NEW SYLLABUS

PG TRB
ZOOLOGY

ANIMAL PHYSIOLOGY

Professor Academy

PG TRB
ZOOLOGY

UNIT - V

ANIMAL PHYSIOLOGY

Professor Academy

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Feel free to mail us at **feedback@professoracademy.com**

INDEX

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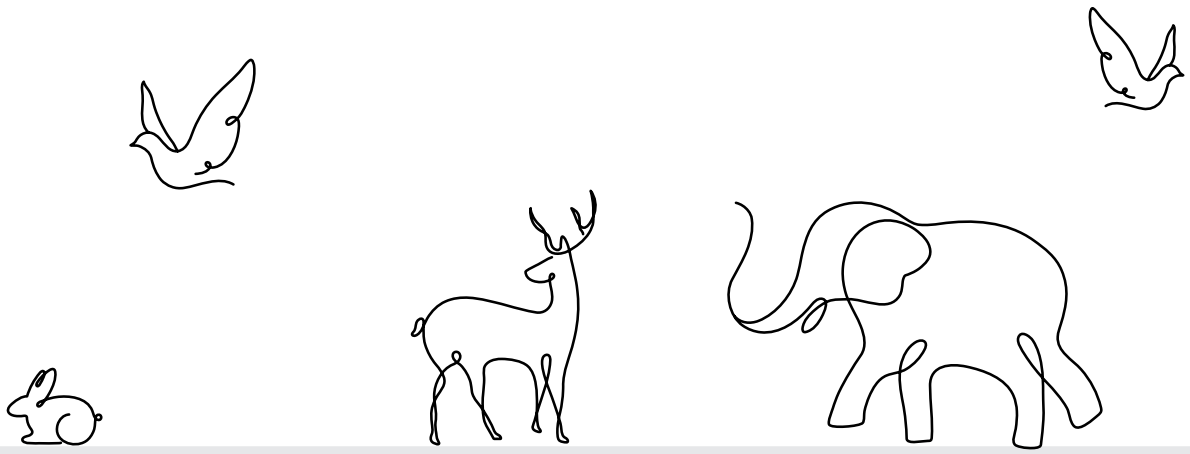

SYLLABUS

ANIMAL PHYSIOLOGY

- System Physiology – Digestion and absorption of Carbohydrates, Proteins, and Lipids, BMR, Nutritional disorders.
- Blood and Circulation – Blood and its composition, function, haemopoiesis and haemostasis, mechanism of blood clotting.
- Cardiovascular system – Structure of myogenic heart, cardiac cycle, pace maker, Pulse pressure and blood pressure, ECG.
- Blood vessels – Arteries, veins and lymphatic vessels.
- Respiratory Physiology – Respiratory structures – Invertebrates, vertebrates – fishes, birds and mammals. Respiratory pigments, Transport of gases, exchange of gases, neural and chemical regulation of respiration.
- Muscle Physiology – Types of muscle cells, ultrastructure of the striated muscle fibre, physiology of muscle contraction.
- Neurophysiology – Central Nervous system, Peripheral and Autonomic nervous system. Structure of Neuron, types, transmission of nerve impulses, action potential, synapse, conduction of nerve impulse across a synapse, neurotransmitters, Neuroanatomy of the brain and spinal cord and Reflex action. EEG.
- Sensory Physiology – Receptors – Photoreceptors, Mechanoreceptors and Gustatoreceptors. Echolocation. Bioluminescence, Mimicry and colouration. Lateral line system in fishes.
- Renal Physiology – Ammonotelism, Uricotelism and Ureotelism process, structure of kidney and Nephron, Mechanism of urine formation, Counter-current principle, micturition, regulation of water balance, electrolyte balance and acid-base balance.
- Thermoregulation and Stress adaptation – Thermoregulation in homeotherms, poikilotherms – acclimation and acclimatization, physical, chemical and neural regulation of body temperature, adaptation to high altitudes, deep sea adaptation.
- Endocrinology – Endocrine glands, mechanism of hormone action – peptide and steroid hormones, membrane receptors and signal transduction. Hormones and diseases, neuroendocrine regulation. Invertebrate hormones.

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CHAPTER 1

CIRCULATORY AND RESPIRATORY SYSTEMS

MODULE 1

SYSTEM PHYSIOLOGY

Digestion of carbohydrates

Among carbohydrates, only the monosaccharide forms are absorbed. Hence, all carbohydrates must be digested into glucose, galactose, and fructose for absorption to proceed.

Enzymes Involved

- a-Amylases (salivary and pancreatic) hydrolyze 1,4-glycosidic bonds in starch, yielding maltose, maltotriose, and α-limit dextrins.
- Maltase, a-dextrinase, and sucrase in the intestinal brush border then hydrolyze the oligosaccharides to glucose.
- Lactase, trehalase, and sucrase degrade their respective disaccharides lactose, trehalose, and sucrose to monosaccharides.
- Lactase degrades lactose to glucose and galactose.
- Trehalase degrades trehalose to glucose.
- Sucrase degrades sucrose to glucose and fructose.

Absorption of carbohydrates

1. Glucose and Galactose

They are transported from the intestinal lumen into the cells by a Na^+-dependent co-transport (SGLT 1) in the luminal membrane. The sugar is transported "uphill" and Na^+ is transported "downhill." They are then transported from cell to blood by facilitated diffusion (GLUT 2). The Na^+–K^+ pump in the basolateral membrane keeps the intracellular [Na+] low, thus maintaining the Na^+ gradient across the luminal membrane.

2. Fructose

Fructose is transported exclusively by facilitated diffusion; therefore, it cannot be absorbed against a concentration gradient.

FACTS CORNER

Chewing your food longer can help break down starches into simpler sugars, making it taste sweeter as you chew.

Fructose, found in fruits, is the sweetest naturally occurring sugar, which explains why fruits taste so delicious.

Contrary to popular belief, sugar doesn't cause hyperactivity; studies show no consistent link between sugar and behavior in children.

Digestion of proteins

Dietary proteins are a source of amino acids that are utilized for the formation of various cellular substances. Mostly, proteins must be broken down into amino acids for absorption. Digestive products of protein can be absorbed as amino acids, dipeptides, and tripeptides.

Both endopeptidase enzymes which degrade proteins by hydrolyzing interior peptide bonds and exopeptidases enzyme **that hydrolyzes** one amino acid at a time from the C-terminus of proteins and peptides are involved in the digestion of proteins. Digestion takes place in the stomach and the small intestine.

Enzymes Involved

Pepsin

Pepsin is secreted in its zymogen form as pepsinogen by the chief cells of the stomach. Pepsinogen is activated to pepsin by gastric H^+. The optimum pH for pepsin is between 1 and 3. Pepsin hydrolyzes proteins into peptones and proteoses. When the pH is >5, pepsin is denatured. Thus, in the intestine, as HCO_3^- is secreted in pancreatic fluids, duodenal pH increases, and pepsin is inactivated.

Pancreatic proteases

The digestion is completed in the small intestine by the action of pancreatic and intestinal juice. The proteases include trypsin, chymotrypsin, elastase, carboxypeptidase A, and carboxypeptidase B. They are secreted in inactive forms that are activated in the small intestine as follows: Trypsinogen is activated to trypsin by a brush border enzyme, enterokinase. Trypsin then converts chymotrypsinogen, proelastase, and procarboxypeptidase A and B to their active forms.

DO YOU KNOW?

The stomach secretes hydrochloric acid with a pH as low as 1, making it strong enough to dissolve metal, though it's kept in check by the stomach lining.

Trypsin, once activated, works like a master switch, activating other enzymes for efficient protein digestion.

Absorption of Proteins

1. Free amino acids

Na^+-dependent amino acid cotransport occurs in the luminal membrane. It is analogous to the cotransporter for glucose and galactose. The amino acids are then transported from cell to blood by facilitated diffusion. There are four separate carriers for neutral, acidic, basic, and imino amino acids, respectively.

2. Dipeptides and tripeptides

They are absorbed faster than free amino acids. H^+-dependent cotransport of dipeptides and tripeptides also occurs in the luminal membrane. After the dipeptides and tripeptides are transported into the intestinal cells, cytoplasmic peptidases hydrolyze them to amino acids. The amino acids are then transported from the cell to the blood by facilitated diffusion.

Digestion of Fats

Fats not being soluble in water by their nature are both difficult to digest and absorb. They do not mix with the stomach or intestinal contents. Lipids include triglycerides, phospholipids, cholesterol, steroids, and fat-soluble vitamins. The first step in lipid digestion is emulsification, which is the transformation of large lipid droplets into much smaller droplets. The emulsification process increases the surface area of the lipid exposed to the digestive enzymes by decreasing the droplet size.

Enzymes Involved

1. In the mouth: Lingual lipases digest some of the ingested triglycerides into monoglycerides and fatty acids. However, most of the ingested lipids are digested in the intestine by pancreatic lipases.

2. Stomach: In the stomach, mixing breaks lipids into droplets to increase the surface area for digestion by pancreatic enzymes.

3. Small intestine: Bile acids emulsify lipids in the small intestine, increasing the surface area for digestion. The hydrophobic products of lipid digestion are solubilized in micelles by bile acids. Pancreatic lipases hydrolyze lipids to fatty acids, monoglycerides, cholesterol, and lysolecithin. The enzymes are pancreatic lipase, cholesterol ester hydrolase, and phospholipase A2.

Absorption of Fats

Micelles bring the products of lipid digestion into contact with the absorptive surface of the intestinal cells. Then, fatty acids, monoglycerides, and cholesterol diffuse across the luminal membrane into the cells. Glycerol is hydrophilic and is not contained in the micelles. In the intestinal cells, the products of lipid digestion are re-esterified to triglycerides, cholesterol ester, and phospholipids and, with apoproteins, form chylomicrons. Chylomicrons are transported out of the intestinal cells by exocytosis. Because chylomicrons are too large to enter the capillaries, they are transferred to lymph vessels and are added to the bloodstream via the thoracic duct.

KNOW MORE!

A single pound of body fat stores roughly 3,500 calories, enough energy to fuel a person for a marathon!

Without bile, fats would float in your digestive tract like oil in water, making digestion nearly impossible.

About 60% of the human brain is composed of fat, making dietary fats essential for brain health and function.

BMR:

Definition of BMR:

Basal metabolic rate is the energy released when the subject is at complete mental and physical rest i.e. in a room with comfortable temperature and humidity, awake and sitting in a reclining position, 10-12 hours after the last meal. It is essentially the minimum energy required to maintain the heart rate, respiration, kidney function etc.

The B.M.R. of an average Indian man is 1750-1900 Kcal/day. In terms of oxygen consumption**,** it would amount to about 15 litres/hr. Heavily built persons have higher BMRs, but the BMR per unit body weight is higher in the smaller built individuals ex. Although the BMR of a man as given above is higher than that of a boy of 15 kg body weight that spends about 800 Kcal/day for its basal metabolism, the BMR per kg/day of man is about 30 Kcal, while that of the boy is about 53 Kcal/kg/day.

The variable that correlates most with the BMR is the surface area of the body. Thus in the case of both boy and man, the BMR is around 1000 Kcal/m^2 body surface/day.

In the case of human beings body surface area can be calculated by the following formula:

$$S = 0.007184 \times W^{0.425} \times h^{0.725}$$

Where

S = surface area in sq metres

W = body weight in kg and

H = height in cm

DO YOU KNOW?

People living in colder climates tend to have higher BMRs due to the extra energy needed to maintain body temperature.

Even at rest, the brain uses about 20% of your body's energy, meaning you're burning calories even while dreaming.

Factors Influencing BMR:

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

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

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

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

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

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

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

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

8. Body temperature/health: For every increase of 0.5° C in the internal temperature of the body, the BMR increases by about 7 percent. The chemical reactions in the body occur more quickly

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

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

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

11. Exercise: Physical exercise not only influences body weight by burning calories, it also helps raise the BMR by building extra lean tissue. (Lean tissue is more metabolically demanding than fat tissue.) So more calories are burnt even when sleeping.

12. Pregnancy: The BMR is not changed during pregnancy. The higher value of BMR in late pregnancy is due to the BMR of the foetus.

Significance of BMR:

- The determination of BMR is the principal guide for the diagnosis and treatment of thyroid disorders.
- If BMR is less than 10% of the normal, it indicates moderate hypothyroidism. In severe hypothyroidism, the BMR may be decreased to 40 to 50 per cent below normal.

BMR aids in knowing the total amount of food or calories required to maintain body weight.

The BMR is low in starvation, undernutrition, hypothalamic disorders, Addison's disease and lipoid nephrosis.

The BMR is above normal in fever, diabetes insipidus, leukaemia and polycythemia.

Nutritional Disorders

There are two types of nutritional disorders overnutrition and undernutrition. The under-nutrition, also called malnutrition, is characterised by nutritional deficiency which may be both qualitative and quantitative. The nutritional deficiency of a nutrient for a long period causes structural and functional disorders of some body parts. Such disorders caused by undernourishment are called diet deficiency diseases.

According to a report of ICMR (Indian Council for Medical Research), nearly 77 per cent of children between one and five years of age in rural areas and 79.3 percent of them in slums in India suffer from mild to severe malnutrition. In India, Uttar Pradesh (2012 Report) has the maximum number of people suffering from malnutrition.

It shows that the physiological fuel value of 1 gram of fat is about 2.5 times than that of glucose so the fats are called concentrated fuels.

PEM/ Protein-energy Malnutrition

PEM or Protein-energy malnutrition (PEM) may affect large sections of the population during drought, famine, etc. This happened in Bangladesh during the liberation war and in Ethiopia during the severe drought in the mid-eighties. PEM affects infants and children.

It is of two types:

Marasmus

It is produced by a simultaneous deficiency of proteins and calories. It is found in infants less than a year in age if the mother's milk is replaced too early by other foods which are poor in both proteins and caloric value. This often happens if the feeding mother has a second pregnancy or childbirth when the older infant is still too young.

Kwashiorkor

It is produced by protein deficiency unaccompanied by calorie deficiency. It results from the replacement of mother's milk by a high calorie-low protein diet in a child more than one year in age. Same as marasmus, kwashiorkor shows wasting of muscles, thinning of limbs, failure of growth and brain development. But unlike marasmus, some fat is still left under the skin, moreover, extensive oedema and swelling of body parts are seen.

Examples of Some Other Disorders:

Rickets

Deficiency of Vitamin D along with calcium and potassium in the body causes rickets. Rickets are characterized by weak and soft bones, bowed legs and bone deformities. Fish, fortified dairy products, liver, oil, and sunlight are some rich sources of Vitamin D.

Pellagra

Pellagra is a disease caused by the lack of Niacin or B_3 in the body. Foods enriched with niacin are tuna, whole grains, peanuts, mushrooms, chicken etc. These should be consumed regularly to ward off this disease.

Scurvy

Low levels of Vitamin C or ascorbic acid in the body can cause scurvy. Citrus fruits like oranges, lemon, strawberries etc. and broccoli are rich in vitamin C.

Beri-Beri

Lack of Vitamin B_1 or thiamine in the body leads to a disease called beriberi. Meat, eggs, whole grains, dried beans, etc. are rich in thiamine.

Xerophthalmia or Night Blindness

Xerophthalmia or night blindness is caused by to deficiency of Vitamin A in the body. In worsened situations, night blindness can aggravate complete loss of vision. Vitamin A is found in natural food sources like carrots, green and leafy vegetables, cantaloupes etc.

Goitre

Iodine in the body is essential for normal cell metabolism in the body; it is the constituent of the thyroid hormones. The deficiency of iodine may cause Goitre.

Iron Deficiency Anaemia

Iron deficiency **anaemia** is a disease caused by the deficiency of iron in the body. It is characterized by a decrease in the red blood cell count or **haemoglobin** in the body.

Osteoporosis

The deficiency of Vitamin D and calcium in the body can negatively affect the health of the bones and spine. It leads to unhealthy, soft, and brittle bones that are prone to fractures and defects in the spine structure. Bananas, spinach, milk, okra, soy, and sunlight are natural sources of Vitamin D and calcium that act to eliminate this deficiency.

INTERESTING FACTS

The name "kwashiorkor" comes from a Ghanaian language, meaning "the disease the first child gets when the second child is born" due to reduced access to breast milk.

Scurvy was once called the "sailor's disease" because it plagued sailors who spent months at sea without fresh fruits and vegetables.

The Inuit traditionally avoided rickets despite living in low-sunlight areas by eating vitamin D-rich fish liver and whale blubber.

QUIZ CORNER

1. Which enzyme hydrolyzes 1,4-glycosidic bonds in starch?

a) Lactase b) α-Amylase
c) Maltase d) Sucrase

2. Which monosaccharides are produced from the digestion of lactose?

a) Glucose and fructose
b) Glucose and galactose
c) Fructose and sucrose
d) Galactose and trehalose

3. What is the primary mode of transport for glucose and galactose into intestinal cells?

a) Facilitated diffusion
b) Na+-dependent cotransport
c) Osmosis
d) Simple diffusion

4. What activates pepsinogen into pepsin in the stomach?

a) Trypsin b) Bile salts
c) Gastric H^+ d) Pancreatic juice

5. Which pancreatic protease activates other proenzymes in the small intestine?

a) Trypsin b) Pepsin
c) Chymotrypsin d) Elastase

6. What forms micelles during lipid digestion?

a) Proteins b) Bile acids
c) Water d) Starch

7. What are chylomicrons primarily composed of?

a) Proteins only
b) Triglycerides, cholesterol, and apoproteins
c) Amino acids and glucose
d) Vitamins and water

8. What is the major hormone regulating BMR?

a) Insulin b) Cortisol
c) Glucagon d) Thyroxine

9. Which condition results from the simultaneous deficiency of proteins and calories?

a) Kwashiorkor b) Marasmus
c) Scurvy d) Pellagra

10. Which vitamin deficiency causes rickets?

a) Vitamin A b) Vitamin C
c) Vitamin D d) Vitamin B_{12}

Ans: 1-b, 2-b, 3-b, 4-c, 5-a, 6-b 7-b, 8-d, 9-b, 10-c.

Nothing is impossible. The word itself says 'I'm possible!

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Blood and Circulation

Blood is a liquid connective tissue made up of blood cells and plasma that circulate inside the blood vessels under the pumping action of the heart.

In the case of human blood, we can say it is red-coloured body fluid circulating inside the blood vessels in order to transport the gases (oxygen and carbon dioxide), nutrients, hormones, and other essential chemical components to every body cell and metabolic wastes from every cell to the excretory organs. Simply, blood is a means of transportation present inside our bodies.

In medical terms, blood is referred to as haemo (hemo) or haemato (hemato). About 7% (8 to 10%) of the body weight of an average human is the weight of blood. In general, an average human (about 70 kg) contains about 5.5 liters of blood. Blood volume per weight is higher in children and comparatively lower in adults. Also, the total volume of blood is low in females than in a male of the same age, weight, and health status.

The blood is slightly basic having a pH of about 7.35 to 7.45. Human blood temperature is slightly higher than the normal body temperature of 37^0C but rarely exceed 38^0C in normal condition.

Components of Blood

Blood is made up of blood cells (also called hematocytes or hematopoietic cells) and plasma.

Blood Cells (Hematocytes)

These are the cellular components of the blood covering about 45 – 46% of total blood. There are four types of blood cells present in humans, namely, (i) Red Blood Cells (RBCs), (ii) White Blood Cells (WBCs), and (iii) Platelets.

Red Blood Cells

Red blood cells also called erythrocytes or RBCs are red-colored biconcave cells lacking a nucleus. They are the most abundant cells covering about 99% of the total blood cells. Structurally they are disk or biconcave in structure with about 7 to 7.5 µm diameter and about 2.5 µm thickness at the edge. They have an average life span of 120 days. They are comparatively more numerous in males (about 42 to 54% of total blood volume or approx. a total of 4.7 to 6.1 million RBCs per cubic microliter of blood) than in females (about 37 to 47% of total blood volume or approx. a total of 4.2 to 5.4 million RBCs per cubic microliter of blood).

The most important components of the RBCs are haemoglobin and antigenic glycoproteins (blood group antigens). Haemoglobin is an iron-rich protein that helps to carry oxygen and carbon dioxide gases. These proteins are packed inside the RBC's cytoplasm and cover about 95% of the dry weight of each RBC. The plasma membrane of RBCs contains blood group antigens that are used to classify the blood into various blood groups. The major antigens of concern are A antigen, B antigen, O antigen, and Rhesus (Rh) antigen. The major function of RBCs is the transportation of gases (oxygen and carbon dioxide).

MORE ABOUTS RBCs

Not all blood is red! Horseshoe crabs have blue blood due to the presence of copper-based hemocyanin instead of Haemoglobin.

Your body produces about 2 million new red blood cells every second to replace old or damaged ones.

In a lifetime, your red blood cells travel approximately 60,000 miles through your circulatory system.

RBCs can change shape to pass through tiny capillaries, which are sometimes smaller than the cells themselves.

White Blood Cells

White blood cells also called leukocytes or WBCs or polymorphonuclear cells are colorless nucleated defensive blood cells. They are the largest blood cells but are the least in number; on average only about 4000 to 11000 WBCs per cubic microliter of blood. WBCs are polymorphic cells

i.e. different types of WBCs have different structures. WBCs are immune cells and their major function is to provide defense or immunity to the body. The WBCs are of various types, and in a broader sense, they can be categorized into two groups: Granulocytes and Agranulocytes.

Granulocytes: Also called polymorphonuclear leukocytes are a group of WBCs characterized by multi-lobed nuclei and cytoplasmic granules. There are three types of granulocytes, namely, eosinophils, basophils, and neutrophils.

Eosinophils are circular granulocytes with bilobed nuclei (roughly of equal size) which take up the acidic red dye and appear red or pink. They are present in low numbers covering only 1 – 6% of total WBCs in blood. Their main role is to defend against parasitic infections and induce inflammation.

Basophils are circular granulocytes with bilobed nuclei (of distinctly different sizes) which stain blue or bluish-purple due to absorption of the basic methylene blue dye. They are the least abundant WBCs covering less than 1% of the total WBCs. Their main role is as a mediator of inflammation and allergic reactions and the destruction of allergens.

Neutrophils are small and the most abundant WBCs with multilobed nuclei (up to 6 lobes) which take up both the acidic and basic dye and stain as purple colored. They are most abundant covering about 40 – 75% of total WBCs and are easy to notice due to their multilobed nuclei. Their primary function is to provide defense against bacteria.

Agranulocytes: These are a group of WBCs characterized by a large single nucleus and cytoplasm lacking granules. There are two types of Agranulocytes; monocytes and lymphocytes.

Monocytes are the largest types of WBCs having a single round and very large nucleus which stains purple or bluish. They cover about 2 – 10% of total WBCs. Monocytes are further of two types; (i) motile monocytes in circulation known as phagocytes, and (ii) mostly non-motile monocytes in tissue known as macrophages. They are very important for defense against microbial infections, regulation of inflammation, and activation of T-lymphocytes.

Lymphocytes are the second most abundant type of WBCs characterized by a large kidney-shaped nucleus. They occupy about 20 – 50% of total WBCs. They are further of two types; (i) T-lymphocytes, and (ii) B-lymphocytes. Lymphocytes keep the memory of infection and antigens and produce specific antibodies to fight against the infection.

The major functions of WBCs are: Providing immunity to defend the body against infections and Regulate the inflammatory response.

KNOW MORE!

Lymphocytes retain a "memory" of past infections, allowing faster responses during reinfection.
Neutrophils die after engulfing bacteria, forming pus at infection sites.
Most WBCs work outside the bloodstream, patrolling tissues for pathogens

Platelets

Platelets also called thrombocytes are tiny anucleated blood cells regulating hemostasis. They are very small disk-shaped blood cells measuring just about 2 to 4 μm in diameter; however, they are present in the large number of 200000 to 500000 thrombocytes per cubic microliter of blood. They have an average lifespan of 8 to 11 days. The main function of thrombocytes is to cause hemostasis (blood clotting).

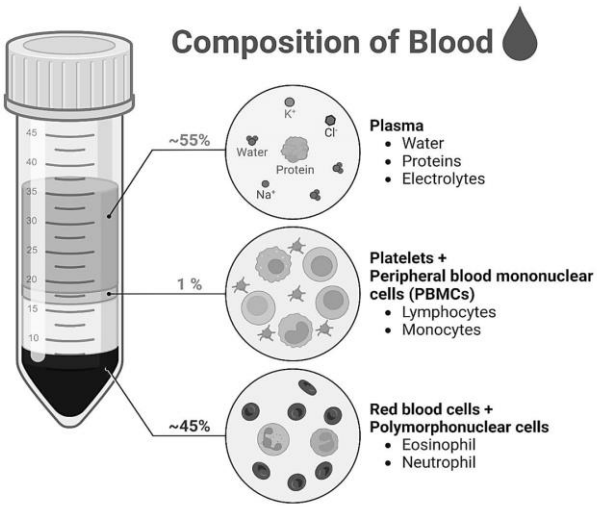


Fig.5.1 Composition of Blood

FACTS CORNER

Platelets live only 8-11 days but are crucial for preventing blood loss.
Blood clots usually form within 6 minutes to prevent significant blood loss.
Inappropriate clotting can lead to a thrombus, which can block blood flow and cause serious issues like strokes.

Blood Plasma

Plasma is the fluid component of blood comprising about 54 to 55% of total blood volume. It is a straw-yellow coloured fluid primarily made of water and plasma proteins and a trace amount of other elements like nutrients, hormones, gases, ions, etc. The plasma without the blood clotting proteins is called serum.

The components of human blood plasma are:

- Water accounting about 90 to 92% of the plasma. It maintains the fluidity of the blood, dissolves the components for transport, and also regulates temperature.
- Plasm proteins comprise about 7 to 8% of the total plasma. There are diverse types of plasma proteins like albumins, globulins (antibodies), clotting proteins (like fibrinogen, prothrombin, etc.), lipoproteins, and other conjugated proteins.
- Electrolytes or ions in trace amounts like Na^{+}, K^{+}, Ca^{++}, PO_4^{+++}, Mg^{++}, Fe^{+}, etc.
- Nutrients like glucose, amino acids, fatty acids, and vitamins.
- Hormones secreted by different endocrine glands.
- Gases like oxygen and carbon dioxide are in dissolved form and bound form.
- Waste products like metabolic wastes, urea, creatinine, etc.

Functions of Blood

- The transportation of gases (oxygen and carbon dioxide) using RBCs or Haemoglobin and in the dissolved state or combined stage.
- Transportation of nutrients, hormones, ions, and other chemical constituents to the cells for different metabolic processes.
- Collection of the metabolic wastes from all the cells and tissues and transporting them to excretory organs for filtration and excretion.
- Circulating WBCs, antibodies and other components provide immunological functions.
- Platelets and other blood clotting factors circulating induce and maintains hemostasis and break down clots.
- Circulating blood also controls the body temperature.
- Maintains homeostasis and osmolarity of cells and tissues.

Formation of Blood Cells

The process of formation of blood cells is called hematopoiesis or hemopoiesis (haemopoies is) or hematogenesis. On average, 200 billion red blood cells, 10 billion white blood cells, and 400 billion platelets are formed each day in a normal adult body. All of the blood cells are formed from a multipotent hematopoietic stem cell (HSC). HSCs are self-replicating cells having the potential to differentiate and mature into different blood cells and lymphocytes. During the fetal stage hematopoiesis occurs in the yolk sac and aorta-gonad-mesonephros, then in the thymus, spleen, and liver in a developing embryo of 2 to 5 months, and finally, they are formed at bone marrow and lymph nodes in all developed embryo of 5 or more month age, infants and adults. The process of the formation of blood cells inside the bone marrow is called medullary hematopoiesis and the process of the formation of blood cells outside the bone marrow is called extramedullary hematopoiesis.

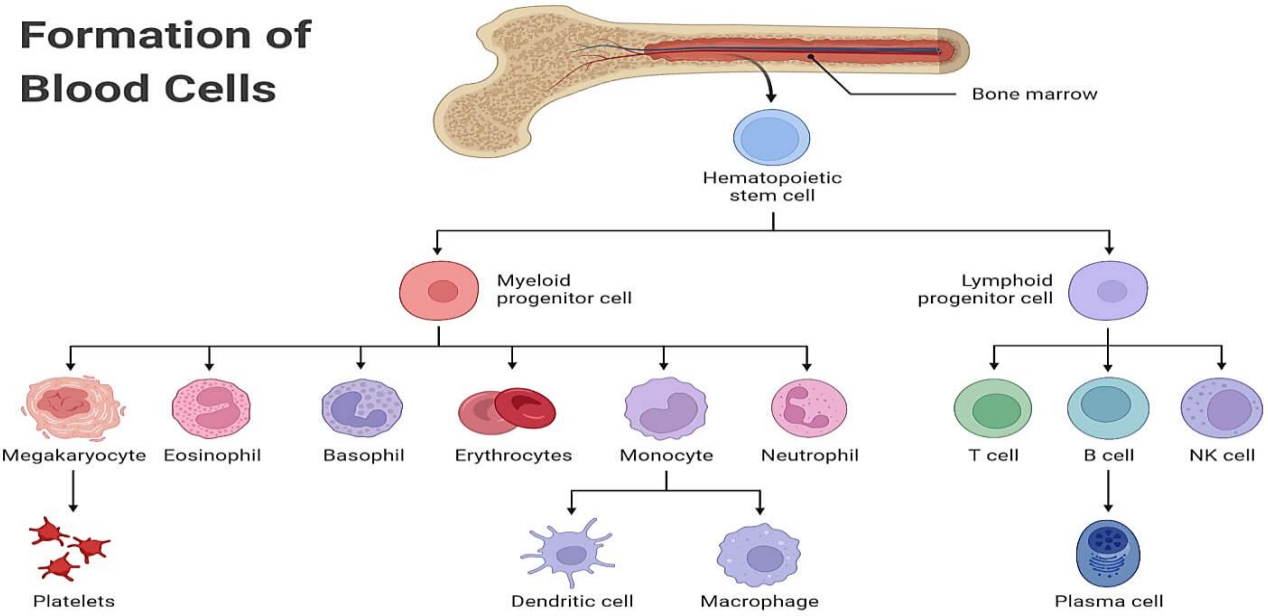


Fig. 5.2 Formation of blood cells

Formation of Blood Cells

In the bone marrow, there is an island of hematopoietic tissue where HSC are present. The HSC is developed into a precursor cell or a progenitor cell; based on the influence of the fate-determining factors the HSC differentiates into either the common myeloid progenitor or the common lymphoid progenitor. The common myeloid progenitor can differentiate into either RBC or WBC, or platelets, and the common lymphoid progenitor can differentiate into lymphocytes. The duration required for the formation of a blood cell is equal to the life span of that particular blood cell, i.e. for RBC it is 120 days, for WBCs few hours to days, and for platelets, it is 5 – 10 days, so that the blood cells can be replenished continuously.

Erythropoiesis: It refers to the formation of the RBCs. The common myeloid progenitor develops into the proerythroblast which then simultaneously develops and differentiates into basophilic erythroblast, polychromatic erythroblast, orthochromatic erythroblast, polychromatic erythrocyte, and then finally metamorphose into the erythrocyte (RBC).

Leukopoiesis: It refers to the formation of leukocytes (WBCs). The common myeloid progenitor can differentiate into the myeloblast which then can differentiate into different granular and agranular leukocytes. The myeloblast develops into a basophil promyelocyte which continuously develops into the basophil myelocyte, basophil metamyelocyte, basophil band, and finally to a basophil. Similarly, the myeloblast can differentiate into neutrophil promyelocyte and eosinophil promyelocyte which undergo similar stages of development like the basophil promyelocyte and finally form neutrophil and eosinophil respectively. Besides, the myeloblast can also develop into a monoblast which then matures into either a monocyte, macrophage, or myeloid dendritic cell.

Thrombopoiesis: The common myeloid progenitor can also metamorphose into a megakaryoblast which ultimately develops to form a thrombocyte through the promegakaryocyte and megakaryocyte stages sequentially.

DO YOU KNOW?

In fetuses, blood cells are first produced in the yolk sac before transitioning to the liver, spleen, and eventually bone marrow.
In cases of bone marrow failure, blood cells may be produced in the liver or spleen.
Red marrow actively produces blood cells, while yellow marrow stores fat but can revert to red during severe blood loss.

Hemostasis Stages

Hemostasis can broadly be classified into two stages; (i) primary hemostasis, and (ii) secondary hemostasis. The primary hemostasis is the process of formation of the soft platelet plugs around the ruptured point. It is the first strategy adopted by the body to prevent blood loss. In this process, collagens are activated and accumulated

in and around the area of the ruptured blood vessel. These accumulated collagens attract platelets and make them stick together to form a seal of the platelet. Besides, the platelets will induce vasoconstriction and release of factors which will attract more platelets in that ruptured site. The secondary hemostasis is the process of formation of fibrin fiber which will solidify the soft platelet plug into a hard and strong fibrin clot.

Mechanism of Hemostasis

As soon as the blood vessel rupture exposing the components inside the vessel wall into the blood and blood leaks outside the vessels, the hemostasis mechanism is triggered. It can be completed within seconds (around 15 seconds) or may take several hours based on the physiological and biochemical status of the person and the site and the degree of blood vessel rupture.

It is a complex process that can be described into three major steps viz. vascular spasm, platelet plug formation, coagulation, and the last step of fibrinolysis.

1. Vascular Spasm

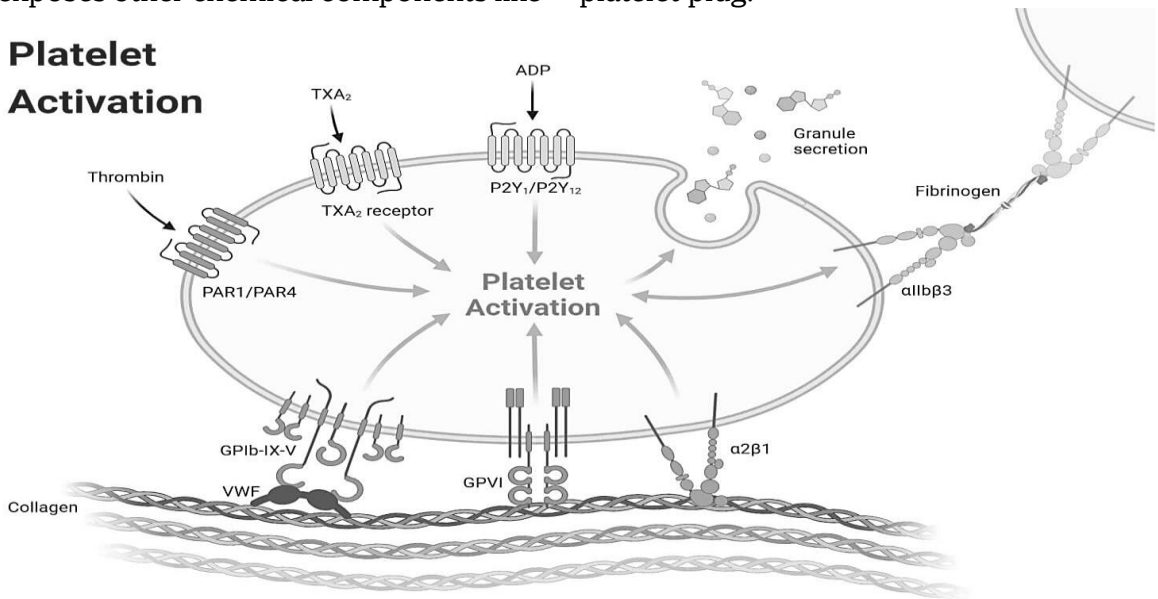
Vascular spasm, also known as vasoconstriction, is the initial response that falls in primary hemostasis. As the endothelium cells are damaged during the vascular rupture, endothelin-1 (a vasoconstrictor) is released which mediates the vasoconstriction. The damaged endothelium of the vessel exposes other chemical components like sub-endothelial collagen, ATP (adenosine triphosphate), von Willebrand factor, and inflammatory mediators into the circulation. All of these promote vasoconstriction.

The sub-endothelial collagens and von Willebrand factors promote platelet accumulation and adhesion in that ruptured site. The attached platelets rupture and release serotonin, ADP (adenosine diphosphate), and thromboxane A2. All these components of the platelets further increase vasoconstriction. During the rupture of the blood vessel, local pain receptors initiate reflexes which further promote the vascular spasm.

The effect of vascular spasm is more promising in smaller vessels with minor rupture. The effect may last for 30 minutes to several hours.

2. Platelet Plug Formation

The freely floating platelets in the circulation begin to clump together forming spiked and sticky platelet clumps and attaching over the exposed vesicular lining and collagen. Under the influence of von Willebrand factors, the platelet plug stabilizes and further accumulates over the exposed endothelial tissue. These attached platelets release their contents, mainly the ADP, further attracting other platelets toward that site. These platelets bound with collagen and endothelial lining form a temporary seal called the platelet plug.



5.3. Platelet Activation

The platelet plug temporarily seals the vessel and prevents or slows down the rate of blood loss. This process results in primary hemostasis. Once the platelet plug is formed, the clotting factors are activated and the secondary hemostasis (blood coagulation process) begins.

Coagulation (Clotting)

Blood coagulation also called blood clotting, is the process of solidification of the blood due to the formation of fibrin fiber-associated blood clots. It is the secondary hemostasis stage and results in a stable solid blood clot. The overall process completes three major tasks; first, the activation of clotting factors, second the conversion of prothrombin into thrombin, and finally the conversion of fibrinogen into fibrin fiber.

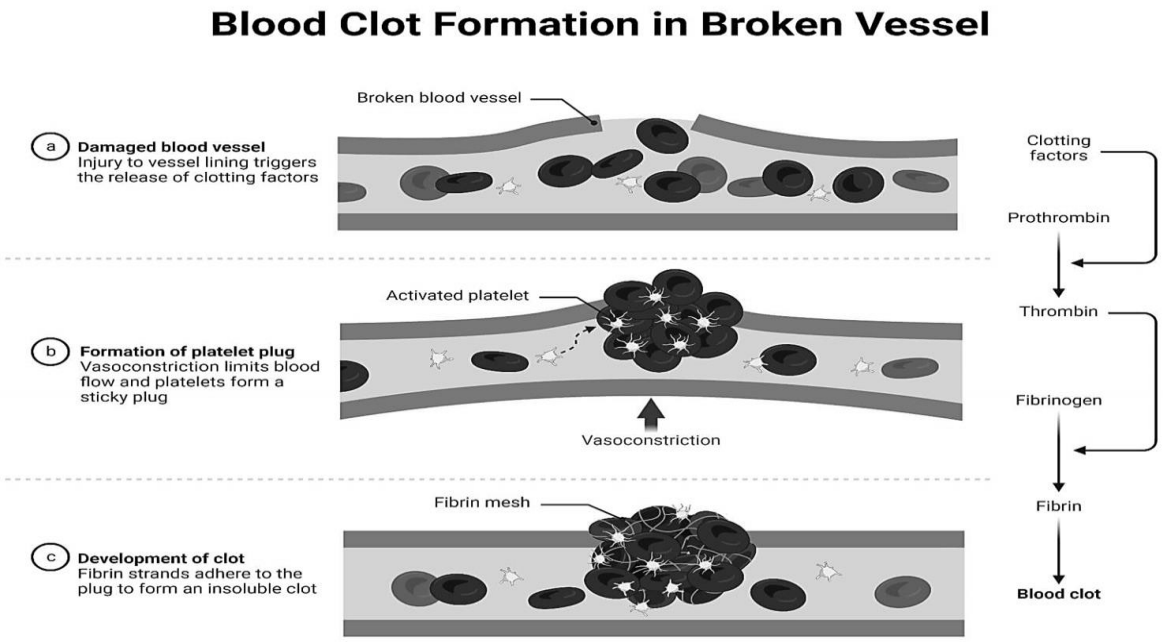


***Fig 5.4. Blood Clot Formation* in Broken Vessel**

Coagulation Pathways

The coagulation process, also called coagulation cascade, is initiated through two different pathways; the extrinsic pathway and the intrinsic pathway, leading to a final common pathway of activating and stabilizing fibrin. The fibrin traps the platelets and blood cells forming a stable, gelatinous, and robust clot that ceases the hemorrhage.

The Extrinsic Pathway (Tissue Factor Pathway)

It is one of the initial cascades leading to the activation of factor X. It is a very fast and explosive pathway that begins immediately after the exposure of tissue factor (factor III) on circulation, and is completed within about 15 seconds of the exposure. It is induced by the tissue factor, hence the pathway is also known as the tissue factor pathway.

Factor III (TF) contacts factor VII (FVII) in circulation and forms the TF-FVIIa complex (activated FVII). The TF-FVIIa complex then leads to the activation of factor X (FX) triggering the common pathway.

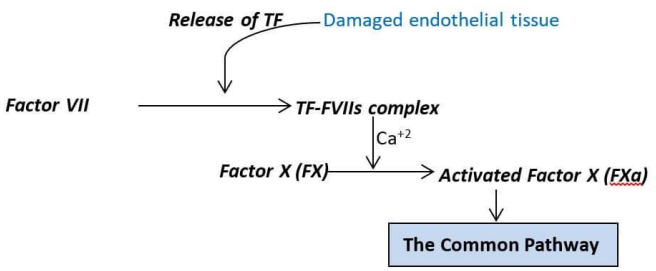


Fig 5.4.1. Representation of the extrinsic pathway of blood coagulation

The Intrinsic Pathway (Contact Activation Pathway)

It is another cascade leading to the activation of factor X. It is comparatively complex and very slow than the extrinsic pathway, and usually takes about 1 to 6 minutes to form a blood clot. All the factors involved in this process are found within the circulation and the process begins when factor XII comes into contact with foreign materials (endothelial cells, or their contents, collagen, or other extravascular components), hence it is also called the contact activation pathway.

The cascade begins when a complex of factor XII (FXII), HMW kininogen (HMWK), and prekallikrein is formed over the collagen fibers. In the complex, the prekallikrein is activated into kallikrein which in turn activates the FXII and forms the activated FXII (FXIIa). The FXIIa, in the presence of Ca^{+2} ions, catalyzes the conversion of the clotting factor XI (FXI) into FXIa, its activated form. Sequentially, the FXIa, in the presence of Ca^{+2} ions, catalyze the conversion of the clotting factor IX (FIX) into its activated form, FIXa. The FIXa, in presence of the Ca^{+2} ions and platelet phospholipids (PL), combines with the activated factor VIII (FVIIIa) and forms the FIXa-FVIIIa complex. This protein complex then activates the factor X (FX) triggering the common pathway.

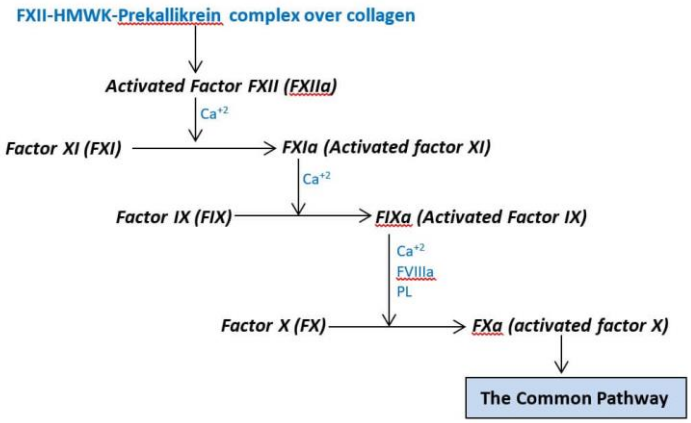


Fig.5.4.2 Representation of the intrinsic pathway of blood coagulation

The Common Pathway

It is the final stage of the blood coagulation cascade which begins after the activation of factor X. The activated factor X (FXa) combines with activated factor V (FVa) and the Ca^{+2} ions on the phospholipid (PL) surface of the platelets and forms the prothrombinase complex. This complex activates the prothrombin (factor II) into thrombin (activated factor II (FIIa)).

Thus, formed thrombin serves two primary functions; first, it activates fibrinogen (factor I) into fibrin (activated factor I (FIa)), and second, it activates fibrin stabilizing factor (Factor XIII (FXIII)) into activated form (activated factor XIII (FXIIIa)). The FXIIIa then stabilizes the fibrin fiber leading to the formation of a stable fibrin blood clot.

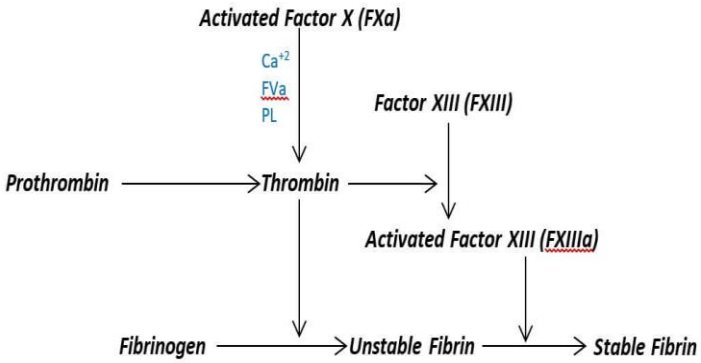


Fig 5.4.3. Representation of the final common pathway of blood coagulation

TRAIN YOUR BRAIN

1. What percentage of total body weight is made up of blood in an average human?

a) 4-5% b) 10-12%
c) 7-8% d) 15%

2. Which protein in red blood cells is responsible for oxygen transport?

a) Albumin b) Haemoglobin
c) Fibrinogen d) Myosin

3. What type of white blood cell is responsible for defense against bacterial infections?

a) Neutrophils b) Basophils
c) Eosinophils d) Monocytes

4. Which granulocyte is associated with allergic reactions and releases histamine?

a) Neutrophils b) Basophils
c) Eosinophils d) Monocytes

5. What is the primary function of platelets?

a) Transport of oxygen
b) Hormone production
c) Immunity
d) Blood clotting

6. What is the fluid component of blood called?

a) Plasma b) Serum
c) Lymph d) Haemoglobin

7. What is the process of blood cell formation called?

a) Hemostasis b) Hematopoiesis
c) Thrombosis d) Leukopoiesis

8. In the coagulation cascade, what is the first factor activated in the intrinsic pathway?

a) Factor III b) Factor X
c) Factor VII d) Factor XII

9. Which ion is crucial for the blood clotting process?

a) Sodium (Na^+) b) Potassium (K^+)
c) Calcium (Ca^{++}) d) Magnesium (Mg^{++})

10. What is the role of fibrin in hemostasis?

a) Activates platelets
b) Forms a stable blood clot
c) Triggers vasoconstriction
d) Converts thrombin into prothrombin

Ans: 1-c, 2-b, 3-a, 4-b, 5-d, 6-a, 7-b, 8-d, 9-c, 10-b

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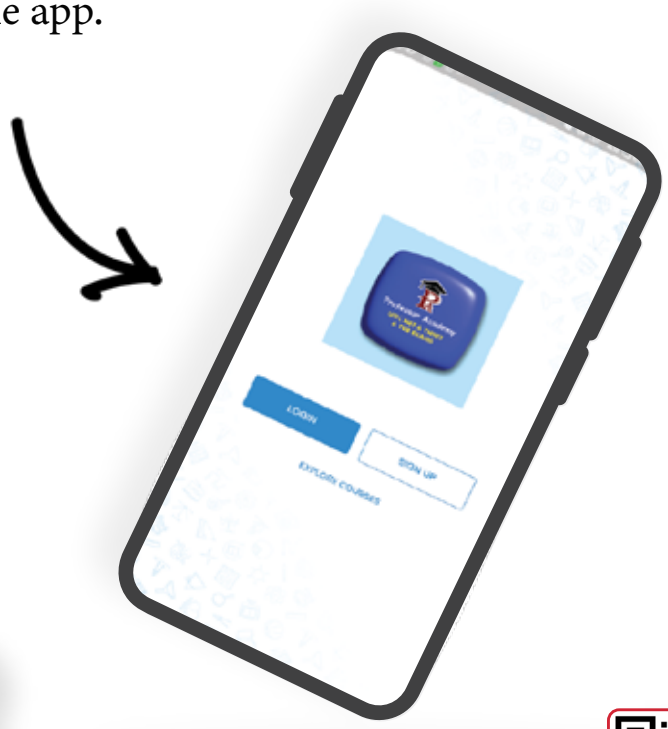

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MODULE 3

CARDIOVASCULAR SYSTEM

Morphology (Size) of Heart

Externally, the heart is cone-shaped with an average dimension of (12- 13)×9×6 cm. It is slightly larger in males than in the female. The weight is about 300 grams (280 to 340) in males and only about 250 grams (230 to 280) in females. In an adult, the heart is approximately equal to the size of a clenched fist. The broader base lies upward slightly towards the right side part of the sternum, while the significant portion of the pointed apex lies slightly left to the sternum facing the diaphragm. The great vessels (aorta and vena cava) seem to be connected in the broader base part. The two major veins, the superior and the inferior vena cave enter the right atrium, and the aorta leaves from the left ventricle. Similarly, the pulmonary veins enter the left atrium, and the pulmonary artery leaves from the left ventricle. The heart is surrounded externally by a protective fluid-filled fibrous membrane called the pericardium.

Pericardium

It is a double-layered tough membrane; the external layer is called the fibrous pericardium and the internal layer is called the serous pericardium. The fibrous pericardium is the outer tough layer made of strong connective tissues. It forms a closed space within the mid-mediastinum to form the pericardial space. Posteriorly, it is fused with the central tendon layer of the diaphragm, anteriorly, it melds with the outer layer of the great vessels and completely seals the heart, and ventrally it is fused with the posterior end of the sternum. It provides mechanical protection to the heart.

The serous pericardium is the double-layered internal layer of the pericardium made up of mesothelium, a single layer of epithelium, which secrets the pericardial fluid. The outer layer internally lining the fibrous pericardium is called the parietal serous pericardium. There is a small cavity between the outer and the inner serous pericardium called the pericardial cavity, which is filled with the pericardial fluid. This fluid provides lubrication that reduces the friction generated during the contraction and relaxation of the cardiac muscles, as well as protects the heart from mechanical shock. Forming the internal lining of the pericardial cavity, there is the inner layer of the serous pericardium called the visceral serous pericardium. It continues with the heart wall and is also called the epicardium.

Functions of Pericardium

- It protects the heart from mechanical shock, friction, and infection by serving as a tough physical barrier.
- It anchors and secures the heart in the mediastinum.
- It secrets the pericardial fluid, which helps to lubricate the heart during the heart contraction-relaxation process.
- It prevents the heart from over-expanding and over-filling and limits the heart's motion by functioning as a tough, inflexible limiting membrane.

Heart Anatomy (Internal Structures)

1. Layers (Walls) of the Heart

The heart is a hollow muscular organ whose wall is anatomically divided into three distinct layers; epicardium, myocardium, and endocardium.

Epicardium

It is the outermost layer of the heart and the inner layer of the serous pericardium. It is composed of mesothelium tissues, fats, and connective tissues. It is fused with the adventitious layer of the major blood vessels. It serves multiple functions like protection from physical stress and friction, secretion of the pericardial fluid and factors for the proliferation of cardiomyocytes, signaling for heart development in the embryonic stage, and triggering the heart's regeneration and healing response.

Myocardium

It is the middle layer of the heart wall made of specialized muscle cells called cardiomyocytes. It is the thickest muscular layer of the heart wall, also known as the heart muscle or the cardiac muscle. It is composed of striated, cardiac muscle cells, the cardiomyocytes, attached together by the intercalated discs and intertwined with the collagen fibers, cardiac fibroblasts, and extracellular matrix. This layer is supplied with coronary arteries and coronary veins for supplying the blood to the heart wall. The myocardium serves by facilitating the rhythmic contraction and relaxation of the heart, providing a pathway for the conduction of the cardiac action potential, and forming the septum, which divides the heart into four chambers.

Endocardium

It is the thin innermost layer of the heart wall composed of three sub-layers the endothelium, the fibro-elastic tissues (collagen fibers, elastic tissues, and smooth muscles), and the connective subendocardial tissues. It internally lines all 4 heart chambers and the heart valves. It provides a smooth surface for the free flow of blood inside the chambers and prevents the attachment of blood components in the heart wall. The connective subendocardial tissue layer contains the Purkinje fibres and hence helps in the transmission of cardiac impulses in the ventricles. Besides, the endocardium also provides covering and protection to the heart valves and regulates the ionic concentration of the cardiac cells.

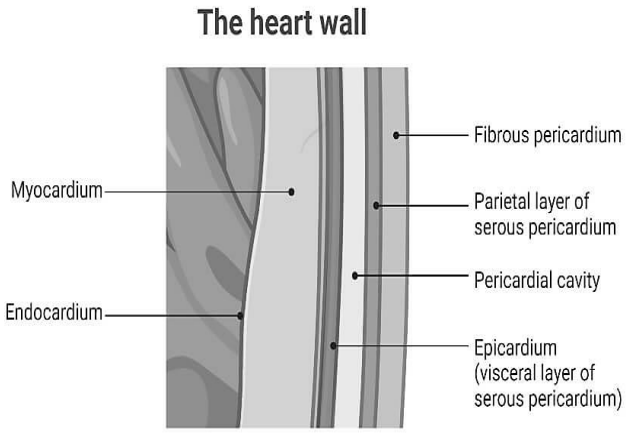


Fig 5.5 : Heart Walls. Created with biorender.

2. Chambers of the Heart

The hollow heart of vertebrates is divided into different chambers by the heart muscles. These chambers serve to separate the pure (oxygenated) and impure (deoxygenated) blood and pump them accordingly for either purification or for the systemic supply. Humans (and other mammals) have four-chambered hearts i.e. our heart is internally divided into four compartments, two auricles (atria) and two ventricles, by the myocardial septum. The upper two chambers that receive blood are called the atria, and the two lower chambers from where blood is pumped out of the heart are called the ventricles.

The heart is divided into the right and the left side by the atrioventricular (AV) septum. The portion of the AV septum that separates the two atria is called the interatrial septum; whereas, the portion of the AV septum that separates the two ventricles is called the interventricular septum. The tricuspid valve and a short extension of the myocardium and AV septum separate the right atrium and the right ventricle. Similarly, the bicuspid valve and a short extension of the myocardium and the AV septum separated the left atria and the left ventricle.

The two chambers at the right part of the heart receive and pump out the impure blood. The right chambers of the heart receive and pump out pure blood.

Atria (Auricles)

Atria are the two upper chambers of the heart that receive blood from the two vena cava and the pulmonary veins. The two atria are named the right atrium and the left atrium based on their position. They are separated by the interatrial septum so that the blood of the two atria never comes in contact with each other. The atria are thin-walled chambers separated from the ventricles by the atrioventricular valves.

The right atrium is the upper right chamber of the heart where the superior and the inferior vena cava pour in the deoxygenated blood. Simply,

it is the chamber for the collection of deoxygenated blood. It is located slightly right to the sternum and is structurally prominent with a slightly bulging and pyramidal shape. It receives blood from the vena cava and passes it to the right ventricle via the tricuspid valve.

The left atrium is the upper left chamber of the heart that receives pure (oxygenated) blood. Simply, it is the chamber that collects the oxygenated blood through the pulmonary veins. The aorta and pulmonary arteries are structurally located just above the left atrium. Structurally, it is slightly smaller than the right atrium and located left and slightly posterior to the right atrium.

Ventricles

Ventricles are the two lower chambers of the heart that receive blood from the atria and pump the blood out of the heart in either the systemic or pulmonary arterial system. Like atria, in a four-chambered heart system, the ventricles are also divided into the right ventricle and the left ventricle. Ventricles are larger than the atria and have a thicker muscular wall for mechanical pumping purposes. The two ventricles are separated by the interventricular septum and the components of the right and the left ventricles never come in contact.

The right ventricle is the lower right chamber that receives and pumps out the deoxygenated blood to the lungs for re-oxygenation. It is located behind the sternum and the terminal end is connected to the diaphragm. Externally, the atrioventricular (AV) groove marks the separating border of the right atrium and the right ventricle, whereas, the tricuspid valve marks the internal dividing border. During the atrial systole, the impure blood passes through the tricuspid valve and enters the right ventricle. During the ventricular systole, the blood is pumped through the pulmonary arteries.

The left ventricle is the terminal left chamber of the heart located slightly left of the sternum. It is the chamber with the thickest muscular wall. It receives the oxygenated blood from the left atrium during the atrial systole stage and pumps out the blood in the aorta (systemic arteries) during the ventricular systole stage. The AV groove marks the border of the left atrium and the left ventricle externally and the bicuspid valve separated them internally.

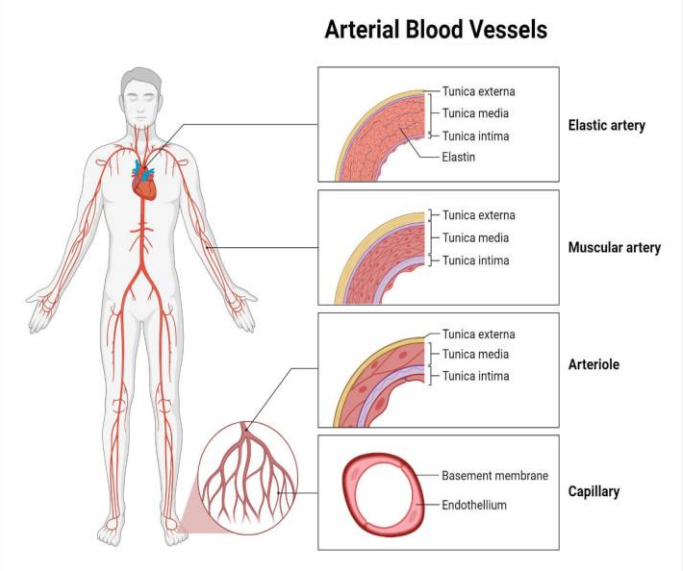


Fig 5.5.1 Arterial Blood Vessels

3. Heart Valves

The human heart is equipped with four major valves to prevent the backflow of blood in the heart chambers. The valves are the leaf-like structures (flaps) that maintain the unidirectional flow of blood inside the heart. These are highly organized connective tissue structures made of valve interstitial cells and organized extracellular matrix (composed of elastin, proteoglycans, and collagens) externally coated by endothelial cells and supported by papillary muscles and tendons. These are activated by the blood pressure and open in one direction only when the blood pressure inside the respective heart chambers exceeds the threshold pressure required to open the valves. There is a total of 4 heart valves that are categorized into two groups; the atrioventricular valves and the semilunar valves.

Atrioventricular (AV) Valves

These are the heart valves present between the atria and ventricles that prevent checks from the backward flow of blood from the ventricles to the atria. The leaflets (cusps) of these valves are attached to the extensions of the ventricular heart walls by the subvalvular apparatus (structure made of chordae tendineae and papillary muscles). The

pressure gradient developed during the atrial systole opens these valves and when they are closed just before the ventricular systole, they produce the first heart sound (S_1) or the "Lub" sound of the heartbeat. There are two AV valves, namely; the tricuspid valve and the bicuspid valve.

The tricuspid valve is located between the right atrium and the right ventricle and prevents the flow of deoxygenated blood from the right ventricle to the right atrium. It contains three leaflets or the cusps, the anterior leaflet, the septal leaflet, and the posterior leaflet, hence got the name 'tricuspid'.

The bicuspid valve, also known as the mitral valve, is located between the left atrium and the left ventricle and checks the flow of blood back to the left atrium from the left ventricle. It contains only two leaflets or the cusps, the aortic (anterior) leaflet and the posterior leaflet, hence got the name 'bicuspid'.

Semilunar Valves

There are two semilunar valves present at the base of major arteries; the aorta and the main pulmonary artery (pulmonary trunk). They prevent the return of blood from the major arteries to the ventricles. These valves don't have chordae tendineae and leaflet structures; instead, they have cusps that are self-supported within the arterial root. The pressure gradient developed during the ventricular systole opens these valves and when they are closed, they produce the second heart sound (S_1) or the "Dub" sound of the heartbeat. There are two semilunar valves, namely; the aortic valve and the pulmonary valve.

The aortic valve is located at the base of the aorta and prevents the return of blood from the aorta to the left ventricle. These valves have three cusps; the left coronary cusp, the right coronary cusp, and the non-coronary cusp.

The pulmonary valve is located at the base of the pulmonary trunk. It is also tricuspid and prevents the return of blood from pulmonary arteries to the right ventricle.

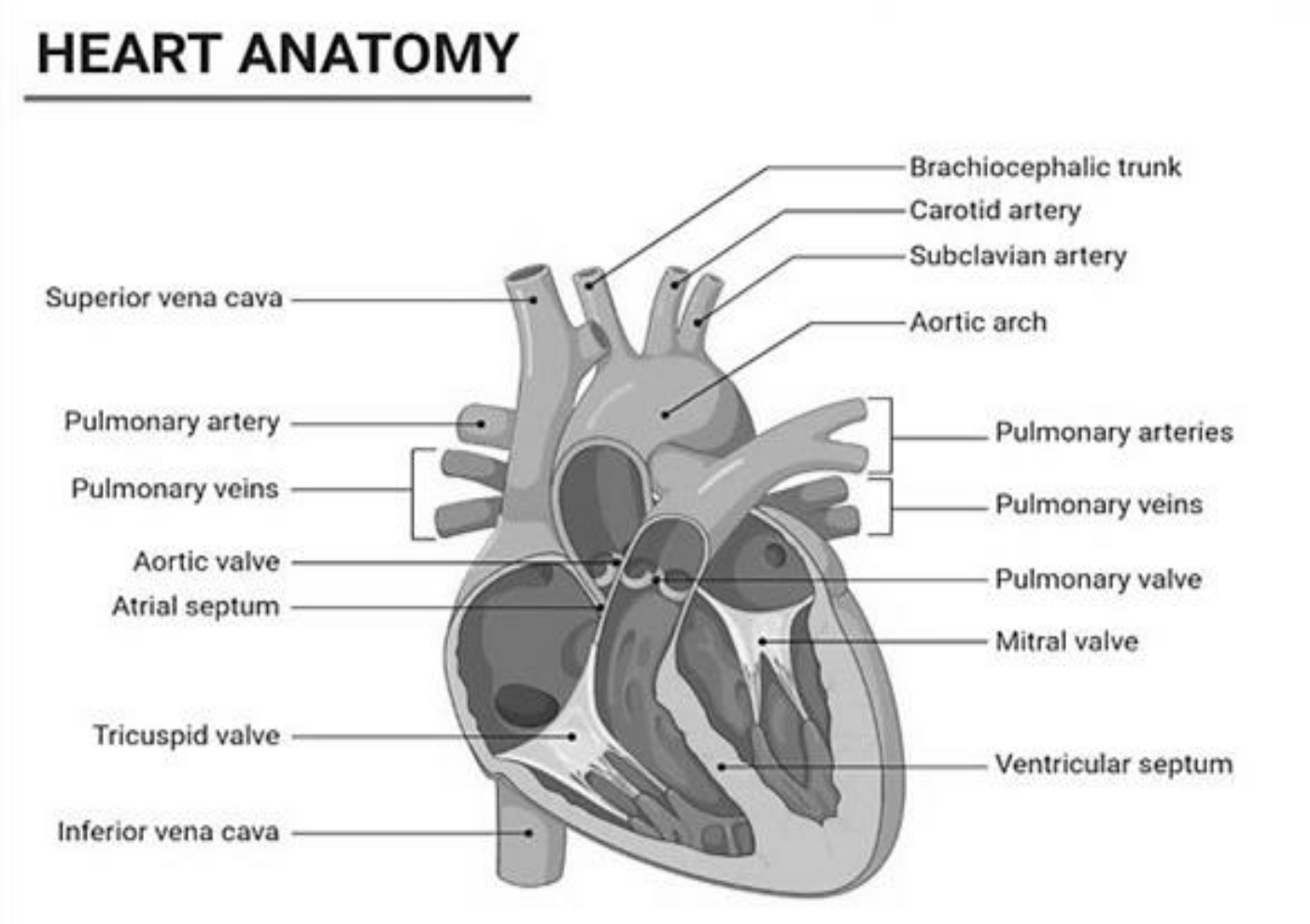


Fig 5.5.2 Human Heart Anatomy.

4. Cardiac Impulse Conduction and Transmitting Channel

Humans have a myogenic heart i.e. the cardiac impulse which triggers the regular contraction and relaxation of the heart is generated by some specialized heart muscles (cardiomyocytes) but not by the neural impulses. These types of the heart are the features of vertebrates including humans. Whereas, some invertebrates like arthropods and annelids have a heart whose beating is initiated by neural impulses. Such types of hearts are called the neurogenic heart.

Cardiac Conduction System

The group of specialized cardiomyocytes that spontaneously generate the cardiac action potential (cardiac impulse) and transmit the generated action potential across the heart's wall for the rhythmic beating of the heart is called the cardiac conduction system (or the heart's conduction system or the electrical conduction system of the heart). The major components of the human heart conduction system include the sinoatrial node, atrioventricular node, Bundle of His, and Purkinje fibers.

Sinoatrial Node (SA Node)

The SA node is the center for the generation of the cardiac action potential at the rate of 60 to 100 times per minute. It is also called the natural Pacemaker of the heart and is composed of specialized cardiomyocytes called cardiac pacemaker cells. It is a small oval-shaped node of about 15 mm 3 mm 1 mm in dimension located at the right atrium below the superior vena cava.

Atrioventricular Node (AV Node)

The AV node is another mass of specialized cardiomyocytes that collects the cardiac impulses from the atria and relays them toward the ventricle for ventricular contraction. It is comparatively smaller than the SA node, measuring just about 5 mm 3 mm 1 mm in dimension, and is located near the ventricles at the end of the interatrial septum. It also generates cardiac impulses at a slower rate of 40 to 60 times per minute; hence it is also called the second pacemaker of the heart.

Bundle of His

It is a bundle of special cardiomyocytes that conducts the cardiac impulse from the AV node to the Purkinje Fibers. It arises from the end of the AV node and branches into the left and the right bundle branch and joins the major Purkinje fibers in the left and the right ventricle respectively.

Purkinje Fibers

These are small networks of specialized impulse-conducting cardiomyocytes that spreads the cardiac impulse across the ventricular wall. These cells are also capable of generating cardiac impulses but at a very slow rate of 20 to 40 times per minute if the pacemakers fail to function properly.

5. Coronary Vessels

Although the heart pumps blood to every part of the body and its chambers are regularly filled with blood, the heart muscles can't absorb essential materials and excrete wastes in the blood within those chambers. Instead, the wall of the heart needs arteries and veins for blood circulation. These vessels supplying blood to the heart walls are called the coronary vessels and the circulation within the heart's wall is called coronary circulation.

Coronary Arteries

These are the arteries that supply the oxygenated blood to the heart wall. They arise from the ascending arch of the aorta, within the cusp of the aortic valve. They arise as two major coronary arteries, the right main coronary artery (RCA) and the left main coronary artery (LCA) from within the right and the left cusps of the aortic valve respectively. These major arteries are further divided into major branches which again divide into smaller coronary arteries and coronary capillaries. The LCA supplies blood to the left ventricle and the left atrium. The LCA further divides into two major branches, the left anterior descending artery supplying the front side of the left side of the heart, and the circumflex artery supplying the outer and the back side of the heart. The RCA supplies blood to the right ventricle, the right atrium, and the AV and SA nodes. The RCA further divides into two major branches, the right marginal arteries, and the posterior descending artery.

Coronary Veins (Cardiac Veins)

Cardiac veins are the veins that drain the deoxygenated blood from the heart walls. There are seven major cardiac veins, (i) the great cardiac vein, (ii) the middle cardiac vein, (iii) the small cardiac vein, (iv) the posterior vein of the left ventricle, (v) the vein of Marshall, (vi) the anterior cardiac vein, and (v) the smallest cardiac vein (venae cordis minima). The first 5 major cardiac veins mentioned above merge together to form the coronary sinus which directly pours the blood into the right atrium. The anterior cardiac vein and the smallest vein independently pour into the right atrium.

6. Nerve Supply

The human heart is myogenic, however, the heartbeat and the heart rate are influenced by the nervous system. The human heart is supplied with a vagus nerve and the sympathetic cardiac nerve. The cardiac vagus nerve is a nerve of the parasympathetic nervous system emerging from the brain stem and branching to connect the SA node and the AV node, which signals the reduction in the heart rate.

Similarly, the sympathetic cardiac nerve also arises from the brain stem, from the T1 to T4 thoracic ganglia. It branches and supply to the SA node, the AV node, the atria, and the ventricles. The sympathetic nerves promote the heart rate and the force of the heartbeat by releasing the noradrenalin neurotransmitter that tends to decrease the repolarization period.

KNOW MORE

The human heart beats approximately 100,000 times a day, pumping about 7,500 liters of blood daily.
The heart's electrical system can continue beating even when separated from the body if oxygen is supplied.
A woman's heart typically beats faster than a man's due to differences in size and hormone levels.
The heart can create enough pressure to squirt blood 30 feet away.
The first open-heart surgery was performed in 1893 by Dr. Daniel Hale Williams, an African-American surgeon.

Cardiac cycle

The cardiac cycle is a continuous closed sequence of events that results in the continuous and systematic contraction and relaxation of the chambers of the heart.

It includes all the events that occur in one heartbeat. It involves the complete contraction and relaxation of the atria and ventricles ensuring efficient blood circulation in arteries and veins in a synchronized manner.

The heart continuously completes the cardiac cycle under the control of the cardiac action potential. Approximately 0.8 seconds are needed for one cardiac cycle to be completed all together.

The human cardiac cycle can be broken down into four main phases; the atrial systole, the ventricular systole, the atrial diastole, and the ventricular diastole. There is an intermediary phase called the protodiastole phase marking the end of the systole and the beginning of the diastole phase.

1. Atrial Systole

This phase is also known as presystole or the last rapid filling phage or atrial kick and is the phase when the atria contract to pump the blood out of the atria into the ventricles. The impulse generated by the natural pacemaker, the sinoatrial (SA) node, is transmitted via the internodal tract all over the right atrial wall and through Bachmann's bundle to the left atrial wall triggering the contraction of the atrial walls. Approximately 20 to 30% of the remaining atrial blood is driven into the ventricle during this stage. This amount of blood forced during the atrial systole is called the atrial kick or the atrial contribution. This step takes roughly 0.11 seconds to complete.

2. Ventricular Systole

It is the stage when the ventricle contracts expelling the blood outside of the ventricles. The Purkinje fibers relay the cardiac impulses all over the ventricular wall stimulating the ventricular wall to contract. This step is completed in about 0.3 seconds.

The ventricular systole can be further subdivided into three sub-phases:

a. Isovolumetric Ventricular Contraction

It is the first stage of ventricular systole when the muscle tension increases and the ventricles begin to contract without any change in the volume of the ventricles. In this stage, the pressure inside the ventricle increases and exceeds the atrial pressure. This pressure difference causes the two atrioventricular (AV) valves (the mitral valve and the tricuspid valve) to close. The two semilunar (SL) valves (the aortic and the pulmonary valves) are also closed in this stage, so the blood can't leave the ventricle. This results in increasing the internal pressure of the ventricles without changing their volume. This stage lasts for about 0.05 seconds.

b. Rapid Ventricular Ejection

In this stage, the SL valves open due to pressure differences in the ventricles and the major arteries forcing about 70% of the ventricular blood in high pressure out of the ventricles through the aorta and the pulmonary arteries within about 0.13 seconds. The pressure inside the left ventricle will be higher, about 80 mm of Hg, than in the right ventricle (about 8 mm of Hg). Hence, the blood is rushed more forcefully in the aorta than in the main pulmonary artery.

c. Reduced Ventricular Ejection

In this stage, the remaining 30% of the blood is ejected from the ventricles. This stage usually lasts for about 0.09 seconds. The ventricular pressure will have decreased by this time, and the blood will have reached the smaller arteries.

3. Protodiastole

It is the intermediary stage which indicates the end of systole and the beginning of the diastole stage. The ventricular ejection will have completely reduced the ventricular pressure making it lower than the blood pressure inside the major arteries. These pressure differences will close the SL valves. This stage lasts for about 0.04 seconds.

4. Atrial Diastole

It is the stage when the atria are filled. During this stage, the AV valves are closed and the superior and the inferior vena cava pours in the deoxygenated blood collected from the body tissue to the right atrium; whereas the pulmonary veins bring the re-oxygenated (purified) blood to the left atrium. This stage lasts about 0.7 seconds and overlaps the ventricular systole phage. This stage occurs immediately before the ventricular diastole stage.

5. Ventricular Diastole

It is the stage when the blood is passed to the ventricles from the atria increasing the ventricular pressure and volume of the ventricles. This stage lasts for about 0.5 seconds and can be further subdivided into the following sub-phases:

a. Isovolumetric Ventricular Relaxation

It is the first stage of ventricular diastole when the muscle tension in the ventricular wall decreases without any change in the volume of the ventricles. This reduced pressure causes the semilunar valves to completely close. The AV valves are also closed in this stage so blood can't flow in the ventricles and the volume of the ventricles remains the same. However, the rapid pressure drop will make the atrial pressure higher and the ventricular pressure lower which triggers the next stage. This stage usually lasts about 0.08 seconds.

b. Rapid Ventricular Filling

It is the stage when the AV valves open rushing about 70% of the atrial blood into the ventricles. This stage lasts for about 0.11 seconds.

c. Reduced Ventricular Filling

It is the stage when about 20% of the atrial blood enters the ventricles at a slower rate. This stage usually lasts for about 0.19 seconds.

d. Last Rapid Ventricular Filling

It is the last stage of ventricular diastole that coincides with the atrial systole phase. In this phase, the remaining 10% of the blood is passed to the ventricle. This stage lasts for about 0.1 seconds.

Pacemaker :

A pacemaker is used to control or increase the heartbeat. It stimulates the heart as needed to keep it beating regularly. The heart's electrical system typically controls the heartbeat. Electrical signals, called impulses, move through the heart chambers. They tell the heart when to beat. Changes in heart signaling may happen if the heart muscle is damaged. Heart signaling problems also may be caused by changes in genes before birth or by using certain medicines. A pacemaker only works when it senses trouble with the heartbeat. For example, if the heart beats too slowly, the pacemaker sends electrical signals to correct the beat. Some pacemakers can increase the heartbeat as needed, such as during exercise.

A pacemaker may have two parts:

- Pulse generator: This small metal box has a battery and electrical parts. It controls the rate of electrical signals sent to the heart.
- Leads: These are flexible, insulated wires. One to three wires are placed in one or more of the heart's chambers. The wires send the electrical signals needed to correct an irregular heartbeat. Some newer pacemakers don't need leads. These devices are called leadless pacemakers.

Components of Arterial Blood Pressure

Arterial blood pressure in the larger vessels consists of several distinct components: systolic and diastolic pressures, pulse pressure, and mean arterial pressure.

Systolic and Diastolic Pressures

When systemic arterial blood pressure is measured, it is recorded as a ratio of two numbers (e.g., 120/80 is a normal adult blood pressure), expressed as systolic pressure over diastolic pressure. The systolic pressure is the higher value (typically around 120 mm Hg) and reflects the arterial pressure resulting from the ejection of blood during ventricular contraction, or systole. The diastolic pressure is the lower value (usually about 80 mm Hg) and represents the arterial pressure of blood during ventricular relaxation, or diastole.

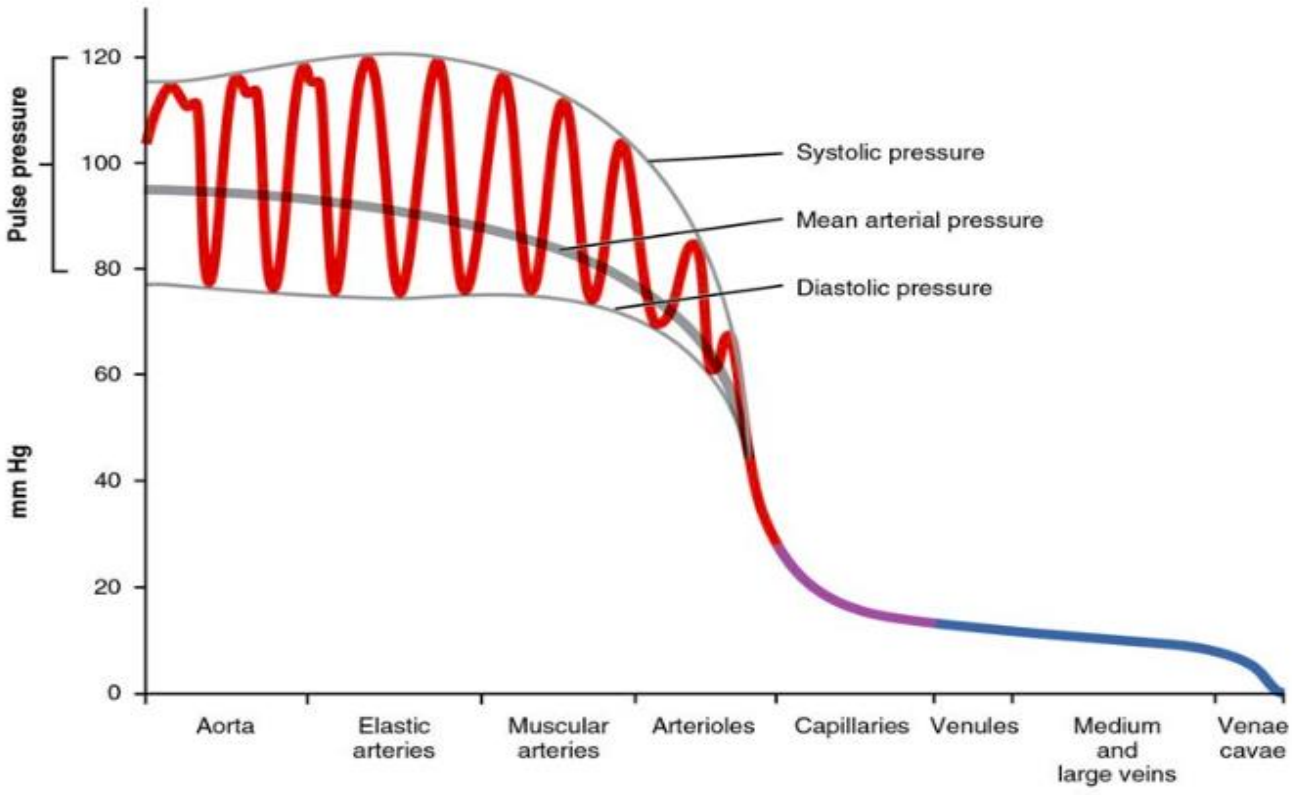


Figure 5.6

The graph shows the components of blood pressure throughout the blood vessels, including systolic, diastolic, mean arterial, and pulse pressures.

Pulse Pressure

As shown in Figure 1, the difference between the systolic pressure and the diastolic pressure is the pulse pressure. For example, an individual with a systolic pressure of 120 mm Hg and a diastolic pressure of 80 mm Hg would have a pulse pressure of 40 mmHg.

Generally, a pulse pressure should be at least 25 percent of the systolic pressure. A pulse pressure below this level is described as low or narrow. This may occur, for example, in patients with a low stroke volume, which may be seen in congestive heart failure, stenosis of the aortic valve, or significant blood loss following trauma. In contrast, a high or wide pulse pressure is common in healthy people following strenuous exercise, when their resting pulse pressure of 30–40 mm Hg may increase temporarily to 100 mm Hg as stroke volume increases. A persistently high pulse pressure at or above 100 mm Hg may indicate excessive resistance in the arteries and can be caused by a variety of disorders. Chronic high resting pulse pressures can degrade the heart, brain, and kidneys, and warrant medical treatment.

Electrocardiogram Instrumentation

ECG test is done using an ECG machine containing a set of electrodes connected to a central signal processor through lead wires and a monitor and a printer to display and print the ECG. Typically 10 electrodes, that receive, collect and transmit the electric potentials from our body (biopotentials), are present in a standard 12-lead ECG-producing machine. The biopotentials collected by the electrodes are carried by lead wires to the central impulse processing machine. The central ECG machine amplifies the received biopotential, filters the signal, and processes it to produce ECG waves in specific intervals and segments. The processed signals are displayed on the monitor and are printed on grid papers to produce an ECG.

Principle of Electrocardiogram

The ECG is based on the cardiac action potential and cardiac conduction. The SA node generates the cardiac action potential which is relayed down the cardiac conduction pathway resulting change in the membrane voltage (potential) across the membrane of cardiomyocytes. This change in cardiac action potential results in the continuous running of the cardiac cycle.

The cardiac impulse transmits through the heart, spreads around the surrounding tissue, and finally reaches the skin of our body. This electric impulse in the skin is received by the electrodes of the ECG machine and processed to produce an ECG.

Procedure of Obtaining an Electrocardiogram

- Guide the patient to lie flat on a bed in a comfortable and relaxed position. Ensure that the patient is not wearing any metallic objects or electrical devices.
- Attach the electrodes in their respective location. In 12-lead ECG, 10 electrodes are attached at specific sites of the patient's body.

There are four arm electrodes, the RA, the LA, the RL, and the LL electrodes. The RA electrode is placed on the right arm, the LA electrode is placed on the left arm, the RL electrode is placed on the right leg, and the LL electrode is placed on the left leg.

There are 6 chest electrodes named V1 to V6. The V1 and V2 are attached in the fourth intercostal space just right and left of the sternum respectively. The V4 is attached in the fifth intercostal space in the mid-clavicular line. The V3 is attached in between the V2 and V4. The V5 is attached horizontally left of the V4 in the left anterior axillary line. The V6 is attached horizontally left of the V5 in the mid-axillary line.

- Lead wires are connected to the electrodes and the ECG machine is turned on.
- The ECG machine is an automated machine that auto-records the cardiac electric impulse activity and develops an ECG.
- Once the adequate ECG is recorded, the leads are disconnected from the electrodes and the electrodes are detached.

Types of Electrocardiogram

There are three main types of ECG that are:

Resting ECG: It is the standard ECG type routinely used for diagnostic purposes in hospital settings. It is performed while staying lying still in a bed.

Exercise ECG: It is the ECG obtained while performing physical activities, generally walking on a treadmill or peddling a stationary bicycle. It is also called the stress test and is performed to monitor the heart and its electrical activity during physical stress.

Ambulatory ECG: It is a type of ECG that represents the continuous electric activity of 24 hours or more of a heart. In this type, a small portable ECG machine called the Holter monitor is attached to the waist, and the person is allowed to work normally for at least a day. After the desired time, the ECG is studied from the Holter machine.

Waves in a Normal Electrocardiogram

In a normal ECG, we can see three distinct waves; the P-wave, the QRS-complex, and the T-wave.

P-wave: It is the first small upward wave in an ECG that represents atrial depolarization. It represents the electric activity that triggers the atrial systole i.e. impulse generated and transmitted by the SA node just before and starting of atrial systole.

QRS-complex: The QRS complex is the second sharply steeper larger upright triangular-shaped wave representing rapid ventricular depolarization. The QRS complex comprises three individual waves; the Q wave represents the initial downward deflection, the R wave represents the sharp ascending deflection, and the S wave represents the sharp descending deflection in the larger upright triangular wave of an ECG. The QRS complex coincides with the ventricular depolarization stage or ventricular systole stage of a cardiac cycle.

T-wave: It is the final dome-shaped upward deflection representing ventricular repolarization. In a few ECGs, a low amplitude barely noticeable small upward deflection is seen just after the T-wave, known as the U-wave. It is believed that the interventricular septum repolarization is responsible for this wave.

Intervals in a Normal Electrocardiogram

In an ECG, the time period between the beginnings of two waves is measured and analyzed. These time periods represent the time required by impulses to transmit in the cardiac conduction pathway causing a coordinated cycle of depolarization and repolarization of the heart's wall. These time periods are termed 'intervals' and there are two main intervals, viz. PR interval and the QT interval.

PR Interval

It is represented in an ECG by the gap between the beginnings of the P-wave to the beginning of the QRS-complex. The PR interval represents the time required by the cardiac impulse to transmit from the SA node, through the atria, and AV bundle, and finally reach the ventricles. It is usually about 120 to 200 milliseconds.

QT Interval

It is represented in an ECG by the gap between the start of the QRS complex to the end of the T wave. It represents the duration between consecutive ventricular depolarization and repolarization. It is usually shorter than 440 milliseconds.

Segments in a Normal Electrocardiogram

A flat horizontal line between two successive waves i.e. from the end of one wave to the beginning of another in an ECG is termed a 'segment'. There are two main segments in an ECG, viz. the PR segment and the ST segment.

PR Segment

The flat line between the P-wave's conclusion and the beginning of the QRS complex is known as the PR segment. It represents the time delay between the atrial systole and the ventricular systole. It is slightly longer than 440 milliseconds.

ST Segment

It is the flat line between the QRS complex and T wave representing the electrically neutral area between the end of ventricular depolarization and the beginning of ventricular repolarization. It is usually around 80 milliseconds long.

Interpretation of ECG

An ECG is analyzed and interpreted by trained medical personnel only. While reading an ECG the P wave, QRS complex, T wave, PR interval, QT interval, PR segment, and ST segment are mainly focused. The elevation and depression of each wave, the duration of the waves, and the duration of the segments and intervals are studied. Additionally, the heart rate, rhythm, and axis on an ECG are also studied. Based on a collective result of all these various components, an ECG report is interpreted.

A normal ECG will show the following results:

1. Heart Rate: Normal heart rate of 60 to 100 beats per minute
2. Heart Rhythm: Heart rhythm will be consistent and even
3. PR Interval: 0.12 to 0.20 seconds
4. QRS Duration: 0.06 to 0.10 seconds
5. QT Interval: 0.40 seconds
6. ST Segment: 0.08 seconds
7. P-wave

- Upright, uniform, and consistent before each QRS complex.
- P duration < 0.12 seconds
- P amplitude < 2.5 mm

8. T-wave: Upright in lead I, II, V3 to V6, and inverted in aVR.

Blood vessels

Lymph Vessels

The lymphatic vessels transport lymph fluid around the body. There are two main systems of lymph vessels – superficial and deep:

- Superficial vessels – arise in the subcutaneous tissue, and tends to accompany venous flow. They eventually drain into deep vessels.
- Deep vessels – drain the deeper structures of the body, such as the internal organs. They tend to accompany deep arteries.

The drainage of lymph begins in lymph channels, which start as blind ended capillaries and gradually develop into vessels. These vessels travel proximally, draining through several lymph nodes.

Eventually the vessels empty into lymphatic trunks (also known as collecting vessels) – and these eventually converge to form the right lymphatic duct and the thoracic duct.

The right lymphatic duct is responsible for draining the lymph from the upper right quadrant of the body. This includes the right side of the head and neck, the right side of the thorax and the right upper limb. The thoracic duct is much larger and drains lymph from the rest of the body. These two ducts then empty into the venous circulation at the subclavian veins, via the right and left venous angles.

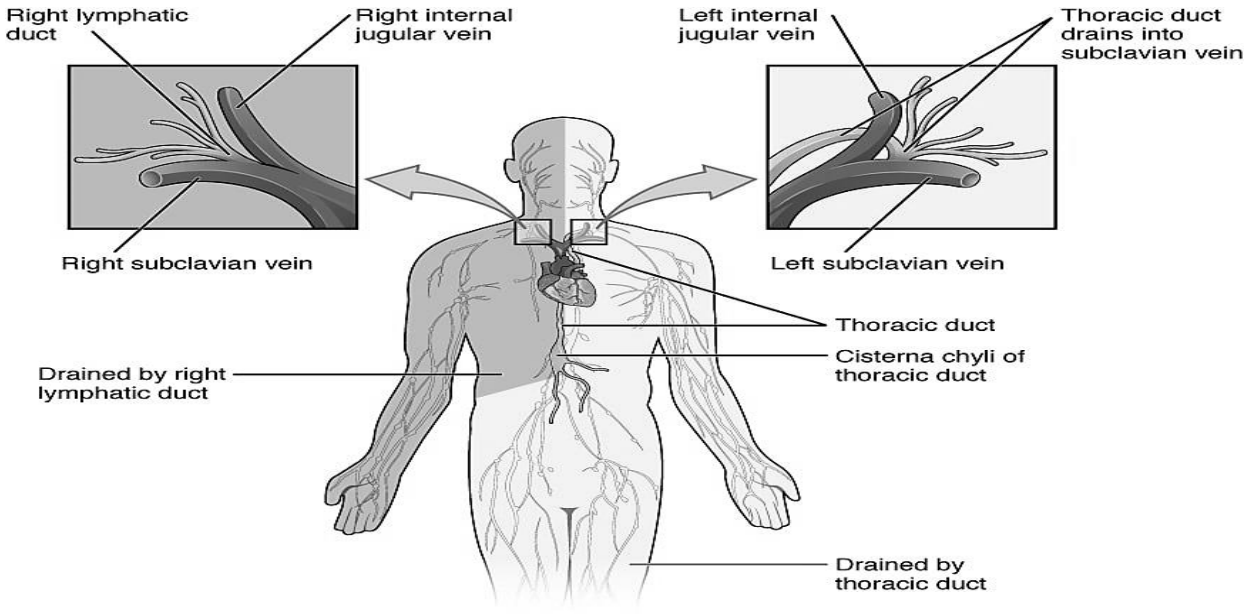


Fig 5.7 The left and right lymphatic ducts

Arteries

An artery is a blood vessel that conducts blood away from the heart. All arteries have relatively thick walls that can withstand the high pressure of blood ejected from the heart. However, those close to the heart have the thickest walls, containing a high percentage of elastic fibers in all three of their tunics. This type of artery is known as an elastic artery. Vessels larger than 10 mm in diameter are typically elastic. Their abundant elastic fibers allow them to expand, as blood pumped from the ventricles passes through them, and then to recoil after the surge has passed. If artery walls were rigid and unable to expand and recoil, their resistance to blood flow would greatly increase and blood pressure would rise to even higher levels, which would in turn require the heart to pump harder to increase the volume of blood expelled by each pump (the stroke volume) and maintain adequate pressure and flow. Artery walls would have to become even thicker in response to this increased pressure. The elastic recoil of the vascular wall helps to maintain the pressure gradient that drives the blood through the arterial system. An elastic artery is also known as a conducting artery, because the large diameter of the lumen enables it to accept a large volume of blood from the heart and conduct it to smaller branches.

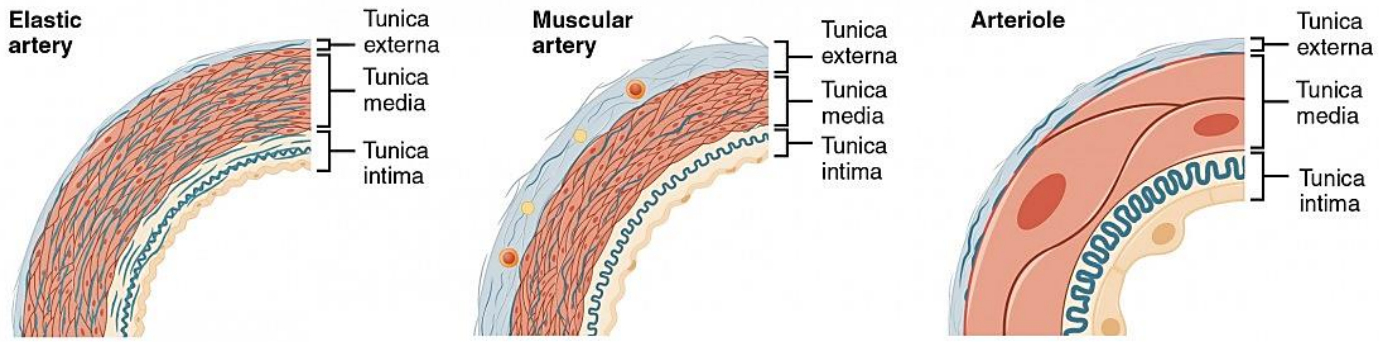
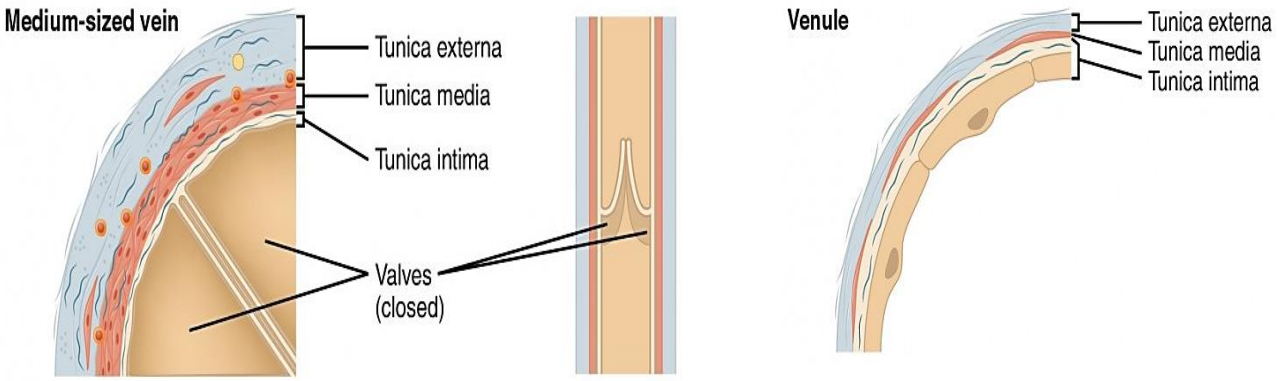


Figure 5.8. Comparison of the walls of an elastic artery, a muscular artery, and an arteriole is shown. In terms of scale, the diameter of an arteriole is measured in micrometers compared to millimeters for elastic and muscular arteries.

Farther from the heart, where the surge of blood has dampened, the percentage of elastic fibers in an artery's tunica intima decreases and the amount of smooth muscle in its tunica media increases. The artery at this point is described as a muscular artery. The diameter of muscular arteries typically ranges from 0.1 mm to 10 mm. Their thick tunica media allows muscular arteries to play a leading role in vasoconstriction. In contrast, their decreased quantity of elastic fibers limits their ability to expand. Fortunately, because the blood pressure has eased by the time it reaches these more distant vessels, elasticity has become less important.

Notice that although the distinctions between elastic and muscular arteries are important, there is no "line of demarcation" where an elastic artery suddenly becomes muscular. Rather, there is a gradual transition as the vascular tree repeatedly branches. In turn, muscular arteries branch to distribute blood to the vast network of arterioles. For this reason, a muscular artery is also known as a distributing artery.



Veins

A vein is a blood vessel that conducts blood toward the heart. Compared to arteries, veins are thin-walled vessels with large and irregular lumens.

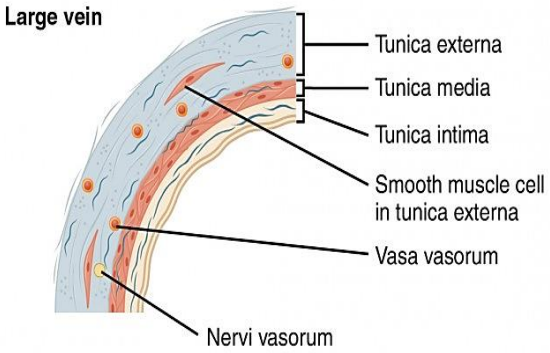


Figure 5.8

Many veins have valves to prevent back flow of blood, whereas venules do not. In terms of scale, the diameter of a venule is measured in micrometers compared to millimeters for veins.

Because they are low-pressure vessels, larger veins are commonly equipped with valves that promote the unidirectional flow of blood toward the heart and prevent backflow toward the capillaries caused by the inherent low blood pressure in veins as well as the pull of gravity. Table 2 compares the features of arteries and veins.

DID YOU KNOW?

If all the blood vessels in the human body were laid end-to-end, they would stretch about 100,000 miles, enough to circle the Earth four times.

Arteries are so elastic that they can expand and contract to match the rhythm of the heart.

Veins have valves that prevent blood from flowing backward, especially in the legs.

The aorta is the largest artery, about the diameter of a garden hose.

Capillaries are so small that red blood cells must pass through them in single file.

BRAIN GYM

1. What is the weight of an average male human heart?

a) 250 grams b) 300 grams
c) 200 grams d) 400 grams

2. What type of tissue makes up the fibrous pericardium?

a) Connective tissue b) Smooth muscle
c) Cardiac muscle d) Epithelial tissue

3. Which layer of the heart wall contains Purkinje fibers?

a) Myocardium b) Epicardium
c) Endocardium d) Pericardium

4. Which valve prevents backflow of blood into the left atrium?

a) Tricuspid valve
b) Pulmonary valve
c) Aortic valve
d) Bicuspid (Mitral) valve

5. Which node is known as the natural pacemaker of the heart?

a) Atrioventricular (AV) node
b) Sinoatrial (SA) node
c) Purkinje fibers
d) Bundle of His

6. What is the function of coronary arteries?

a) Transport deoxygenated blood
b) Supply oxygenated blood to the heart wall
c) Carry waste products
d) Drain blood from the heart

7. Which phase of the cardiac cycle involves the contraction of the ventricles?

a) Atrial diastole b) Ventricular diastole
c) Protodiastole d) Ventricular systole

8. Which type of ECG is performed while walking on a treadmill?

a) Resting ECG b) Ambulatory ECG
c) Exercise ECG d) Dynamic ECG

9. What is the normal systolic blood pressure in adults?

a) 90 mmHg b) 100 mmHg
c) 120 mmHg d) 140 mmHg

10. What is the primary role of elastic arteries?

a) Absorb nutrients
b) Store blood
c) Conduct blood away from the heart
d) Facilitate gas exchange

Ans: 1-b, 2-a, 3-c, 4-d, 5-b, 6-b, 7-d, 8-c, 9-c, 10-c

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RESPIRATORY SYSTEM

Introduction

Respiration involves the exchange of gases between the body and environment. The animals take oxygen from m the surroundings and give off carbon dioxide to the environment. The oxygen is chemically utilized to oxidize foodstuffs to produce energy. The energy is utilized by the living organisms. Animals may have skin, lungs, gills, etc. as the devices of respiration. Physiologically animals get oxygen from water, from air or livingin water but breathe air. All these devices and categories are met in aquaticarthropods as described below:

In aquatic arthropods, gills, book gills, epipodites, tracheal gills, bloodgills, rectal gills, etc. are found as respiratory organs.

Gills: The gills (originated as out pushing of body wall) are well developed incrustaceans and typically associated with appendages. The organization of gills includes the following:

Origin of gills

These are outgrowths of thoracic limbs in arthropods and in isopods, 2nd and 5th pleopods are modified as gills.

Shape of gills

It is typically crescent-shaped containing a rod and blade like gill filaments. One end of filament connected with rod and blood vessel entersinto it through this region. The other end of filament is free. The decapods contain all the types of gill with great variation. Number of gills. Gills are absent in *Lucifer* (Shrimps) but Penacid, *Homarus*, Peacarb has 24, 20 and 6 gills respectively.

Size of gills

The anterior gills are small and the size increases towards the posterior end.

Types of gills

On the basis of position

- Dendrobranchiate gills: It contains a central axis and two steroids ofmain branches with a number of sub-branches or dendrites. e.g., *Penaeus*.
- Phyllobranchiate (=lamellar) gills: It have a central axis and two series of leaf like flattened gill plates arranged in the form of leaves of a book.e.g., *Palaemon* (Prawn).
- Trichobranchiate (=filamettous) gills: It contains a central axis andseveral series of filamentous branches. e.g., Cray fish (*Astacus*).

On the basis of origin of attachment

- Pleurobranch or aide gills: It is attached to lateral wall of segmentabove the origin of thoracic appanges.
- Podobrach or foot gills: It is attached to coxa of the appendages and represents a modification of a part of an epipodite.
- Arthrobranch or joint gill: It is attached to arthrodial membrane.

Modifications of gills:

- Broad epipodites of thoracic appendages work as gills in phyllocardiaand cumacea.
- In *Palianus* (Decapoda), gills are flattened.
- Gills are plate like in amphipoda. Leaf like pleopods work as gills inPhyllopoda.
- In Euphausiacea, tufted podobranchs are not covered by carapace.
- The gills are a row of small branchial lamellae on each side ofcyprididae.
- Abdominal gills are present in stomatopoda and isopoda.

Tracheal gills

A series of simple and divided external process attached to abdominalsegments. These are richly supplied with trachea and tracheoles. e.g., Aquatic larvae of many insects. In *Culex*, four leaves like tracheal gills are present surrounding the anus. It probably takes oxygen dissolve in water. Naiad of mayfly and damselfly bears 7 pairs and 3 pairs of tracheal gills.

Blood gills

The tracheas are replaced by branching of blood vessels. e.g., Trichopterous and tripulid larvae.

Rectal gills

The inner surface of rectum bears gills. e.g., Nymphs of several insects.

Book gills

These are formed by evagination of posterior border of opishthosomafrom 9th to 13th segments. Each gill contains nearly 100-200 lamellae as delicate leaves of a book. The lamellae are the actual surface for gaseous exchange. The movement of gill lamellae maintains the circulation of water around the gills where gaseous exchange takes place.

Aerial respiratory organs (trachea and lungs) in arthropods

In arthropods, aerial respiration occurs through the trachea, lungs, book lungs, spiracular gills, tracheal gills and modification of the trachea.

Trachea

It is present in almost all aerial arthropods but is well-developed in insects. In insects, respiration has no relation with circulation. The trachea (circulatory system of vertebrates) is an invagination of cuticle. Each trachea opens to the exterior through a small circular opening or spiracles. Generally, the thorax and abdomen bear two and eight pairs of spiracles respectively. The spiracle is supported by peritreme (annular sclerite) and capable of being closed by sphincter or spiracular muscle. In some insects, spiracles are present in a cavity or atrium. In some terrestrial insects, the atrium is provided with a filtering apparatus.

The wall of the tracheal tube is made up of polygonal cells having spiral ridges of cuticle or taenidia. The smallest subdivision of the trachea is known as the trachiole. The tracheoles are present in clusters. The cuticle of trachioles is not shed during moulting. The trachioles are lined by trachcin. The spiracles are present on a plate like structure called penetreme. Each spiracle has two lids for opening and closing.

Some parts of trachea are dilated to form air-sacs which work as reservoir. The air-sac lacks taenidia. Air-sacs are present in grass hopper, butter fly, cicadas, scarab and beetles.

Types of trachea

Based on appearance:

- Ventilation trachea: This is oval in section, and collapses afterexhaustion of air and
- Diffused trachea: They are rigid and do not collapse after exhaustion.

In larval stages:

Polypneustic: It has eight or more functional spiracles. It issubdivided into:

- Holopneustic: Two thoracic and eight adnominal open spiracles present. E.g., cockroaches, most adults.
- Peripneustic: One thoracic and eight adnominal openspiracles present.
- Hemipneustic: One thoracic and seven adnominal open spiracles present. E.g., beetles and butterflies.

Oligopneustic: It has one or two functional spiracles. It issubdivided into:

- Amphipneustic: One pair of thoracic and one pair of posteriorabdominal spiracles.
- Metapneustic: One pair of posterior abdominal spiracles.
- Propneustic: One pair of thoracic spiracles.

Apeustic: Functional spiracles absent. e.g., Collmebole. Parasitic larvae, Hymenoptera, endoparasite insects.

Number of spiracles

- In certain insects, spiracles are absent but they are present duringlarval stages.
- Queen of termite has only six abdominal spiracles.
- Metathoracic spiracles are absent in Lepidoptera, Hymenoptera andColeoptera.

DID YOU KNOW?

Shrimp can pump water through their gills even when stationary, ensuring constant gas exchange. Horseshoe crabs have book gills, which also help them swim!

Some crustaceans can regenerate damaged gills. Gills can be highly efficient, extracting up to 80% of available oxygen from water.

Certain deep-sea crustaceans have bioluminescent gills for communication.

Modifications of spiracles

Irregular tracheal pits open to unbranched tracheal systems in Onychophora. Tracheas are absent in Collembola. In *Machiles*, segmental tracheae originate from spiracles but do nothave trunks. In the larvae of a housefly, dorsal longitudinal turns are provided withone pair of anterior and posterior apertures. A single spiracle is connected to the dorsal trunk in mosquito larvae. In Myriapoda, stigmata open within the air chamber from where a large number of tracheae are given off. Tracheae are branched in Diplopoda. Symphyla has only two tracheae on the heart. Pseudotracheae are present in crustacea, woodlice. These are formed by numerous minute tube-like structures which traverse the pleopods.

Lungs: The upper part of the gill chamber is separated from the rest and forms a closed chamber within which the vascular tuft project is known as the lung. E.g., *Birgus*.

Book lungs: These are modified abdominal appendages and originate from evaginations of opisthosoma as blind sacs. It is divided into a ventral (=atrial) chamber and a dorsal or posterior (=pulmonary) chamber. The atrial chamberopens to the exterior through stigmata and the pulmonary chamber receives the pulmonary vein. The pulmonary chamber contains 150 lamellae in vertical folds. The lamellae are highly vascular, parallel arranged as leaves of a bookand bear air spaces filled with air. The respiratory movement is regulated by atrial muscles. It is best seen in scorpionids.

Plastron respiration: In aquatic insects, the angle of contact between water surface and particular body region is known as hydrofuge. The air film is held so firmly bya region of hydrofuge hair which cannot be replaced by water. This very thin,firmly held layer of air is known as plastron. Functionally, it resembles a tracheal gill more than an air store. It is seen in riffle, beetle, *Coxelmis, Eimis*.

Spiracular gills: These are filamentous outgrowth of ectoderm, covered with a thin cuticle. It can resist high pressure. E.g., larvae of Teicheomyza, pupa of *Simuliura* and sphenoids etc.

Anal respiration: Rhythmic contraction of the intestine takes in and expels out water. It is common in Cyclops.

Respiratory organs in fishes

Adult fishes relied mostly on their pharyngeal gills for water breathing. Other technologies, however, are used to complement or replace gill respiration. Accessory respiratory organs are usually found in tropical freshwater fishes and are extremely seldom found in marine fishes.

Because depletion of oxygen happens during summers when the water level lowers to a significant degree, tropical freshwater and hill-stream fish can grow auxiliary respiratory organs to fulfil additional demand for oxygen. Accessory respiratory organs allow fish to thrive in oxygen-depleted water, aestivate during protracted droughts in the summer, go on terrestrial excursions, or simply satisfy increased oxygen demand. Accessory respiratory organs that can operate in an aquatic and aerial environment have been evolved in fish to solve these challenges.

As a result, the evolution of such structures is mostly adaptive in nature. Aquatic respiration is served by some accessory organs, whereas aerial respiration is served by others.

Water inhaled constantly via the mouth travels backward between the gill bars and across the gill filaments, where gases are exchanged. In teleosts and many other fishes, the gills are covered by a gill cover, but in sharks, rays, and some of the oldest prehistoric fish families, the gills are protected by skin flaps. The blood

capillaries in the gill filaments are near to the gill surface, allowing them to absorb oxygen from the water and expel excess carbon dioxide.

The swim bladder, a hydrostatic (ballast) organ found in most contemporary fishes, is located in the body cavity slightly below the kidney and above the stomach and intestine. It started off as a digestive canal diverticulum. The bladder has lost its link with the digestive system in mature tetrapods, particularly acanthopterygian, a trait known as physoclistous.

Many rather primitive teleosts have kept the link (physostomous). The bladder has evolved into a lung or, at the very least, a highly vascularized supplementary respiratory organ in numerous unrelated fish species. Even in well-oxygenated water, some fish with such auxiliary organs are compulsive air breathers and would perish if refused access to the surface. Fish with a hydrostatic swim bladder may regulate the quantity of gas in the bladder to control their depth. Particular glands produce the gas, which is largely oxygen, into the bladder, making the fish more buoyant; the gas is then absorbed into the circulation by another special organ, lowering total buoyancy and allowing the fish to sink.

The following are examples of fish auxiliary respiratory organs

- Integument or Skin
- Bucco – Pharyngeal Epithelium
- Epithelium of the Gut
- Pelvic Fins Expansions
- Diverticula of the Pharynx
- Aerial Respiration in an Opercular Chamber
- Air-Bladders

Accessory Respiratory Organs and Their Functions

The oxygen content of the auxiliary respiratory organs is greater. Fish with such respiratory organs can survive in water with very low oxygen concentrations. These fish come to the top of the water to gulp in the air for transmission to the accessory respiratory organs in this situation. If these fish are not allowed to reach the surface, they will die of asphyxiation owing to a lack of oxygen. As a result, fish' development of auxiliary respiratory organs is an adaptive trait.

Furthermore, it has been shown that the rate of oxygen absorption in such organs is substantially higher than the rate of carbon dioxide removal. As a result, it's only natural that the gills expel the majority of carbon dioxide. The major function of the auxiliary respiratory organs appears to be oxygen absorption.

Adult fishes relied mostly on their pharyngeal gills for water breathing. Other technologies, however, are used to complement or replace gill respiration. Accessory respiratory organs refer to any extra respiratory organs that aren't gills. Accessory respiratory organs are usually found in tropical freshwater fishes and are extremely seldom found in marine fishes.

Because depletion of oxygen happens during summers when the water level lowers to a significant degree, tropical freshwater and hill-stream fish can grow auxiliary respiratory organs to fulfil additional demand for oxygen. Accessory respiratory organs allow fish to thrive in oxygen-depleted water, aestivate during protracted droughts in the summer, go on terrestrial excursions, or simply satisfy increased oxygen demand.

Accessory respiratory organs that can operate in an aquatic and/or aerial environment have been evolved in fish to solve these challenges. As a result, the evolution of such structures is mostly adaptive in nature. Some auxiliary organs provide support for aquatic respiration, whereas others provide support for aerial respiration.

Aside from the gills, all additional respiratory organs found in fish are referred to as auxiliary respiratory organs. These auxiliary respiratory organs are produced as an extra portion of the gills in fish to adapt to different conditions. These organs are most commonly encountered in tropical freshwater fish, but they are extremely rare in marine fish.

These organs are found in tropical freshwater and mountain river fish in some circumstances, especially during the summer and when the water level decreases, to fulfil the requirement for more oxygen. To defend themselves from extreme drought, some fish have been chopped to the ground for a short time.

Some fish have such a high metabolic rate they cannot be met by oxygen in the water, which has led to the development of some accessory respiratory organs for aquatic or terrestrial respiration.

The accessory respiratory organs of fish can be divided into aerial and aquatic. The teleost has 140 different types of aerial respiratory organs. When these fish spend a portion of their life on land, they rely on these organs in times of need.

Oxygen and carbon dioxide dissolve in water, and most fishes exchange dissolved oxygen and carbon dioxide in water using the gills. The gills lie behind and to the side of the mouth cavity and consist of fleshy filaments supported by the gill arches and filled with blood vessels, which give gills a bright red colour. Water taken in continuously through the mouth passes backwards between the gill bars and over the gill filaments, where the exchange of gases takes place. The gills are protected by a gill cover in teleosts and many other fishes but by flaps of skin in sharks, rays, and some of the older fossil fish groups. The blood capillaries in the gill filaments are close to the gill surface to take up oxygen from the water and to give up excess carbon dioxide to the water.

Most modern fishes have a hydrostatic (ballast) organ, called the swim bladder, which lies in the body cavity just below the kidney and above the stomach and intestine. It originated as a diverticulum of the digestive canal. In advanced teleosts, especially the acanthopterygians, the bladder has lost its connection with the digestive tract, a condition called physoclistic. The connection has been retained (physostomous) by many relatively primitive teleosts. In several unrelated lines of fish, the bladder has become specialized as a lung or, at least, as a highly vascularized accessory breathing organ. Some fishes with such accessory organs are obligate air breathers and will drown if denied access to the surface, even in well-oxygenated water. Fishes with a hydrostatic form of swim bladder can control their depth by regulating the amount of gas in the bladder. The gas, mostly oxygen, is secreted into the bladder by special glands, rendering the fish more buoyant; the gas is absorbed into the bloodstream by another special organ, reducing the overall buoyancy and allowing the fish to sink. Some deep-sea fishes may have oils, rather than gas, in the bladder. Other deep-sea and some bottom-living forms have much-reduced swim bladders or have lost their organs entirely.

The swim bladder of fishes follows the same developmental pattern as the lungs of land vertebrates. There is no doubt that the two structures have the same historical origin in primitive fishes. More or less intermediate forms still survive among the more primitive types of fishes, such as the lungfishes *Lepidosiren* and *Protopterus*.

Respiratory structures: Birds

The avian respiratory system is notably different from the mammalian respiratory system, in both its structure and its ability to exchange gas as efficiently as possible.

It consists of paired lungs, which contain static structures with surfaces for gas exchange, and connected air sacs, which expand and contract causing air to move through the static lungs. A breath of oxygen-rich inhaled air remains in the respiratory system for two complete inhalation and exhalation cycles before it is fully spent and exhaled out of the body.

When fresh air is first inhaled through a bird's nares (nostrils), it travels through the trachea (a large tube extending from the throat), which splits into left and right primary bronchi

(called "mesobronchi," with each bronchus leading to a lung). The inhaled air travels down each primary bronchus and then divides: some air enters the lungs where gas exchange occurs, while the remaining air fills the posterior (rear) air sacs. Then, during the first exhalation, the fresh air in the posterior sacs enters the lungs and undergoes gas exchange. The spent air in the lungs is displaced by this incoming air and flows out of the body through the trachea. During the second inhalation, fresh air again enters both the posterior sacs and the lungs. Spent air in the lungs is again displaced by incoming air, but it cannot exit through the trachea because fresh air is flowing inward. Instead, the spent air from the lungs enters anterior (forward) air sacs. Then, during the second exhalation, the spent air in the anterior sacs and in the lungs flows out through the trachea, and fresh air in the posterior sacs enters the lungs for gas exchange.

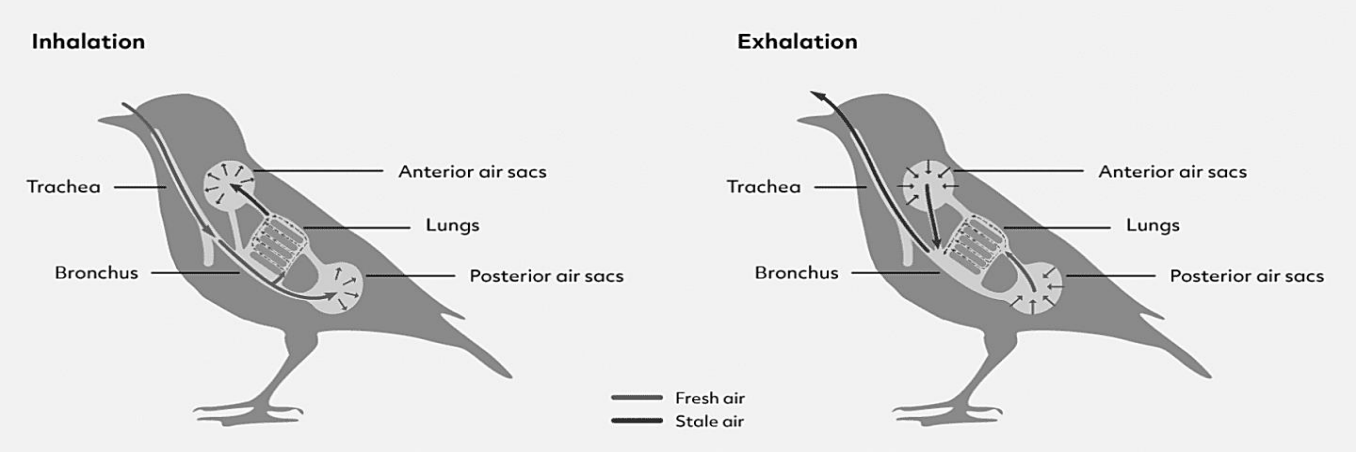


Fig 5.9. Inhalation and exhalation in birds

When a bird inhales, fresh air (blue) enters through the trachea and bronchus and flows into the lungs and posterior air sacs. The fresh air moving into the lungs displaces stale air (red) from the previous breath, moving it into the anterior air sacs. During exhalation, fresh air from the posterior air sac moves into the lungs, while stale air from the anterior air sacs is expelled through the bronchus and trachea.

This pattern of airflow through the respiratory system creates unidirectional (one-way) flow of fresh air over the gas exchange surfaces in the lungs. Furthermore, fresh air passes over the gas exchange surfaces during both inhalation and exhalation, resulting in a constant supply of fresh air enabling the bird to experience a near-continuous state of gas exchange within the lungs. This contrasts with mammalian lungs, which experience bidirectional (two-way) airflow over the gas exchange surfaces.

The efficiency of the avian respiratory system is owed in part to its unidirectional nature and in part to the structure of its parabronchial system (the smaller passages within the lungs). The air capillaries in the walls of the parabronchial system have a much larger overall surface area than that found in the mammalian respiratory system. The greater surface area allows a greater proportion of oxygen from each breath to be exchanged for carbon dioxide from the blood and tissues.

KNOW MORE!

Birds can extract oxygen from both inhaled and exhaled air, ensuring high efficiency.
High-altitude birds like bar-headed geese can fly over Mount Everest due to their advanced respiratory system.
Air sacs in birds not only help with breathing but also lighten their body for flight.
The avian respiratory system can remove 90% of oxygen from the air they breathe.
Some birds, like penguins, use their air sacs to conserve heat in icy environments.

Mammalian Respiratory System

In mammals, pulmonary ventilation occurs via inhalation when air enters the body through the nasal cavity. Air passes through the nasal cavity

and is warmed to body temperature and humidified. The respiratory tract is coated with mucus that is high in water to seal the tissues from direct contact with air. As air crosses the surfaces of the mucous membranes, it picks up water. This equilibrates the air to the body, reducing damage that cold, dry air can cause. Particulates in the air are also removed in the nasal passages. These processes are all protective mechanisms that prevent damage to the trachea and lungs.

From the nasal cavity, air passes through the pharynx and the larynx to the trachea. The function of the trachea is to funnel the inhaled air to the lungs and the exhaled air out of the body. The human trachea, a cylinder about 10-12cm long, 2cm in diameter found in front of the esophagus, extends from the larynx into the chest cavity. It is made of incomplete rings of hyaline cartilage and smooth muscle that divides into the two primary bronchi at the midthorax. The trachea is lined with mucus-producing goblet cells and ciliated epithelia that propel foreign particles trapped in the mucus toward the pharynx. The cartilage provides strength and support to the trachea to keep the passage open. The smooth muscle can contract, causing a decrease in the trachea's diameter, which propels expired air upwards from the lungs at a great force. The forced exhalation helps expel mucus when we cough.

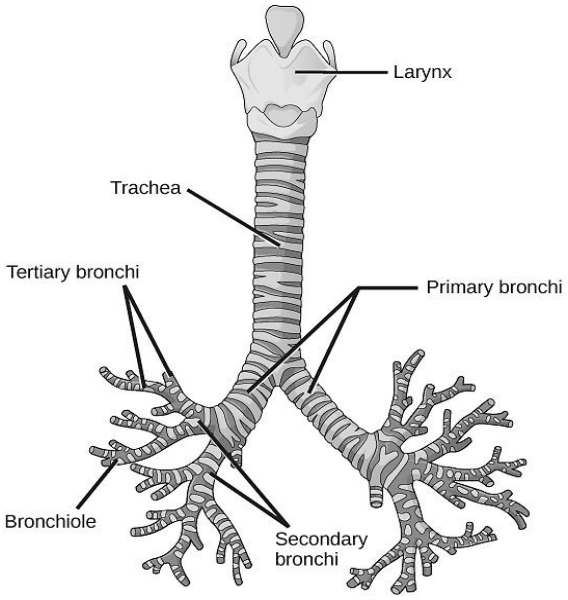


Figure 5.10. Trachea and bronchi structure

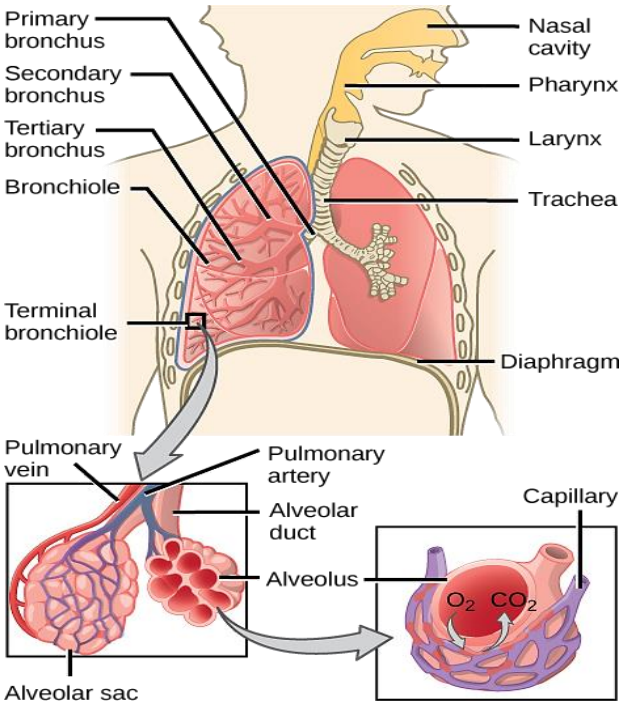


Fig.5.10.1

Route of inhalation: Air enters the respiratory system through the nasal cavity and pharynx. It then passes through the trachea and into the bronchi, which bring air into the lungs.

Lungs: Bronchi and Alveoli

The end of the trachea bifurcates to the right and left lungs, which are not identical. The larger right lung has three lobes, while the smaller left lung has two lobes. The muscular diaphragm, which facilitates breathing, is inferior to the lungs, marking the end of the thoracic cavity.

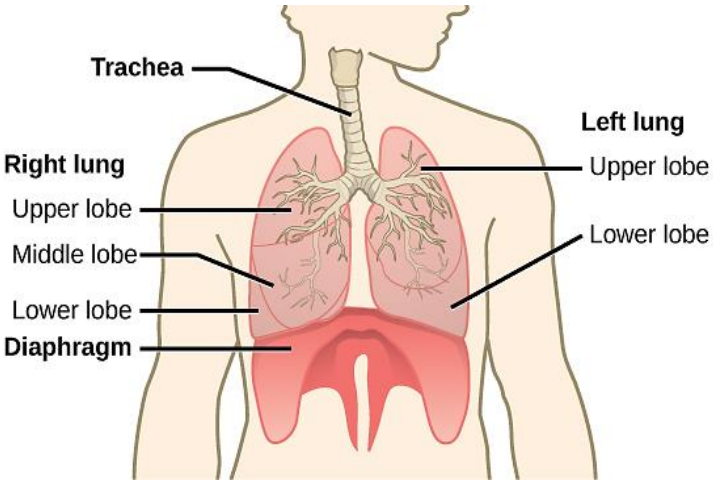


Fig .5.10.2

Lung structure: The trachea bifurcates into the right and left bronchi in the lungs. The larger right lung is made of three lobes. To accommodate the heart, the left lung is smaller, having only two lobes.

As air enters the lungs, it is diverted through bronchi beginning with the two primary bronchi. Each bronchus divides into secondary, then into tertiary bronchi, which further divide to create smaller diameter bronchioles that split and spread through the lung. The bronchi are made of cartilage and smooth muscle; at the bronchioles, the cartilage is replaced with elastic fibers. Bronchi are innervated by nerves of both the parasympathetic and sympathetic nervous systems that control muscle contraction or relaxation, respectively. In humans, bronchioles with a diameter smaller than 0.5 mm are the respiratory bronchioles. Since they lack cartilage, they rely on inhaled air to support their shape. As the passageways decrease in diameter, the relative amount of smooth muscle increases.

The terminal bronchioles then subdivide into respiratory bronchioles which subdivide into alveolar ducts. Numerous alveoli (sing. alveolus) and alveolar sacs surround the alveolar ducts. The alveolar ducts are attached to the end of each bronchiole; each duct ends in approximately 100 alveolar sacs. Each sac contains 20-30 alveoli that are 200-300 microns in diameter. Alveoli are made of thin-walled, parenchymal cells that are in direct contact with capillaries of the circulatory system. This ensures that oxygen will diffuse from alveoli into the blood and that carbon dioxide produced by cells as a waste product will diffuse from the blood into alveoli to be exhaled. The anatomical arrangement of capillaries and alveoli emphasizes the relationship of the respiratory and circulatory systems. As there are so many alveoli (around 300 million per lung) within each alveolar sac and so many sacs at the end of each alveolar duct, the lungs have a sponge-like consistency. This organization produces a very large surface area that is available for gas exchange.

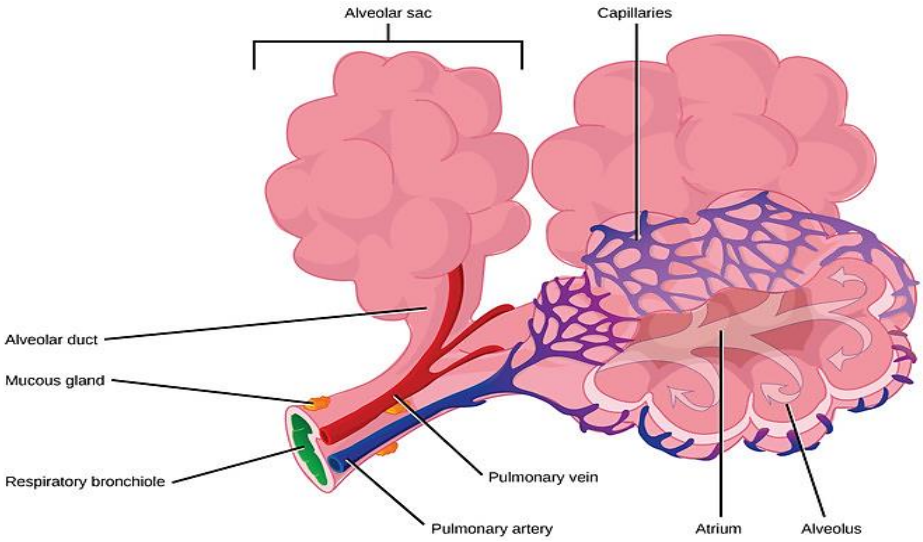


Fig.5.10.3

Alveolar structure: Terminal bronchioles are connected by respiratory bronchioles to alveolar ducts and alveolar sacs. Each alveolar sac contains 20 to 30 spherical alveoli and has the appearance of a bunch of grapes. Air flows into the atrium of the alveolar sac, then circulates into alveoli where gas exchange occurs with the capillaries. Mucus glands secrete mucus into the airways, keeping them moist and flexible.

DO YOU KNOW?

The human respiratory system processes about 11,000 liters of air every day.

The left lung is smaller than the right lung to make room for the heart.

Coughing can expel air at speeds of up to 100 mph.

Alveoli in human lungs provide a surface area equivalent to a tennis court.

Yawning helps cool the brain by drawing in large amounts of air.

Respiratory pigments

The respiratory pigment is a material which is mainly responsible for the transportation and exchange of respiratory gases (oxygen and carbon dioxide). In mammals, it is the haemoglobin.

Haemoglobin is a conjugated protein, where globin protein is combined with ' haem', which means iron. Haemoglobin is produced by liver cells and is synthesised from acetic acid and glycine. The combined product is called porphyrin, which again combines with iron to produce haem molecule. Four molecules of haem then combine with one globin molecule to form haemoglobin. The iron molecule is joined by four of its coordinated bonds to N atoms of the porphyrin and by two bonds to Imidazole N contained in histidine residues within the globin protein.

Acetic acid + glycine → Prophyrin

Prophyrin + iron → Haem

4 Haem + Globin → Haemoglobin

Iron serves as a point of lose physical attachment for O_2 and remains in ferrous (Fe^{2+}) state throughout. Since one molecule of haemoglobin contain four haem group, and each one is able to take up one molecule of oxygen; so one haemoglobin molecule can carry four O_2 molecule at a time. Haemoglobin is dark red in colour, whereas after oxyhaemoglobin, $Hb(O_2)4$ is bright red.

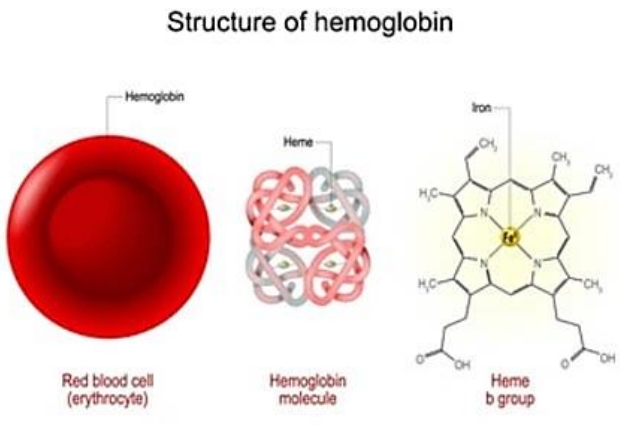


Fig 5.11. Structure of Haemoglobin

Hemocyanin

Hemocyanin is a respiratory pigment found in many invertebrates, including arthropods and mollusks. Unlike haemoglobin, hemocyanin is not bound within cells but circulates freely in the hemolymph. It contains copper atoms instead of iron, giving it a blue or green coloration. Hemocyanin functions by binding oxygen directly to the copper atoms. This pigment is particularly efficient in oxygen transport at low oxygen partial pressures, making it well-suited for organisms inhabiting cold environments.

Chlorocruorin

Chlorocruorin is a respiratory pigment found in some annelids, particularly polychaetes. It contains iron atoms and a green-coloured protein, allowing for oxygen binding and transport. Chlorocruorin has a high affinity for oxygen, making it useful for organisms living in low-oxygen environments, such as muddy sediments or deep-sea habitats.

Haemoerythrin:

It is a reddish-violet-coloured pigment. It is formed of iron and protein. It is less efficient in oxygen-carrying capacity. It occurs in peanut, worms and polychaete Magelona.

Molpadin:

It occurs in phylum Echinodermata e.g. Molpadia.

Echniochrome:

It is a red-coloured pigment containing iron. It is found in the coelomic fluid of sea urchins (an Echinoderm).

Pinnaglobin:

It is a brown pigment containing manganese. it occurs in blood fluid of some molluscs.

Vanadium:

It is present in the blood of many tunicates. Most tunicates can extract vanadium from sea water. Ciona contains vanadium in plasma and Ascidia in special green blood corpuscles called vanadocytes.

WHAT HAS WHAT?

Haemoglobin turns bright red when it binds with oxygen and dark red when deoxygenated.

Haemocyanin, found in molluscs and arthropods, turns blue when oxygenated.

Some Antarctic fish lack haemoglobin entirely due to their oxygen-rich cold water environment.

Chlorocruorin gives certain marine worms their greenish blood.

The blood of certain sea cucumbers contains vanadium, making it green or yellow.

Transport of gases

Oxygen Transport in the Blood

Even though oxygen is transported via the blood, you may recall that oxygen is not very soluble in liquids. A small amount of oxygen does dissolve in the blood and is transported in the bloodstream, but it is only about 1.5% of the total amount. The majority of oxygen molecules are carried from the lungs to the body's tissues by a specialized transport system, which relies on the erythrocyte—the red blood cell. Erythrocytes contain a metalloprotein, Haemoglobin, which serves to bind oxygen molecules to the erythrocyte . Heme is the portion of Haemoglobin that contains iron, and it is heme that binds oxygen. One Haemoglobin molecule contains iron-containing Heme molecules, and because of this, each Haemoglobin molecule is capable of carrying up to four molecules of oxygen. As oxygen diffuses across the respiratory membrane from the alveolus to the capillary, it also diffuses into the red blood cell and is bound by Haemoglobin. The following reversible chemical reaction describes the production of the final product, oxyHaemoglobin ($Hb–O_2$), which is formed when oxygen binds to Haemoglobin. OxyHaemoglobin is a bright red-colored molecule that contributes to the bright red color of oxygenated blood.

$$Hb + O_2 \leftrightarrow Hb - O_2$$

In this formula, Hb represents reduced Haemoglobin, that is, Haemoglobin that does not have oxygen bound to it. There are multiple factors involved in how readily heme binds to and dissociates from oxygen, which will be discussed in the subsequent sections.

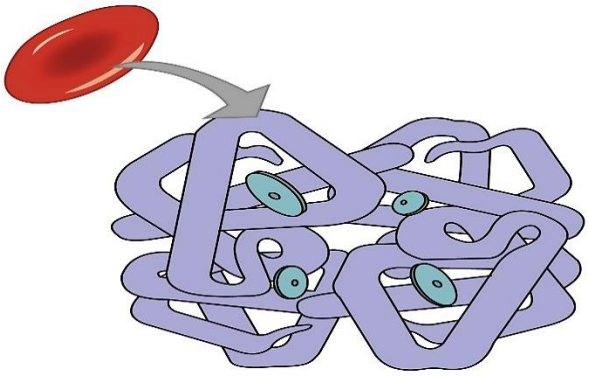
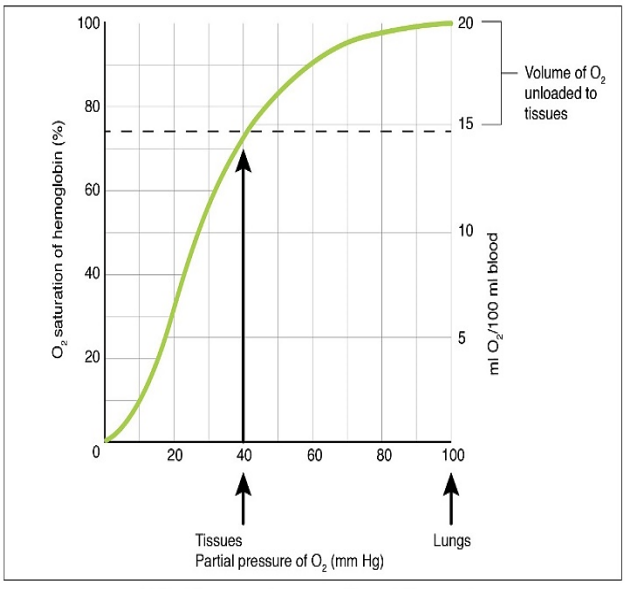


Fig .5.12

Erythrocyte and Haemoglobin: Haemoglobin consists of four subunits, each of which contains one molecule of iron.

Function of Haemoglobin

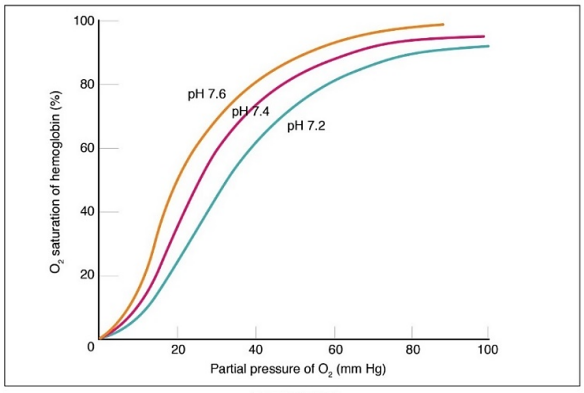
Haemoglobin is composed of subunits, a protein structure that is referred to as a quaternary structure. Each of the four subunits that make up haemoglobin is arranged in a ring-like fashion, with an iron atom covalently bound to the heme in the centre of each subunit. The binding of the first oxygen molecule causes a conformational change in haemoglobin that allows the second molecule of oxygen to bind more readily. As each molecule of oxygen is bound, it further facilitates the binding of the next molecule, until all four heme sites are occupied by oxygen. The opposite occurs as well: After the first oxygen molecule dissociates and is "dropped off" at the tissues, the next oxygen molecule dissociates more readily. When all four heme sites are occupied, the haemoglobin is said to be saturated. When one to three heme sites are occupied, the haemoglobin is said to be partially saturated. Therefore, when considering the blood as a whole, the percent of the available heme units that are bound to oxygen at a given time is called haemoglobin saturation. Haemoglobin saturation of 100 percent means that every heme unit in all of the erythrocytes of the body is bound to oxygen. In a healthy individual with normal haemoglobin levels, haemoglobin saturation generally ranges from 95 percent to 99 percent.



(a) Partial pressure of oxygen and hemoglobin saturation

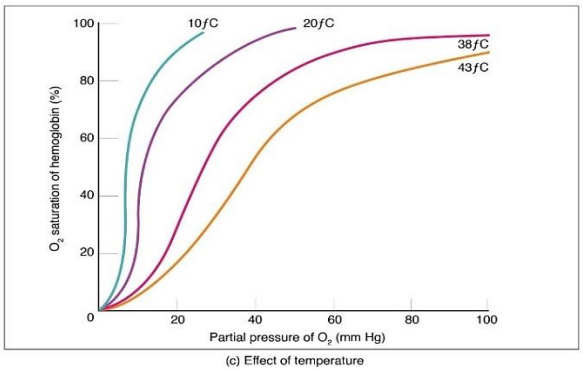
Oxygen Dissociation from Haemoglobin

Partial pressure is an important aspect of the binding of oxygen to and disassociation from heme. An oxygen–Haemoglobin dissociation curve is a graph that describes the relationship of partial pressure to the binding of oxygen to heme and its subsequent dissociation from heme .Remember that gases travel from an area of higher partial pressure to an area of lower partial pressure. In addition, the affinity of an oxygen molecule for heme increases as more oxygen molecules are bound. Therefore, in the oxygen–Haemoglobin saturation curve, as the partial pressure of oxygen increases, a proportionately greater number of oxygen molecules are bound by heme. Not surprisingly, the oxygen–Haemoglobin saturation/dissociation curve also shows that the lower the partial pressure of oxygen, the fewer oxygen molecules are bound to heme. As a result, the partial pressure of oxygen plays a major role in determining the degree of binding of oxygen to heme at the site of the respiratory membrane, as well as the degree of dissociation of oxygen from heme at the site of body tissues.



(b) Effect of pH

Fig.5.12.1 – Oxygen-Haemoglobin Dissociation and Effects of pH and Temperature



(c) Effect of temperature

These three graphs show (a) the relationship between the partial pressure of oxygen and Haemoglobin saturation, (b) the effect of pH on the oxygen–Haemoglobin dissociation curve, and (c) the effect of temperature on the oxygen–Haemoglobin dissociation curve.

The mechanisms behind the oxygen–Haemoglobin saturation/dissociation curve also serve as automatic control mechanisms that regulate how much oxygen is delivered to different tissues throughout the body. This is important because some tissues have a higher metabolic rate than others. Highly active tissues, such as muscle, rapidly use oxygen to produce ATP, lowering the partial pressure of oxygen in the tissue to about 20 mm Hg. The partial pressure of oxygen inside capillaries is about 100 mm Hg, so the difference between the two becomes quite high, about 80 mm Hg. As a result, a greater number of oxygen molecules dissociate from Haemoglobin and enter the tissues.

The reverse is true of tissues, such as adipose (body fat), which have lower metabolic rates. Because less oxygen is used by these cells, the partial pressure of oxygen within such tissues remains relatively high, resulting in fewer oxygen molecules dissociating from Haemoglobin and entering the tissue interstitial fluid. Although venous blood is said to be deoxygenated, some oxygen is still bound to Haemoglobin in its red blood cells. This provides an oxygen reserve that can be used when tissues suddenly demand more oxygen.

Factors other than partial pressure also affect the oxygen–Haemoglobin saturation/dissociation curve. For example, a higher temperature promotes Haemoglobin and oxygen to dissociate faster, whereas a lower temperature inhibits dissociation .However, the human body tightly regulates temperature, so this factor may not affect gas exchange throughout the body. The exception to this is in highly active tissues, which may release a larger amount of energy than is given off as heat. As a result, oxygen readily dissociates from Haemoglobin, which is a mechanism that helps to provide active tissues with more oxygen.

Certain hormones, such as androgens, epinephrine, thyroid hormones, and growth hormone, can affect the oxygen–Haemoglobin saturation/disassociation curve by stimulating the production of a compound called 2,3-bisphosphoglycerate (BPG) by erythrocytes. BPG is a byproduct of glycolysis. Because erythrocytes do not contain mitochondria, glycolysis is the sole method by which these cells produce ATP. BPG promotes the disassociation of oxygen from Haemoglobin. Therefore, the greater the concentration of BPG, the more readily oxygen dissociates from Haemoglobin, despite its partial pressure.

The pH of the blood is another factor that influences the oxygen–Haemoglobin saturation/dissociation curve .The Bohr effect is a phenomenon that arises from the relationship between pH and oxygen's affinity for Haemoglobin: A lower, more acidic pH promotes oxygen dissociation from Haemoglobin. In contrast, a higher, or more basic, pH inhibits oxygen dissociation from Haemoglobin. The greater the amount of carbon dioxide in the blood, the more molecules that must be converted, which in turn generates hydrogen ions and thus lowers blood pH. Furthermore, blood pH may become more acidic when certain byproducts of cell metabolism, such as lactic acid, carbonic acid, and carbon dioxide, are released into the bloodstream.

Haemoglobin of the Fetus

The fetus has its own circulation with its own erythrocytes; however, it is dependent on the mother for oxygen. Blood is supplied to the fetus by way of the umbilical cord, which is connected to the placenta and separated from maternal blood by the chorion. The mechanism of gas exchange at the chorion is similar to gas exchange at the respiratory membrane. However, the partial pressure of oxygen is lower in the maternal blood in the placenta, at about 35 to 50 mm Hg, than it is in maternal arterial blood. The difference in partial pressures between maternal and fetal blood is not large, as the partial pressure of oxygen in fetal blood at the placenta is about 20 mm Hg. Therefore, there is not as much diffusion of oxygen into the fetal blood supply. The fetus' Haemoglobin overcomes this problem by having a greater affinity for oxygen than maternal Haemoglobin . Both fetal and adult Haemoglobin have four subunits, but two of the subunits of fetal Haemoglobin have a different structure that causes fetal Haemoglobin to have a greater affinity for oxygen than does adult Haemoglobin. Pr@fess@r Ac.ademy

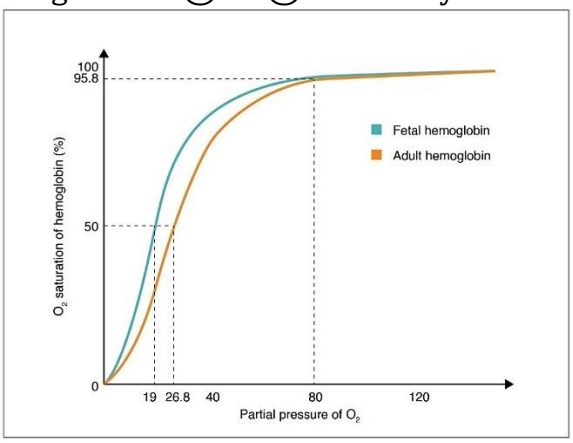


Fig 5.12.2.

Oxygen-Haemoglobin Dissociation Curves in Fetus and Adult: Fetal Haemoglobin has a greater affinity for oxygen than does adult Haemoglobin.

Carbon Dioxide Transport in the Blood

Carbon dioxide is transported by three major mechanisms. The first mechanism of carbon dioxide transport is by blood plasma, as some carbon dioxide molecules dissolve in the blood. The second mechanism is transport in the form of bicarbonate (HCO_3^-), which also dissolves in plasma. The third mechanism of carbon dioxide transport is similar to the transport of oxygen by erythrocytes.

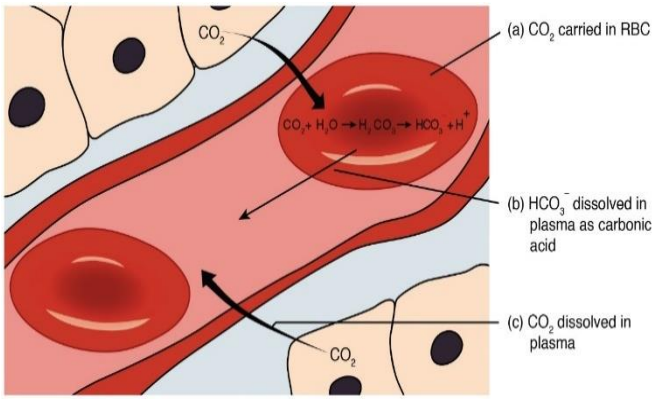


Fig 5.12.3

Carbon Dioxide Transport: Carbon dioxide is transported by three different methods: (a) in erythrocytes; (b) after forming carbonic acid (H_2CO_3), which is dissolved in plasma; (c) and in plasma.

Dissolved Carbon Dioxide

Although carbon dioxide is not considered to be highly soluble in blood, a small fraction—about 7 to 10 percent—of the carbon dioxide that diffuses into the blood from the tissues dissolves in plasma. The dissolved carbon dioxide then travels in the bloodstream and when the blood reaches the pulmonary capillaries, the dissolved carbon dioxide diffuses across the respiratory membrane into the alveoli, where it is then exhaled during pulmonary ventilation.

Bicarbonate Buffer

A large fraction—about 70 percent—of the carbon dioxide molecules that diffuse into the blood is transported to the lungs as bicarbonate. Most bicarbonate is produced in erythrocytes after carbon dioxide diffuses into the capillaries, and subsequently into red blood cells. Carbonic anhydrase (CA) causes carbon dioxide and water to form carbonic acid (H_2CO_3), which dissociates into two ions: bicarbonate (HCO_3^-) and hydrogen (H^+). The following formula depicts this reaction:

$$\mathbf{CO_2 + H_2O \ CA \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-}$$

Bicarbonate tends to build up in the erythrocytes, so that there is a greater concentration of bicarbonate in the erythrocytes than in the surrounding blood plasma. As a result, some of the bicarbonate will leave the erythrocytes and move down its concentration gradient into the plasma in exchange for chloride (Cl^-) ions. This phenomenon is referred to as the chloride shift and occurs because by exchanging one negative ion for another negative ion, neither the electrical charge of the erythrocytes nor that of the blood is altered.

At the pulmonary capillaries, the chemical reaction that produced bicarbonate (shown above) is reversed, and carbon dioxide and water are the products. Much of the bicarbonate in the plasma re-enters the erythrocytes in exchange for chloride ions. Hydrogen ions and bicarbonate ions join to form carbonic acid, which is converted into carbon dioxide and water by carbonic anhydrase. Carbon dioxide diffuses out of the erythrocytes and into the plasma, where it can further diffuse across the respiratory membrane into the alveoli to be exhaled during pulmonary ventilation.

CarbaminoHaemoglobin

About 20 percent of carbon dioxide is bound by Haemoglobin and is transported to the lungs. Carbon dioxide does not bind to iron as oxygen does; instead, carbon dioxide binds amino acid moieties on the globin portions of Haemoglobin to form carbaminoHaemoglobin, which forms when Haemoglobin and carbon dioxide bind. When Haemoglobin is not transporting oxygen, it tends to have a bluish-purple tone to it, creating the darker maroon color typical of deoxygenated blood. The following formula depicts this reversible reaction:

$$\mathbf{CO_2 + Hb \leftrightarrow HbCO_2}$$

Similar to the transport of oxygen by heme, the binding and dissociation of carbon dioxide to and from Haemoglobin is dependent on the partial pressure of carbon dioxide. Because carbon dioxide is released from the lungs, blood that leaves the lungs and reaches body tissues has a lower partial pressure of carbon dioxide than is found in the tissues. As a result, carbon dioxide leaves the tissues because of its higher partial pressure, enters the blood, and then moves into red blood cells, binding to Haemoglobin. In contrast, in the pulmonary capillaries, the partial pressure of carbon dioxide is high compared to within the alveoli. As a result, carbon dioxide dissociates readily from Haemoglobin and diffuses across the respiratory membrane into the air.

In addition to the partial pressure of carbon dioxide, the oxygen saturation of Haemoglobin and the partial pressure of oxygen in the blood also influence the affinity of Haemoglobin for carbon dioxide. The Haldane effect is a phenomenon that arises from the relationship between the partial pressure of oxygen and the affinity of Haemoglobin for carbon dioxide. Haemoglobin that is saturated with oxygen does not readily bind carbon dioxide. However, when oxygen is not bound to heme and the partial pressure of oxygen is low, Haemoglobin readily binds to carbon dioxide

Gas Exchange:

The main part of gas exchange occurs in the alveoli. The exchange of gases takes place between blood and tissues. Gas exchange occurs by simple diffusion based on a pressure gradient or a concentration gradient. The solubility of the gas and the thickness of the film are the important factors affecting diffusion. The partial pressure is the pressure of a single gas in a gas mixture. The partial pressure of oxygen is represented by pO_2, and the m=partial pressure of carbon dioxide is represented by pCO_2.

Respiratory Gases	Partial Pressure mm Hg				
	Atmospheric air	Alveoli	Deoxygenated Blood	Oxygenated Blood	Tissues
O_2	159	104	40	95	40
CO_2	0.3	40	45	40	45

Partial pressures of oxygen and carbon dioxide (in mm Hg) at different parts as compared to the other gases present in atmosphere

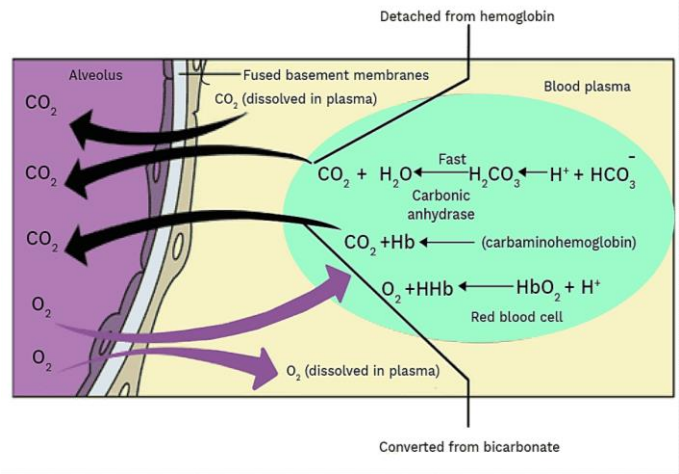


Fig 5.13.Diagrammatic Representation of Gas exchange Between Alveoli and Other Body Parts

The amount of CO_2 that can diffuse through the diffusion membrane is greater than the O_2 partial pressure. The diffusion membrane is formed by the layer of the squamous epithelium of the alveoli, the endothelium of the capillaries of the alveoli and the basement material between the two layers. The total thickness of the diffusion membrane is less than one millimetre. The diffusion of O2 from the alveoli to the tissues and the diffusion of CO2 from the tissues to the alveoli are aided by all variables in our bodies.

Regulation of respiration

The ability of humans to control or regulate their breathing rhythm to meet their body's needs is significantly known as the regulation of respiration. The complex interaction of three respiratory system parts.

- the control centres,
- the sensors,
- the effector organs—is essential for controlling breathing. The brainstem is home to the control centres, which are in charge of breathing's automaticity.

Respiration Center of Brain control Center

Both of these structures, the pons Varolii and the medulla oblongata, are found in the brain stem and are in charge of autonomic breathing. The higher brain centres provide the input necessary for these centres to produce the necessary voluntary breathing efforts.

Sensors

These include both chemoreceptors and sensory receptors.

- Chemoreceptors: The chemoreceptors deliver impulses to the control centres in response to variations in the blood's concentration of carbon dioxide, oxygen, and hydrogen ions. Having an impact on the effector organs will change the pattern of breathing.
- Sensory receptors: The lung and breathing muscles all include sensory receptors in our upper and lower airways.

Effector Organs

Other breathing muscles as well as the internal and external intercostal muscles of the rib cage and the abdominal muscles.

Types of Respiratory Regulations

There are two mechanisms that can control breathing.

- Neural regulation: Respiratory centres located in the medulla oblongata are part of the nervous system that controls breathing. It measures the blood's level of oxygen and carbon dioxide and uses the respiratory muscles to provide the

appropriate signals. More specifically, there are two categories of respiratory centres.

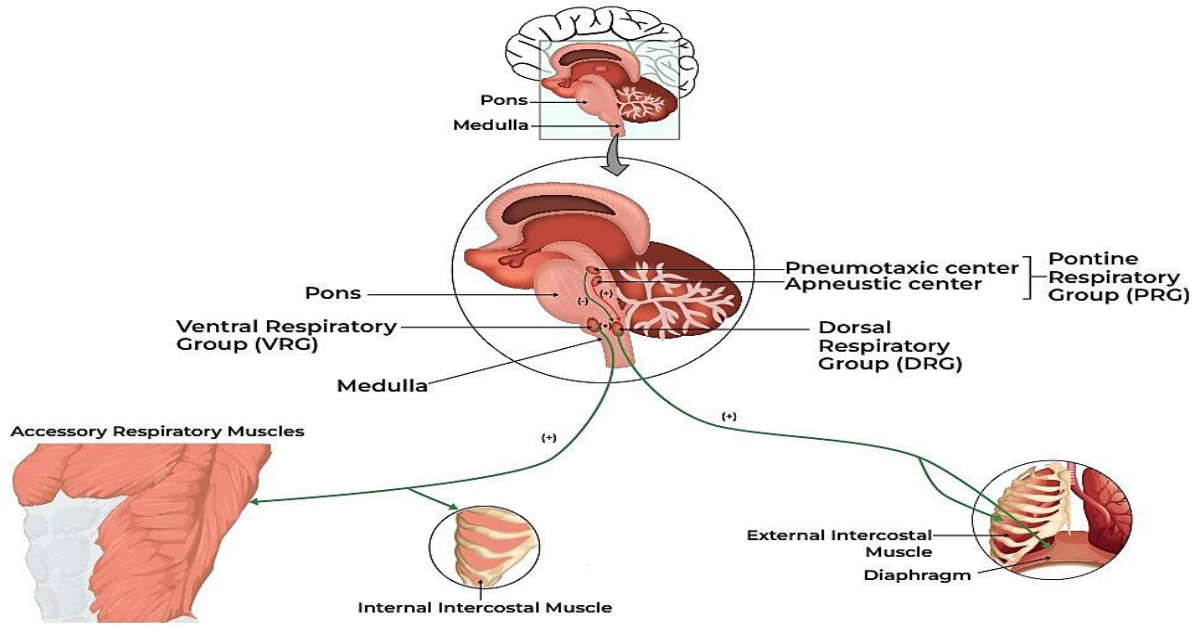
- Chemical regulation: Centres associated with the chemical regulation of respiration are as follows:
- medullary oblongata close to the inspiratory centre.
- The concentration of pCO_2 and H^+ ions affects this region. Therefore, a rise in pCO_2 and H^+ ions activates these receptors, which in turn activates the inspiratory centre or the respiratory rhythm centre.

Central chemoreceptors:

- These can be found in the area of the
- The rate of inspiration or respiration is altered when rhythm centres are active. As a result, the respiratory system will need to change in order to clear these pollutants.

Peripheral chemoreceptors:

- In hypoxemia, peripheral chemoreceptors detect changes in arterial blood oxygen levels and trigger reflexes that are essential for maintaining homeostasis.
- peripheral chemoreceptor responses are important because of how they react to various pathological and physiological situations.
- Both the carotid and aortic bodies experience an increase in sensory discharge in response to hypoxia.
- It has been shown that the carotid bodies, the main peripheral chemoreceptor, are more responsible for the hypoxic response.



Respiration is modulated by neural impulses that travel from the brain's respiratory centres to the muscles of the chest and diaphragm. The three major brain centres that control respiration are, they can be found in the pons and medulla of the brain. They stimulate the diaphragm and intercostal muscles to contract, which controls breathing.

Respiratory Rhythm Center

The pneumotaxic centre, which controls how well the respiratory rhythm centre works, is located in the pons, while the respiratory rhythm centre is located in the medulla oblongata. The inspiration centre in the medulla, which controls the dorsal respiratory rhythm, is primarily in charge of maintaining a normal breathing rhythm. When engaging in physical activity that results in deep breathing, the ventral respiratory centre of the medulla (expiratory centre) is in charge of sending signals to control the rhythm of both expiration and inspiration.

In Pons Pneumotaxic Center

The upper pons contains the pneumotaxic centre, which controls inspiratory volume and respiratory rate by sending inhibitory impulses to the inspiratory centre and shopping inspiration. This centre is probably important in fine-tuning breathing.

Apneustic Centre

- The inspiratory centre is hypothesised to be stimulated by the lower pons' apneustic centre. Stimulation of the apneustic centre results in a gradual increase in the firing rate of the inspiratory muscles rather than providing signals to them to contract instantly.
- Along with the respiratory rhythm centre, the

brain stem also has a chemosensitive region. It is very reactive to hydrogen ions and CO_2. This centre is activated by an increase in CO_2 and H^+ ions, which instructs the rhythm centre to modify the breathing process and expel these substances.

- There are certain receptors that, in addition to respiratory centres, have the ability to recognise changes in CO_2 and H^+ ion concentration and provide signals to control breathing. While some of them are receptors in the walls of bronchi and bronchioles, others are chemoreceptors found in the medulla, aortic arch, and carotid artery.

Factors Affecting the Rate of Respiration

Temperature: At a very high temperature, the rate of respiration decreases with time, and at a very low temperature, the respiration rate is insignificant. The optimum temperature for respiration is 20 – 30 °C.

Carbon dioxide: Higher concentration of carbon dioxide lower the rate of respiration. An increase in carbon dioxide concentration and the absence of oxygen adversely affect the rate of aerobic respiration.

Water: As the respiring organism's water content rises, the respiratory rate does as well.

Light: Light regulates respiration by increasing an organism's body temperature.

MEMORY TEST

1. What is the primary function of gills in aquatic arthropods?
a) Gas exchange b) Excretion
c) Food digestion d) Sensory detection

2. Which type of gill is characterized by leaf-like flattened gill plates?
a) Dendrobranchiate gills b) Phyllobranchiate gills
c) Trichobranchiate gills d) Arthrobranch

3. What type of respiratory organ is found in the larvae of Culex mosquitoes?
a) Blood gills b) Rectal gills
c) Tracheal gills d) Book lungs

4. What is the respiratory pigment in most mammals?
a) Hemocyanin b) Chlorocruorin
c) Hemoglobin d) Vanadium

5. What is the unique feature of bird respiration compared to mammals?
a) Bidirectional airflow b) Fewer alveoli
c) Lack of air sacs d) Unidirectional airflow

6. Which organ is responsible for gas exchange in birds?
a) Lungs b) Air sacs
c) Parabronchi d) Swim bladder

7. What structure connects the lungs to the external environment in mammals?
a) Trachea b) Alveoli
c) Bronchioles d) Diaphragm

8. What happens to haemoglobin when it binds with oxygen?
a) It becomes carbaminohemoglobin
b) It becomes oxyhemoglobin
c) It releases carbon dioxide
d) It forms a bicarbonate ion

9. What is the role of the pneumotaxic center in the brain?
a) Stimulates inspiration
b) Controls respiratory rhythm
c) Fine-tunes breathing
d) Detects blood pH levels

10.Which accessory respiratory organ allows some fish to survive in oxygen-depleted water?
a) Tracheal gills b) Air-bladders
c) Book lungs d) Book gills

Ans: 1-a, 2-b, 3-c, 4-c, 5-d, 6-a,7-a, 8-b, 9-c, 10-b

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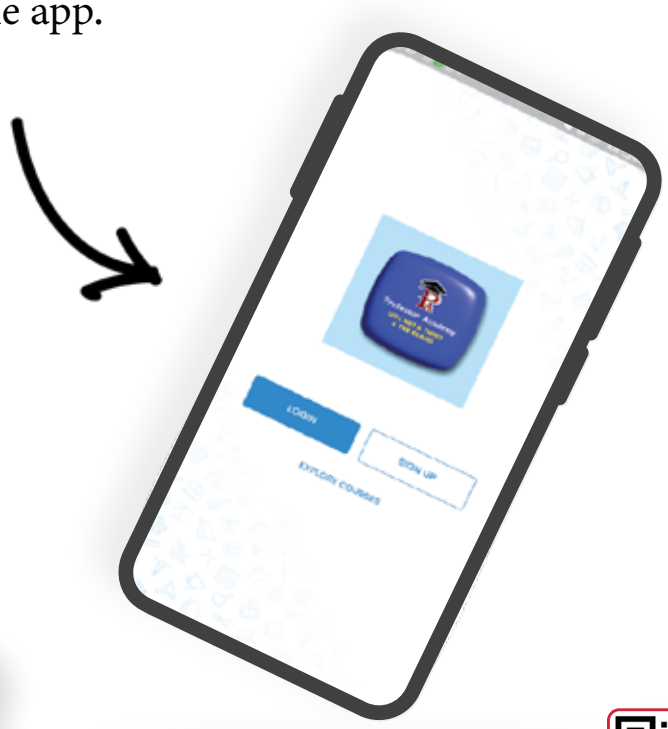

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