each muscle fibre develops an electric potential of 80mv across its membrane and the inside becomes negative. When the excited state ceases, the sarcoplasmic reticulum of the muscle fibre concentrates calcium ions from its surrounding fluid an ATP-requiring active transport process. With decline in calcium ions, myosin ATPase activity is inhibited, and the resting state is re-established. ATP is replenished form ADD via phosphagens.

5.2.6 Andrew Szent – Gyorgy Theory

In 1053, Andrew Szent – Gyorgy showed that myosin is split by trysin into two fragments, called light meromyosin (LMM) and heavy meromyosin (HMM), light meromyosin forms filaments. However, it lacks ATPase activity and does not combine with actin. Electron micrographs reveal that LMM is a two stranded α-helical rods for its entire length of 850 A^o.

Heavy meromyosin (HMM) catalyzes the hydrolysis of ATP. It binds to actin but does not form filaments. HMM consists of a rod attached to a double headed globular region. It can be split further into two globular subfragments (called HMMS-1) and one rodshaped subfragment (called HMM S-2). Each HMM S-1 fragment contains an ATPase active site and a binding site for actin. Furthermore, the light chains of myosin are bound to the HMM S-1 fragments. Probably, the light chains modulate the ATPase activities of myosin.

5.2.7. Biochemical events in muscle contraction

The immediate energy source for muscle contraction is ATP which is present only in small quantities at any given time in the muscle. ATP required for contraction is generated in muscles by four important processes:

1. Oxidation of food stuffs
2. Enzymatic transfer of high energy phosphate from phosphagens to ADP
3. Lactic acid formation
4. Myokinase actin

1. Oxidation of food stuffs

The ultimate sources of the energy required for contraction is, of course, the oxidation of food stuffs. Resting muscle and also muscles with greater oxidation capacity derive a large portion of their energy from the oxidation of fatty acids and acetoacetate, and, to a lesser extent, glucose.

2. Muscle phosphatogens

Although ATP is the immediate source of energy for musclar contraction, the amount of ATP in muscles is extremely small-only enough to sustain contraction for a fractin of a second. In vertebrate muscle, there is however, back up source of high energy phosphate in the form of phosphocreatine. Since the compounds have a higher phosphate group-transfer potential than ATP, it can donate a high-energy phosphate group to ADP to reform ATP. Compounds of this type carrying high energy phosphates are also known as phosphagens. Some invertebrates utilize phosphoarginine in an analogous manner. Consequently this compound may be regarded as the invertebrate phosphogen phosphocreatine is the vertebrate phosphagen.

In the resting state, mammalian muscle contains 4-6 times as much phosphocreatine as ATP. The transfer of high energy phosphate from creatine phosphate to ADP (the Lohmann reactin) is catalyzed by the enzyme creatine kinase.

Phosphocreatine + ADP creatin + ATP

Transphosphorylase

The reactin is reversible, so that resynthesis of creatin phosphate can take place when ATP later becomes available, as during the recovery period following a period of musclar contraction. Transfer of phosphate from ATP to creatine to form creatine phosphate is catalyzed by the enzyme ATP – creatine transphosphorylase.

The ATP that is used to regenerate creatine phosphate is derived essentially from a source extent to the contractile system presumably the mitochondria of the sarcoplasm. The energy for the regeneration of creatine phosphate is thus derived ultimately from oxidative metabolism.

ATP, together with muscle proteins actin and myosin, forms an actomyosin – ATP complex.

3. Lactic acid formation

A muscle can continue to contract in the absence of oxygen during periods of rapid activity when the respiratory system cannot supply sufficient oxygen for the needs of the muscle. Under these circumstances, the pyruvic acid (formed via glycolytic pathway) that would normally be oxidized to carbon dioxide and water during oxidative metabolism, is transformed instead into lactic acid. Under the influence of the enzyme lacticdehydrogenase, hydrogen is removed from reduced NAD and from solution for this reactin.

$CH_3CO.COOH + NADH + H^+ \quad CH_3CHOH.COOH + NAD$

Lactic acid thus formed diffuses into the interstitial fluid and is carried by the circulation to the liver. Under such circumstances the muscle builds up a so called oxygen debt, which is paid back by heavy, prolonged breathing when the strenuous physical activity ceases. During the resting phase, when oxygen becomes available, $4/5^{th}$ of liver lactic acid is resynthesized into glycogen.

$2C_3H_6O_3 \longrightarrow H_2O + C_6H_{10}O_5$

Lactic acid Glycogen

at the expense of ATP derived from the oxidation of remaining $1/5^{th}$ of lactic acid.

$2C_3H_6O_3 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$

The liver glycogen thus formed may be stored or may provide glucose to the blood from which muscle glycogen may again be formed. This series of reactin is illustrated in figure (Cori's cycle).

5. Myokinase actin in the muscle

A further source of ATP in muscles is attributed to the presence of an enzyme myokinase. This muscle enzyme catalyze the transfer of a high-energy phosphate from one molecules of ADP to another to form ATP and adenosine monophosphate (AMP).

2ADP ATP + AMP

5.2.9. Reference books

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- W.S. Hoar

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EXPECTED QUESTIONS :

1. Describe the functions of muscles.
2. What are the chemical constituents of the skeletal muscle?
3. Write in detail the Biochemical events that takes place in the process of muscle contraction.

Lesson-5.3

ENDOCRINE SYSTEM

Objective:

To study the structure and functioning of the endocrine system in vertebrates

CONTENTS

5.3.1 Introduction

In living organisms various activities performed by cells, tissues and organ systems in the body are well coordinated by the interplay of different types of communication systems, which include a) Neural b) Endocrine and c) Neuroendocrine d) Paracrine and e) autocrine. In this chapter we discuss mainly the Endocrine and Neuroendocrine systems as many of the body's chemical messenger systems interact with one another to maintain homeostasis.

Endocrine systems are responsible for the synthesis and secretion of Hormones, which act as chemical messengers. The hormones are carried by the circulatory system to the cells in various locations throughout the body where they bound with the receptors on the cells and initiate reactions. Some of the hormones affect only specific tissues called the target tissues, since these tissues only possess the receptor for that hormone. e.g. the hormone Adreno Cortico Trophic Hormone (ACTH) secreted by the anterior region of the pituitary gland stimulates specifically the adrenal cortex causing it to secrete the adrenocortical hormones. Some of the hormones are general in function, affecting most of the cells of the body e.g. growth hormone, secreted by the anterior region of the pituitary gland, which influences the general growth of the cells. Other hormones act locally often arriving at their site of action by way of a specialized microcirculation.

In association with the nervous system, hormones coordinate and integrate the functions of all the physiological systems.

The endocrine system in animals is constituted of some endocrine glands present as discrete organs e.g. Pituitary, Thyroid, Parathyroid and Adrenal glands. Certain endocrine tissues found in association with other exocrine glands such as Pancreas or within the complex organs such as Kidney, Testis, Ovary, Placenta, Brain and the Gastro intestinal tract .

The endocrine system functions in a well-coordinated manner with the nervous system to maintain a harmonious state with in the body.

In accordance with their active synthetic function, the endocrine secretory cells are characterized by the presence of prominent nuclei and abundant cytoplasmic organelle, such as mitochondria, endoplasmic reticulum, Golgi bodies and secretory vesicles the lysosomes.

Endocrine glands are generally composed of islands of secretory cells of epithelial origin with intervening supporting tissue, which is rich in blood and lymphatic capillaries. The secretory cells discharge their products, into the interstitial spaces from which they rapidly enter into the circulatory system. As these glands do not possess ducts for conducting their secretions, they are also referred to as **ductless glands**. As the hormones function as a chemical messengers they possess the following properties:

a. hormones are formed of small soluble organic molecules
b. they are known to be quite effective even at low concentrations
c. hormones are transported in the blood circulation from the site of secretion
d. the organ system which the hormone effects often is called the target tissue and is different from the one where is it is produced
e. hormones are very specific in their function as the specific receptor molecule present in the target cells receive them.

ENDOCRINE GLANDS

In vertebrate animals the endocrine glands are located in various locations in the body. The chief function of these glands is to secrete hormones which act upon the target cells producing desired effect. The location, structure and functioning of each endocrine gland is presented hereunder.

A. PITUITARY GLAND

The **pituitary gland** also known as the **hypothysis** is a pea-sized small rounded structure hanging from the base of the brain lying immediately the third ventricle in a bony cavity called the **sella turcica** in the base of the skull.

The gland is divided in to the anterior and posterior parts, which have different embryological origin, and is reflected in their structure and function.

Structure :

i. Anterior pituitary :

The anterior pituitary is formed as the epithelial upgrowth of the roof of the primitive buccal cavity known as **Rathke's pouch**.

This is also called as the adenohypophysis.

It represents the specialized glandular epithelium covering the anterior portion of the posterior pituitary.

The adenohypophysis shows a cleft, the vestigial lumen of the Ratchke's pouch.

This vestigial cleft divides the major part of the anterior pituitary from a thin zone of tissue lying apposed to the posterior pituitary known as **pars intermedia**.

The secretary cells of the anterior pituitary have been recognized as **chromophils and chromophobes** based on their affinity for the histological stains. The chromophils are further identified into acidophils and basophils according to the staining properties.

Recent studies using Immunohistochemical techniques, based on the nature of the secretory product, the secretory cells have been recognized under five types; a) **somatotrophs,** the cells responsible for the secretion of growth hormone b**) mammotrophs** (lectotrophs): the prolactin secreting cells, c**) corticotrophs** : the adrenocorticotrophic hormone (ACTH) secreting cells d) **thyrotrophs** : cells secreting thyrotrophin(TSH) and e) **gonadotrophs**: cells responsible for the secretion of FSH and LH. The somatotrophs and monotrophs are acidophils while the thyrotrophs, gonadotrophs and corticotrophs are basophils.

ii. Posterior pituitary*:*

The posterior pituitary also called the **neurohypophysis** or **pars nervosa,** is derived from the downward growth of the nervous tissue from the hypothalamus, to which it remains attached by the pituitary stalk This part originates as an extension of the brain and does not synthesize the hormones but only stores and releases them.

Posterior pituitary contains the non-myelinated axons of the neurosecretory cells and the cell bodies of which are located in the hypothalamus. The neurosecretory axons are supported by cells called **pituicytes**, which are similar in structure and function to the neuroglial cells of the Central Nervous System.(CNS).

Hormones secreted by the pituitary :

The type of secretions and the mode of formation of the secretary products differ greatly between the anterior and posterior parts of the pituitary gland. The anterior pituitary secretes both

the trophic and direct acting hormones A trophic hormone is one, which stimulates other endocrine glands to release their hormones. e.g. **thyroid stimulating hormone (TSH)**; **adrenocorticotrophic hormone(ACTH)** and the **gonadotrophic hormones, follicle stimulating hormone (FSH)** and **leuteinising hormone (LH).**. The tropic hormones are produced and stored by the anterior pituitary. These six trophic hormones pass into the blood vessels that leave the pituitary gland and exert their effects on the specific target organs distributed throughout the body.

These include growth hormone, prolactin, FSH, LH. TSH and ACTH. The release of the GTH and prolactin is stimulated and also is inhibited by the hypothalamus, whereas the release of the other four is regulated by the negative feed back of hormones from the target glands acting as receptors in the hypothalamus and anterior pituitary.

These six types of hormones stimulate the release of the target gland hormones and as the levels of these rises they inhibit the secretion of the hypothalamus. and the pituitary hormones. When the blood levels of these target hormones fall below a certain level inhibition of the Pituitary and Hypothalamus ceases allowing increased secretion from these glands. This is an example of negative feed back mechanism. The direct acting hormones are **Growth hormone** (GH) and **Prolactin** (Recently, it was established that prolactin exhibits a trophic action on the endocrine tissues of the ovary in some animals).

The posterior pituitary secretes two hormones, **antidiuretic hormone (ADH)** also called **vasopressin** and **Oxytocin,** both of which act directly on the non- endocrine tissues. ADH is synthesized in the neurone cell bodies of the supraoptic nucleus while the oxytocin is synthesized in the neurone cell bodies of the paraventricular nucleus of the hypothalamus. These hormones pass down the axons of the hypothalamohypophysial tract, through the pituitary stalk, to the posterior pituitary where they are stored in the distended terminal parts of the axons. Since the process involves both the nervous and endocrine system, the response is called neuroendocrine response. They result in nuroendocrine reflexes - a type of behavioral pattern. Release of these posterior pituitary hormones is controlled directly by the nerve impulse passing down the axons from the hypothalamus—a process that is referred to as **neurosecretion**

Nerve terminals from the specialized neurosecretory cells release two distinct groups of chemical substances known as releasing factors and inhibiting factors into the blood capillaries at the hypothalamus end of the portal system. These pass to the pituitary-end where they cause the release of the six types of hormones known as trophic hormones. The trophic hormones are produced and stored by the anterior pituitary gland. These six hormones pass into blood vessels that leave the pituitary gland and exert their effects on the specific target organs distributed throughout the body. These include the growth hormone, prolactin, FSH, LH, TSH and ACTH.

Hypothalamic control of the anterior pituitary secretion is mediated by specific hypothalamic releasing hormones e.g**. thyroid stimulating hormone releasing hormone (TSHRH).** Exceptions to this rule are prolactin secretion, which is under the control of **dopamine** and secretion of growth hormone which is controlled by releasing and inhibitory hormones.

These releasing and inhibitory hormones are conducted from the median hypothalamic eminence to the anterior pituitary by a unique system of portal veins (the pituitary portal system)

The **pars intermedia** of the pituitary gland synthesizes and secretes **melanocyte stimulating hormone (MSH)**, which functions in maintenance of the skin colour in the animals.

B. HYPOTHALAMUS :

Hypothalamus is situated at the base of the fore brain, immediately beneath the thalamus and is present above the pituitary gland. It plays a dominant role in collecting information from the other regions of the brain. The information is passed to the pituitary gland, which directly or indirectly regulates the activity of the other endocrine glands.

Hypothalamus contains distinct regions of nerve cells whose axons terminate on blood capillaries in the hypothalamus and the posterior part of pituitary. Hypothalamus is part of the brain that possesses cluster of neurosecretary cells. These neurosecretary cells synthesize peptide hormones and store them. Many physiological activities are regulated through nervous control, by the nerve impulses passing from the hypothalamus along the neurons of the autonomic nervous system, resulting in involuntary-reflex control, of these processes. Control of endocrine secretion lies in the ability of the hypothalamus to monitor the metabolites and hormone levels in the blood. A metabolite is any molecule taking part in metabolism eg. Glucose. The information relayed by the neurons passes through specialized neurons called the neurosecretory cells. All nerve cells release a chemical, at their terminal synapse referred to as the neurotransmitter

C. THYROID GLAND

The **thyroid gland** is unique in that it stores large amounts of hormone in an inactive form, in extracellular compartments in the centre of the follicles, in contrast to other endocrine glands, which store only small quantities of hormone in intracellular sites. Thyroid gland is located in the neck region, in the lobes present on each side of the trachea and larynx connected by a band of tissue, and is enveloped by a fibrous capsule from which fine collagenous septa extend into the gland dividing into distinct lobules. The major portion of the gland develops from the epithelium, down growth of the epithelium in the mouth cavity during the foetal development, while the calcitonin- secreting cells are derived from the ultimobranchial element of the fourth branchial pouch in the foetus. It is made up of hundreds of thousands of tiny follicles- the functional units, which are about 0.1 mm in diameter. Each follicle is a hollow spheroidal structure composed of a single layer of cuboidal epithelial cells bounded by a basement membrane. These cells secrete the hormones **T3** and **T4**. They become columnar in shape and develop microvilli on inner surface when the gland is activated by **thyroid stimulating hormone (TSH)** from the anterior pituitary.

The thyroid gland produces three active hormones **triiodothyroxin** (T3), **thyroxin** (T4) and **calcitonin.** T3 and T4 regulate metabolic rate, growth and development of the organism while calcitonin is involved in the regulation of calcium levels in the blood. The main effect of the

thyroxin is to control the basal metabolic rate. Protein synthesis is stimulated by both the Thyroxin and Growth hormone, leading to an increase in growth, particularly of the selected systems.

The levels of the T4 circulating in the blood controls its release from the thyroid gland by negative feed back mechanisms involving the hypothalamus and the anterior pituitary. If excess of T4 is present in the blood it switches off its own production by switching off the production of the **thyroxin releasing hormone** (TRH) by the hypothalamus and TSH by the anterior pituitary. This is referred to as the feed back mechanism.

Over activity or under activity of the thyroid produces a swelling in the neck in human beings, referred to as Goiter. The symptoms include an increase in the heart and ventilation rate and body temperature. Extreme hyperthyroidism is termed the thyrotoxicosis and is associated with the increased excitability of the cardiac muscle. Hypothyroidism is the result of deficiency of enzyme system in hormone production, due to lack of TSH production in the anterior pituitary or iodine deficiency in the diet. Thyroxin deficiency at birth leads to poor growth, mental retardation, and a condition known as cretinism. The deficiency at a later period in life gives rise to a condition, myxoderma. The symptoms include reduction in metabolic rate, accompanied by decreased O_2 consumption, ventilation, heart rate and body temperature. Mental activity becomes slower, weight increase due to formation and storage of semi fluid under the skin. Face of the individual becomes puffy, swelling of the tongue, rough skin and loss of hair from the scalp.

D. PARATHYROID GLAND :

Parathyroid glands are small oval endocrine glands closely associated on each side with the thyroid gland. These glands are derived embryologically from the third and fourth branchial (pharyngeal) pouches. They are usually found embedded in the thyroids. The thin fibrous capsules of the parathyroid gland gives rise to delicate septa, which divide the cells into nodules of secretory cells. The glandular cells are of two types: the principal or chief cells and Oxyphil cells. These cells are arranged in the form of clusters, ribbons or glands.

The parathyroid gland regulates the serum calcium and phosphate levels via parathyroid hormone, called the **paratharmone (PTH)**. The parathormone increases the serum calcium levels in three ways: a) by direct action on bone, increasing the rate of osteoclastic resorption and promoting breakdown of the bone matrix b) by direct action on the kidney, increasing the renal tubular reabsorption of calcium ions and inhibiting the resorption of phosphate ions from glomular filtrate and c) by promotion of the absorption of calcium from the small intestine; this effect involves Vitamin D.. The activity of the parathyroid gland is controlled by the simple negative feed back mechanism.

Hyper activity of the gland is known to reduces the calcium levels in the plasma and tissues due to calcium excretion in the urine. It also reduces the rate of excretion of phosphate and as a result there is an increase of phosphate levels in the plasma membrane.

E. ADRENAL GLANDS

Adrenal glands (ad, to; renes, kidney) are a pair of glands located just above each kidney. Each gland is composed of two types of cells of different origin and these cells function independently. The outer region commonly called the **cortex** forms about 80% of the gland and the inner region the **medulla,** is closely linked to the nervous system.

i. Adrenal cortex:

The adrenal cortex is distinguishable into three histological zones named according to the arrangement of the secretory cells.: **Zona glomerulosa** in which the cells are arranged in rounded clusters, **Zona fasciculata** cells arranged in parallel cords at right angles to the capsules and **zona reticularis,** in which the small closely packed cells arranged in irregular cords. The Zona glomerulosa secretes the mineralocorticoid hormones principally aldosterone. It acts directly on the renal tubules to increase sodium and therefore water retention thus increasing extracellular fluid volume and the arterial blood pressure. Aldosterone secretion is independent of ACTH. The Zona fasciculata secretes glucocorticosteriod hormones, principally **Cortisol**, which has wide ranging metabolic effects. It raises the blood glucose levels and increase cellular synthesis of glycogen. Cortisol secretion is controlled by the hypothalamus via the anterior pituitary hormone ACTH. By this means it promotes the secretion of glucosorticoids, which adjust body metabolism. The Zona reticulata secretes small quantities of androgens and glucocorticoids. All these steroid hormones are formed from a molecule called the cholesterol, which is synthesized by the cortex and also taken up from circulation following the absorption from the diet. Steroids diffuse through the cell membranes and attach to the cytoplasmic receptor proteins. These pass into the nucleus, attach to specific areas of the chromosome and switch on or of certain genes.

ii. Adrenal medulla:

Adrenal medulla forms the centre of the adrenal gland and is richly supplied with nerves and blood vessels. It is supplied by long cortical secretory arteries composed of closely packed clusters of secretory cells. The medullary capillaries drain in to the central vein of the medulla. The secretory cells are exposed to fresh supply of arterial blood rich in adrenocorticosteroids, which are known to influence the synthesis of adrenaline by the medulla

It secretes catecholamine hormones **nonadrenaline** and **adrenaline,** under the direct control of the sympathetic nervous system. The adrenal medullary hormones are stored in the membrane-bound dense core cytoplasmic granules and are released only in response to nervous stimulation. Secretion of catechelamines by the sympathetic nervous system. Acute physical and psychological stresses in human beings initiate release of adrenal medullary hormones. The released catecholamines act on adenergic receptors present throughout the body particularly in the heart, blood vessels bronchioles, visceral muscle and skeletal muscle producing physiological effects. Adrenaline promotes glycogenolysis in the liver and skeletal muscles during stress situations.

E. PANCREAS :

Pancreas is located associated with the intestines in vertebrates. Pancreas has both exocrine and endocrine functions. It is a major exocrine gland. The bulk of the gland is made up of cells which surround the numerous branches of the pancreatic duct. A ring of cells called acinus surrounds each branch. These acinar cells are exocrine cells. They secrete the pancreatic juice. The secretary endocrine cells with rich supply of blood become clustered and are known as **islets of Langerhans** after its discoverer Paul Langerhans in 1868**.** These contain a small number of large cells known as alpha cells and many smaller cells known as beta cells scattered throughout the exocrine glandular tissue and the blood capillaries. The islets vary in size. They contain a variety of cell types each is responsible for secretion of one type of hormone. The endocrine pancreas contains secretory cells of several types. Traditionally the **glucagons, insulin and somatostatin** secreting cells have been designated as **alpha, beta** and **delta** cells respectively.

The important secretary products of the endocrine pancreas are **insulin** and **glucagons**. They play an important role in carbohydrate metabolism. The hormone insulin was isolated by Bauting, Best and Maclod in 1921. Insulin is known to be secreted by the beta –cells and the glucagons by alpha-cells. These two hormones function antagonistically on the glucose level in the blood. **Insulin** is known to be released in response to a rise in blood glucose level (> 90 mg per 100 cc of blood) It is carried in the plasma, bound to beta globulin Insulin promotes the uptake of glucose by most cells particularly those of liver, skeletal muscle and adipose tissue, thus lowering the plasma glucose concentration. Production of insulin is regulated by a negative feed back mechanism. A rise in blood sugar is detected by beta cells in the pancreas, which in response produce more insulin. As the blood sugar gets lower, beta cells reduce the output of the insulin. A deficiency of insulin production leads to a disorder known as **diabetes mellitus**. **Glucagon** is released in response to fall in blood glucose level below normal. Its role is to increase blood glucose level and its main target is liver. Glucagon stimulates the conversion of glycogen to glucose and the process is called **glycogenolysis**. It also functions in the break down of proteins and fats to glucose and conversion of lactic acid to glucose-called **glucone ogenesis**. Glucagon has no effect on the muscle glycogen. Regulation of glucagons secretion is similar to that of insulin, but here alpha cells are involved and they respond to falling blood glucose levels.

Four other types of endocrine cells are known to be present in the islets of Langerhans in the Pancreas, scattered, single or in smaller groups between the exocrine acini and also along the ducts. Their secretory products include **somatostatin** (inhibits insulin and glucagons secretion) **vasoactive intestinal peptide (VIP) and pancreatic polypeptide (PP)**. Another cell type, the **enterochromoffian cell (EC)**, appears to secrete several different peptides including **motilin, serotonin** and **substance P**.

F. PINEAL GLAND :

The **Pineal gland** is a small organ 6-8 mm long represents an evagination of the posterior part of the of the roof of the 3rd ventricle in the mid ventral line of the brain. The pineal is connected to the brain via a short stalk containing nerve fibres, many of which communicate with the hypothalamus. In reptiles and other lower vertebrates, the penial lies at or near the skin surface

and functions as a photoreceptor organ secreting the hormone melatonin, which lightens the skin colour by acting on melanophores. The pineal consists of two main cell types: Pinealocytes and neuroglial cells. **Pinealocytes** are modified neurons while the neuroglial cells are similar in structure to the astrocytes of the CNS

Melatonin synthesis from the amino acid **Tryptophan** is induced by darkness and inhibited by the light. Information received by the retina of the eye in the form of light is converted by Pineal into a chemical signal melatonin. It is now known that melatonin regulates the circadian rhythms of the body and also functions on seasonal reproduction in animals, effect the ageing and regulates the immune system.

G. GASTROINTESTINAL ENDOCRINE SYSTEM :

Neuroendocrine cells are found scattered in the gastrointestinal tract and in the pancreatic and bilary ducts. These cells are known to secrete hormones, which include **Gastrin, secretin, CCK. Serotonin, enteroglucagon. Somatin, substance P, vasoactive intestinal peptide(VIP), bombesin,gastric inhibitory polypeptide(GIP), motilin and pancreatic polypeptide(PP).**. These hormones collectively regulate and coordinate most aspects of gastroinstinal activity in close association with the autonomic nervous system. While some of the hormones are true endocrine hormones that act on target organs at a distance, others are locally acting mediators known as paracine hormones. Some act by neurotransmitter activity and are called the neuroendocrine hormones and indeed they act as neurotransmitters with in the **Central Nervous System.**

F. RESPIRATORY ENDOCRINE SYSTEM :

Similar to the ones in the gastrointestinal tract, the lower respiratory tract contains scattered peptide and amine secreting endocrine cells, which are involved in local or autonomic ally mediated regulation of respiratory tract function particularly among children. These endocrine cells are scattered individually in epithelium and produce a variety of secretory products such as **serotonin, calcitonin, bombesin** and **leu-enkephalin**.

TABLE MAJOR ENDOCRINE GLANDS HORMONES AND FUNCTIONS

Gland	Hormone	Function of hormone	Means of Control
Posterior pituitary (neurohypaphysis)	Antidiuretic hormone (ADH) vasopressin)	increases water absorption from kidney tubules; raises blood presure	Synthesized in hypothalamus released from neurohypophysis
	Oxytocin	Stimulates contractions of pregnant uterus, milk ejection from breasts after childbirth	Synthesized in hypothalamus released from neurohypophysiss
Anterior pituitary (adenolypopliysis)	Growth hormones (GH) somatotropic hormone, STH)	Stimulates growth of bone muscle; promotes protein synthesis, fat mobilization, slows Carbohydrate metabolism	Hypothalamic growth, hormone releasing hormone GHRH; growth-hormone inhibition bornone (CHH)
	prolaction	Promotes beast development during pregnancy,milk production after childbirth.	Hypothalamic prolactin-inhibiting hormone (PIH): prolactin-releasing hormone (PRH)
	Thyroid stimulating hormone (TSH)	Stimulates production and secretion of thyroid hormones.	Hypothalamic thyrotropinreleasing hormone (TRH)
	Adrenocotropic hormone (ACTH)	Stimulates production and secretion of adrenal cortex steroids.	Hypothalamic corticortropinreleasin g hormone (CRH)
	Luteinizing hormone (LH)	Female: Stimulates development of corpus lutetium, release of acolyte, production of progesterone and estrogen. Male: stimulates secretion of testosterone, development of	Hypothalamic gondadotropin releasing hormone (GnRH)

		interstitial tissue of testes.	
	Follicle-stimulating hormone (FSH)	female: stimulates growth of ovarian follicle, ovulation, Male: stimulates sperm production	Hypothalamic gonadotropinreleasin g hormone (GnRH)
	Melanocyte stimulating hormone (MSH)	Apparently involved with skin color (melanocytes) in combination with ACTHthe role uncertain.	Uncertain
Thyroid (follicular cells)	Thyroid hormones: thyroxin (T4), tridothyronice (T3)	Increase metabolic rate, sensitivity of cardiovascular system to sympathetic nervous activity; affect maturation, homeostasis of skeletal muscle.	Thyroid stimulating hormone (TSH) from adenohypophysisthe TSH regulated by hydrotropic _ releasing hormone (TRH) glom nosing
Thyroid (Para follicular cells)	Calcitonin	Lowers blood calcium and phosphate concentrations; acts on bone, kidney, and other cells.	Blood calcium concentration
Parathyroid	Para hormone (PTH; parathyroid hormone)	Increase blood calcium concentration, decreases blood phosphate level; acts on bone, intestine, kidney, and other cells.	Blood calcium concentration
Adrenal medulla	Epinephrine (adrenaline)	Increase heart rate; blood pressure; regulates diameter of arterioles; stimulates contraction of smooth muscle. Increase blood glucose concentration.	Sympathetic nervous system

	Nor epinephrine (noradrernaline)	Constricts arterioles increases metabolic rate	Sympathetic nervous system

Gland	Hormone	Function of hormone	Means of control
Adrenal cortex	Glucocorticoids, manly cortical (hydrocortisone), corticosterone, 11-deoxycorticosterone	Affect metabolism of all nutrients; regulate blood glucose concentration anti-inflammatory; affect growth; decrease effects of stress, ACTH secretion	Corticotrophin-releasing hormone (CRH) from hypothalamus, ACTH from ademohypophysis
	Mineralocorticord, mainly aldosterore	Control sodium retention and potassium loss in kidney tubules	Angiotensin if, blood potassium concentration
	Conadocorticoids (adrenal sex hormones)	Sight effect on ovaries and testes.	ACTH
Pancreas beta cells in pancreatic idets)	Insulin	Lowers blood glucose by facilitating glucose transport across plaza membranes and increasing givcogen storage the affects muscle, liver, adipose tissue	Blood glucose concentration
Pancreas	Glucose	Increase blood glucose concentration	Blood glucose concentration
Ovaries (follicle)	Estrogens	Affect development of sex organs and female characteristics, initiates development of ovarian follicle.	Follicle-stimulating hormone (PSH)
Ovaries (corpus frustum)	Progesterone,	Influence menstrual cycle the stimulates growth of uterine	Uateinizing hormone (LH)

		wall, maintains pregnancy	
Placenta	Estrogens, progesterone, human chariots gonadotropin (hCC)	Maintains pregnancy	Uncertain
Tests	Androgens, mainly testosterone	Affect development of sex organs and male characteristics, ads sperm production,	Luterinizing hormones (LH)
Thymus	Thymuses alpha, thymuses B1, to B2, thymoponetin 1 and 11, thymes humeral factor (THF), thymoslimulin, factor thymes serum (FTS)	Help develop T cells in thymus, maintain T cells in other lymphoid issue, involved in development of some b cells into anthodia-producing plasma cells.	Uncertain
Digestive system	Secreting	Stimulates release of pancreatic juice to neutralize stomach acid.	Acid in small intestine
	Gastric	Produces digestive enzymes and hydrochloric acid in stomach	Food entering stomach
	Cholerystokinin (CCK)	Stimulates release of pancreatic enzymes, gallbladder contraction	Food in duodenum
Heart	Atnopeptin tatrial natriuretic factor, (ANF)	Helps maintain balance of fluids, electrolytes, Decreases blood pressure and volume	Salt concentration, blood pressure, blood volume

1.2.10 Hormones as major vehicles for intercellular communication

Intercellular communication is a result of the signals sent and signals received by the cells. Most cells produce signals in the form of either specific cell surface receptors or secreted molecules. Some signals are effective only if the signaling cell is in direct contact with the signaled cells. Other signals are effective only on cells that are near by.

Hormones produced by the specialized endocrines constitute the best-studied signals. The hormones are effective over a long range. Each cell is programmed to respond to a select group of hormonal signals in a specific way. The responding cell should have the receptor that interacts with the signaling molecule otherwise the signal is ignored. Further the type of response evoked by a signal-sensitive cell depends upon the way in which the signal binding receptor is hooked to the other signal-relay chains in the cells. The various aspects of hormone-receptor interaction and the direct biochemical consequences of these interactions and the ways in which the hormonal circuits are regulated are of prime importance.

In all vertebrate animals, hormones belong to the following chemical groups a. Polypeptides b. derivatives of Amines . c. Steroids d. Fatty acids. Hormones that are released by the presence of another circulating hormone are usually under the control of an endocrine gland, a small quantity of the initial hormones becomes amplified at each stage in the pathway and this phenomenon is referred to as 'cascade effect'

Polypeptide hormones:

All peptide hormones that contain signal peptides; direct them in to the lumen of the endoplasmic reticulum. Polypeptide hormones are generally stored in secretory granules after their passage through the endoplasmic reticulum and Golgi apparatus. Release of these hormones into the blood stream is accomplished by fusing of the secretary granule membranes with the plasma membrane. Polypeptide hormones are removed from the circulation by serum and cell surface proteases, by endocytosis, followed by lysosomal degradation and by glomular filtration in the kidney

Amino acids and their derivatives:

The hormones Thyronine (T4), and triiodothyronine (T3) and the epinephrine also called the adrenaline are amino acid derivatives. These are mostly associated with carrier proteins in the serum. These carrier proteins are called Thyrosine- binding globulin.

Steroid hormones:

Steroid hormones Cortisol, Corticosterone, aldosterone, and Testosterone are the derivates of the Cholesterol. These are taken up by the liver and metabolized to inactive forms, which are extracted in to the bile duct or back into the blood for removal by the kidneys. These are associated with the carrier proteins transcortin for cortisol and other sex- steroid binding proteins.

Lesson –5.4

ROLE OF HORMONES IN REPRODUCTION

Objective:

To understand the role of hormones in reproduction in vertebrate animals

CONTENTS

A. The process of reproduction

B. Action of different hormones in reproduction and parental care

C. Harmones in invertebrato organisms.

A. The process of reproduction:

In animals the process of reproduction is controlled by different hormones. In animals the hormones start acting on the gonads when the animal becomes an adult and is capable of participating in the process of reproduction. The time of onset of maturity differs in different animals. The attainment of puberty is also under the hormonal control.

B. Action of different hormones in reproduction and parental care:

The endocrine glands through production of hormones are concerned with coordinated functioning of the reproductive glands for a successful reproduction of a species. The activities ranging from development and maturation of eggs and sperms and care of the young by the parents involve complex endocrine functions that affect the development of each step for proper synchronization of events and the associated behavior of the mates.

In most animals the season for reproduction is adjusted to the most favourable time of the year. In many vertebrate animals, in temporate regions of the world, spring and summer are the seasons ideal for reproduction because that is the most favourable time of the year for the availability of food in nature and the favorable environmental temperatures. An important environmental clue is the length of the day and night this light cycle is also termed as the **photoperiod**.

There is good evidence to show that the effect of the light in animals is transmitted from the pineal gland to the hypothalamus. The hypothalamus in turn controls the adenohypophysis and the entire reproductive process. The Hypothalamus through the appropriate releasing hormones

stimulates the adenohypophysis to release the gonadotrophins: **follicle stimulating hormone (FSH)** and **leutinising hormone (LH)**. FSH is known to stimulate the growth of the ovarian follicles and their metabolism; while LH stimulates the persistence of the follicle. **Estrogens** produced by the ovarian follicle cells prepare themselves for reception and implantation of the fertilized egg and trigger other secondary changes in the female reproductive organs. Towards the end of the pregnancy in mammals, neurohypophysis releases the hormone **Oxytocin** which causes the contraction of the uterus and the birth of the young. Preceding this the hormone **relaxin**, a polypeptide originating from the **corpus luteum** causes relaxation of the fused bones of the pelvis. Also relaxin is known to inhibit the contractility of the uterine muscle, to prevent premature birth. In addition the corpus luteum secretes progesterone and oestrogens which influence the menustral cycle, stimulates the growth of the uterine wall and maintain the pregnancy. Placenta, the organic connection between the developing embryo and the uterine wall of the mother is known to secrete estrogens, progesterone and human chorionic yondobripin which help in maintenancy of the pregnancy.

In males the tests produces androgens mainly testosterone which affect development of sex organs and male characteristics and also in sperm production

In mammals the production of milk in females after giving birth to individuals is stimulated by the hormone **prolactin**, released from the adenohypophysis. In pigeons and penguins **prolactin** is known to promote a secretion from the crop, referred to as pigeons milk that is fed to the young by regurgitation.

C. Hormones in invertebrate organisms :

In the more highly organized invertebrates physiological functions are under the control endocrines and the Nervous control. As in vertebrates and endocrine system produces hormones that control slower processes such as growth, maturation and many other metabolic functions. In certain groups of organized invertebrates specialized neurosecretory cells and tissues are present. Neurosecretory organs are groups of neurons that are the source of secretion. These cells have nerve fibers in which the secretions are transported, which terminates in a vascular structure. Together they form a neurohaemal organ. where the secreted product is stored and released.

In all highly organized phyla, neurosecretory systems are important for control and operation of endocrine secretory mechanism. Neurosecretory systems are important in annelids and crustaceans. They are involve a in the control of reproductive metabolism, molting and pigmentation of the outer skin. The presence of organs of internal secretion, the endocrines, have been clearly demonstrated and their functioning has been reasonably understood in groups such as gatropods (Cephalopoda),annelids ,crustaceans, insects and tunicates. The invertebrate hormones differ in chemical structure. The effects they produce are different when compared to the vertebrate hormones.

Among insects, hormones play an important role in the processes such as growth, molting, pupation and metamorphosis. The process of molting is stimulated by a hormone, **Ecdyosone** also called the moulting hormon, secreted by the Prothoracic glands, located in the thoracic region of the insects. The prothoracic glands in turn are stimulated by the hormone secreted by the specialized neurosecretory cells located in the brain of the insect. Corpora allata, a tiny cluster of cells located just behind the brain in insects, secretes a hormone called the **Juvenile hormone**. The juvenile hormone determines whether the new cuticle developed below the old one will have nymphal characters or not. When the quantity of the Juvenile hormone declines at the nymphal phase, the development of characters such as the development of wings, takes place after the moult. In the last molt the imago emerges, as the juvenile hormone is absent. Ecdysone is needed for each molt and its effects are merely modified by the juvenile hormone. The chemical structure of the ecdysone is that of a steroid while that of the juvenile hormone is similar to that of terpenes.