	phosphorus (as inorganic phosphate), sulfate and iron. These are referred as plasma electrolytes.
Foodstuffs (nutrients)	Glucose, amino acids, fats and vitamins
Waste products	Urea, uric acid and creatinine
Fibrinogen, prothrombin hormones, enzymes	Necessary for the clotting of blood

The plasma proteins are generally too large a molecule to leave the blood vessels. They are thus important for maintaining the osmotic pressure of blood and preventing loss of fluid from the circulation. At the arterial end of the capillary, the hydrostatic force within the vascular compartment is sufficient to cause fluid to pass into the interstitial space. However, at the venous end of the capillary, the osmostic pressure of the plasma proteins exceeds the hydrostatic pressure and most of the fluid is returned to vascular compartment. The residual fluid is usually drained away by the lymphatic system. In some disorders of kidney, protein is lost in the urine in large amounts, osmotic pressure of blood falls and fluid gathers in the intercellular tissue spaces causing swelling, known as edema. Plasma proteins have some buffering capacity and this way they help to maintain a constant blood pH .

The globulin fraction of the plasma proteins contains the antibodies which are important in the body's defence against infection.

THE BLOOD CELLS

There are three type of blood cells:

1. Red cells (erythrocytes),
2. White cells (leucocytes) and
3. Platelets (thrombocytes).

The erythrocytes are most numerous of the blood cells, biconcave (this shape provides larger surface area for oxygen and carbon dioxide exchange than a spherical one), non-nucleated discs about 7.2 cm in diameter. The cell membrane is elastic and deformable allowing the red cell to be distorted to pass through narrow capillaries. Their normal count in an adult male is 5×10^{12}/L of blood.

The erythrocyte contain a special colored protein called hemoglobin in combination of haem (ferrous-iron-containing pigment) and globin. A normal person has about 14.5 gm hemoglobin/100 ml of blood. Hemoglobin has a marked affinity for oxygen with which it combines reversibly in the lungs where oxygen tension is high. In tissue where cell metabolism produces carbon dioxide, hemoglobin delivers its oxygen. Increasing of hemoglobin within the cells, prevents its loss in urine and destruction by macrophages.

The formation of erythrocytes (erythropoesis) take place in the red bone marrow from large nucleated cells. These cells divide to form progressively smaller cells and as the erythrocytes mature they loose their nucleus. In the absence of sufficient iron and vitamin B_{12}, folic acid, the cells produced are microcytic and macrocytic respectively.

A normal red cells has life span of 120 days in the circulation. Afterwards the cell is destroyed in the macrophage system. The hemoglobin is released, iron and globin are separated out. Thus bile pigment (bilirubin) is formed in the liver, excreted in bile, whereas iron is stored as ferritin until needed for new hemoglobin formation.

If anticoagulated blood is allowed to stand in a narrow vertical tube (western green/ wintrobe), the erythrocytes will settle (ESR) at a particular rate. This rate is increased in various diseases.

Anemia is the condition in which the hemoglobin concentration is below normal. There may be following causes:

1. Blood loss—either acute or chronic
2. **Inadaquate red cell production:** This may occur due to the lack of essential factors (iron, vitamin B_{12} or folate) and may be caused by destruction of the bone marrow by certain chemicals, X-rays, drugs, secondary carcinoma invasion or leukemia.
3. Increased red cell destruction, known as hemolysis. Hemolytic anemias may be due to abnormalities of the red cells, which are, therefore, destroyed more quickly than normal red cells or due to the factors (malaria, drugs or antibodies) which lead to premature destruction of normal red cells.

The leucocytes or white blood cells are fewer in number than the red cells. The normal count ranges from 4 to 11×10^9/I and also there are variations from hour to hour in a healthy individuals. The white cells can be classified—granulocytes and agranulocytes. Granulocytes are of three type:

1. Neutrophils
2. Eosinophils
3. Basophils

These are 10 to 14 µm in diameter, the neutrophil plays a significant role in body's defence mechanism against infection (bacterial) by reaching at the site of infection as they are highly motile cells. Eosinophil which are phagocytic but less motile respondants to allergic conditions. Basophil are the least numerous of the granulocyte series. They are similar to tissue mast cells and are important in certain hypersensitivity reactions.

Lymphocytes are formed in the bone marrow, from there they migrate to thymus (to become ' T ' lymphocytes or killer cells), and lymphatic tissue of GI tract (to become 'B' lymphocyte having capability to produce antibodies.

Monocytes are the largest cells amongst white blood cells (14–18 µm). They are phagocytic. Some circulate in the blood stream while others leave to join the macrophage system. The proportions of all the white cells in healthy are as follows:

Granulocytes 70% (neutrophil 40–75%).

Eosinophil 16% and basophil 0–1%, lymphocytes 20–45% and monocytes 2 to 10%.

Platelets (thrombocytes) are colorless cells, vary in shape, small (2–4 µm), non-nucleated and are $150–400 \times 10^9$ L in number. They are formed in bone marrow from magakaryocytes. Platelets play a very significant role in blood clotting.

Bone marrow: Bone marrow is found in the center of all bones and is of two types, red marrow and yellow marrow. Red marrow is usually present throughout the skeleton at birth but after the age of five years it is gradually replaced in the long bones by yellow marrow. By the age of 20–25 years, the red marrow is present only in the ribs, the sternum, the vertebrae, the skull, the pelvis and upper ends of the femora and humeri.

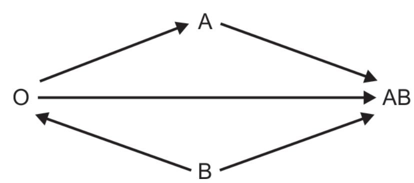
Blood Groups

The moderate to severe blood loss is often treated by transfusion and if blood of an incompatible group is transfused the cells of the given blood agglutinate (clumping or sticking of cells). This phenomenon gave the origin to blood group. There are four main blood groups—A, B, AB and O. The process of agglutination is caused by a substance, called an agglutinogen, which is present on the red cells, of one group react with a substance called an agglutinin which is present in the plasma of another group. The distribution of agglutinogens and agglutinins in people with different ABO blood group shown in Table 2.1.

Table 2.1: The distribution of agglutinogens and agglutinins in people with different ABO blood group

Blood group	O	A	B	AB
% age of population	46%	42%	9%	3%
Cells	—	Agglutinogen	Agglutinogen	A and B agglutinogen
Plasma	Anti-A and Anti-B agglutinins	Anti-B agglutinin	Anti-A agglutinin	–

Since blood group AB has no agglutinins in the plasma, persons of this blood group can often be transfused with blood of the other groups (universal receipient) whereas blood group O has no agglutinogen (universal donor) can donate blood to others without much complications. Thus blood transfusion may be given along with the lines indicated by the arrows.



In 1940 another important blood group was discovered and has been named Rhesus factor or Rh system. Unlike ABO system, no preformed Rhesus agglutinin (Anti-D) is found. However, a Rhesus negative (Rh-ve) person, can make Anti-D following sensitization with Rhesus positive blood. The ABO and Rhesus blood group systems are the main groups but there are others such as the M, N, Kell, Luther and Duffy which may be occasional causes of blood transfusion reactions.

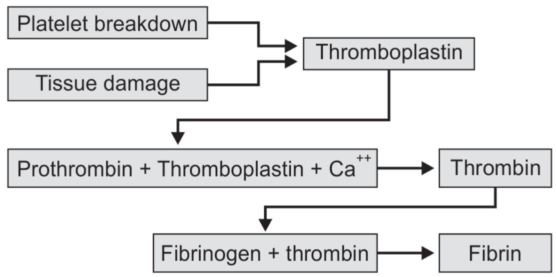
The Clotting of Blood

Whenever blood oozes from an injured blood vessel, it tends to clot, in an attempt to prevent further blood loss. The mechanism involved in blood clotting are complex. The process involves a number of steps in a so-called cascade system. The clotting cascad is a chain reaction initiated either by contact of platelets with damaged vascular endothelium or by contact with tissue fluid when the vessel wall is breached. In brief, it is a three stage process.

Stage I: The formation of thromboplastin (thrombokinase)

Stage II: Conversion of prothrombin to thrombin by the thromboplastin in the presence of Ca^{++}.

Stage III: Conversion of fibrinogen by the thrombin to fibrin.



There are thirteen clotting factors in all, which are required for the clotting mechanism to complete. Out of these in the absence of factor VIII, anti-hemophilic globulin (AHg), a condition known as hemophilia does occur. It is a sex linked disease in which males are the sufferer and females are the transmitters.

THROMBOSIS AND FIBRINOLYSIS

Normally blood does not clot within blood vessels but occasionally sometime this happen and is called thrombosis. There is also a natural system exists in blood vessels which opposes the clotting of blood. Plasminogen is converted to the active plasmin, which digests the insoluble fibrin. In healthy individuals the activities of the coagulation and fibrinolytic systems are balanced.

Bone marrow transplantation: Bone marrow transplantation is now being used to replace diseased marrow with healthy bone marrow cells obtained from suitably matched donor.

THE BLOOD VESSELS

The blood is pumped by the heart through a closed system of vessels. These vessels are of three types: arteries, capillaries and veins.

Arteries

The arteries carry the blood away from the heart to the tissues. They all consists of three coats: (i) Tunica adventitia (outer coat) is composed of fibrous tissue containing a few elastic fibers. (ii) Tunica media (middle coat) consists of smooth muscle fiber which run in circular direction. (iii) Tunica intima (inner coat) is composed of a single layer of endothelial cells with underlying elastic tissue (Fig. 2.1). In large arteries, there is more elastic tissues in tunica media than in small arteries. The very small arteries are called arterioles.

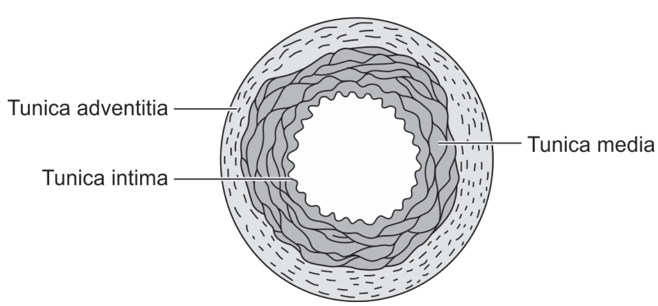


Fig. 2.1: Cross-section of an artery

Capillaries

The arterioles divide into very small vessels called capillaries. The wall of the capillary is composed of a single layer of endothelial cells which is continuous with the endothelial lining of the arterioles. It is through the wall of the capillaries that the exchanges between plasma and interstitial fluid take place. The diameter of a capillary is about the same as that of a red blood cell.

Veins

Veins, like arteries have three coat wall with some differences like the thickness of middle coat is much thinner and the lumen is larger as compared with arteries (Fig. 2.2a and b). Most of the large veins have on their inner surface, valves which serve to prevent back flow of blood. These are folds of tunica intima strengthened by connective tissue and elastic fibers. They are of particular importance in the lower part of the body when the blood is returning towards the heart against gravity.

The Heart and Circulation

The heart is a muscular pump, consisting of four chambers, two right and two left with normally no direct communication between two sides (Fig. 2.3). Blood is returned to the heart from the body through the superior and inferior venae cavae open into a thin walled chamber called the right atrium. The right atrium pumps the blood through a valve called the tricuspid valve into a chamber called right ventricle, the right ventricle in its turn pumps the blood through the pulmonary artery into the lungs. In the capillaries of the lungs, the blood takes up oxygen and releases carbon dioxide. The oxygenated blood passes through the pulmonary veins into a thin walled chamber called the left atrium. The left atrium pumps the blood through a valve, called the mitral valve, into the thickest walled chamber of the heart, the left ventricle. The left ventricle in turn pumps the blood into the aorta from where it is distributed to the body. These series of events occur in parallel so that left and right ventricles contract together. The general circulation of the body is known as the systemic circulation and the circulation of the lungs is called the pulmonary circulation. Greater pressure is required to pump the blood through systemic circulation as compared with pulmonary circulation. Thus the thickness of left atrium and left ventricle are self-explantory.

The Nerve Supply to the Heart

The heart is supplied by branches of the vagus and sympathetic nervous system.

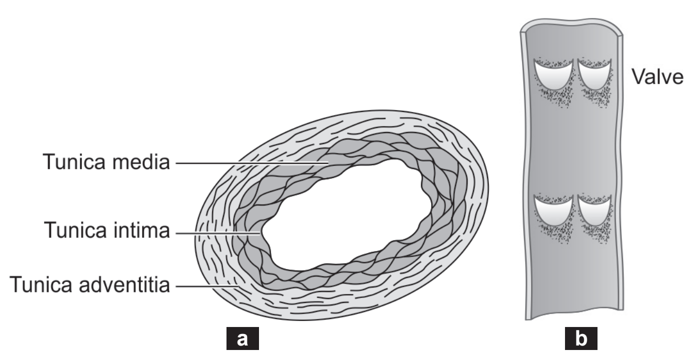


Fig. 2.2: Structure of a vein: (a) transverse section, and (b) longitudinal

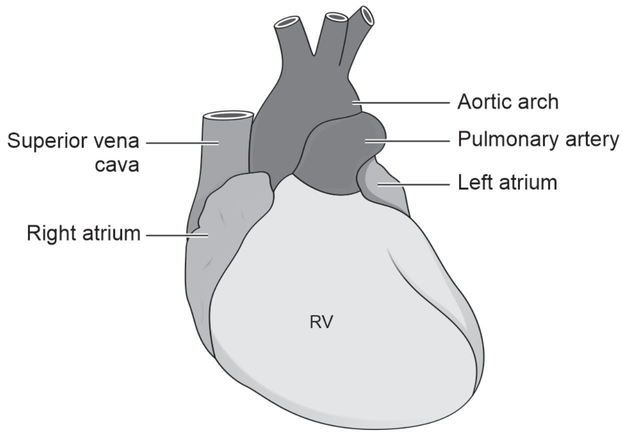


Fig. 2.3: The heart, anterior view

The Functions of the Heart

The functions of the cardiovascular system is to maintain an adequate supply of blood to all the body tissues according to their metabolic needs. Arterial blood carries oxygen, glucose and other nutrients to organs and tissues. Venous blood transport the 'waste' products of tissue metabolism such as carbon dioxide and lactic acid away from these tissues.

The blood supply to the vital systems, such as the brain and kidneys are always looked after by special features such as high atmospheric pressure in the arteries of these even after blood loss.

The flow of blood to exercising muscle is increased and this is important so that adequate supply of nutrients and simultaneouly removal of products of metabolism are maintained.

Cardiac Cycle

The heart muscle contracts rhythmically at the rate of 72 beats/min (in the resting state). Each contraction is in a cyclic manner. The origin of the impulse is at sinoatrial node (SA node) (Fig. 2.4) which is a group of specialized cells situated in the wall of the right atrium near the enterance of the superior vena cava. The SA node originates each heartbeat, therefore it is also known as pacemaker. The cardiac muscles are striated like skeletal muscle but they have syncytical like arrangement (having inter calated discs of low resistance area) enables a contraction wave to spread rapidly from cell to cell until the whole muscle mass is in a state of contraction. No nerves are involved in the spread of the contraction waves through cardiac muscle. Therefore, from SA node, the impulse spreads to AV (atrioventricular) node situated in the interatrial septum near the mouth of the coronary sinus. These two nodes (SA and AV) are supplied by fibers from sympathetic and vagal fibers of parasympathetic systems. From AV node, the contraction wave spreads to atrioventricular bundle (bundle of His). This bundle runs into the ventricles in the septum between the right and left ventricle. The sequence of events of heart contraction and relaxation, are known as cardiac cycle, which are as follows (Fig. 2.5). With the onset of ventricular systole, the pressure in the ventricle starts to rise.

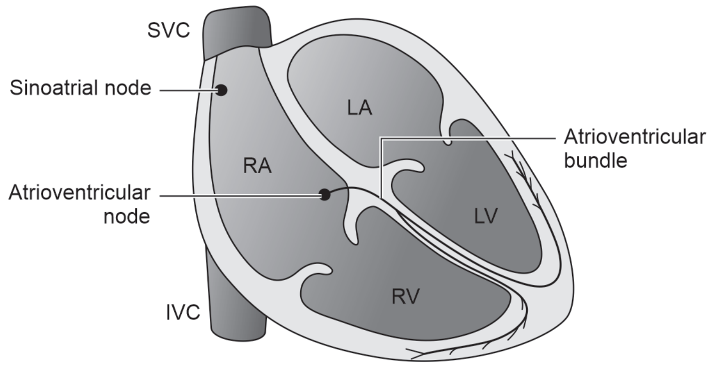


Fig. 2.4: Diagrammatic representation of the conducting system of the heart

As soon as it exceeds that in the corresponding atrium, the atrioventricular valves will shut. This simultaneous closure of the mitral valve (between left atrium and left ventricle) and tricuspid (between right atrium and right ventricle) valves with the onset of systole produces the first heart sound. It can be heard by applying the ear to the chest wall of the subject. The sound heard may be likened to the word 'lub' spoken very softly. It lasts for 0.15 seconds and the principal frequency of the sound produced are in the range of 25–45 cycles per second. As soon as the ventricular pressure exceed those in the aorta and the pulmonary artery (120 mm Hg), the aortic and pulmonary valves will open (semilunar). The opening of the valves does not produce any detectable sound. During the short interval of the time between the closure of the mitral valve and tricuspid valve and the opening of the aortic valve and pulmonary valve the left and right ventricle are closed chamber. Since blood is incompressible and although the contraction of the ventricular muscle is increasing the pressure in the ventricles, though there is no actual change in the volume is known isometric contraction phase. Soon after this the aortic and pulmonary valves are opened, the ventricle ejects their blood first rapidly (rapid ejection phase) and then slowly into aorta and in pulmonary artery. At the end of ventricular systole, the pressure in the ventricle drops and the aortic and pulmonary valves are closed as the pressure in these vessels now exceeds that in the ventricles. There is a short 'isometric relaxation phase' during which time the ventricles once again are closed chambers but as soon as the ventricular pressure has fallen below to that in the atria, the mitral and tricuspid valves are open, causing filling of ventricles.

The closure of the aortic and pulmonary valves gives rise to the second heart sound. This is of short duration and high pitched heard as 'Dup'. It lasts for 0.1 seconds the principle frequency is around of 50 cycles/second. The pressure and volume changes in all the heart chambers during cardiac cycle along with the heart sounds and ECG are shown in Fig. 2.5.

Electrocardiography (ECG)

Each impulse generated by the SA node and passing through the conducting system of the heart causes a series of electrical changes in the heart muscle which preceed the associated mechanical events. These electrical changes can be recorded by placing the electrode on the surface of the body. There are two basic type of electrode (lead system)—

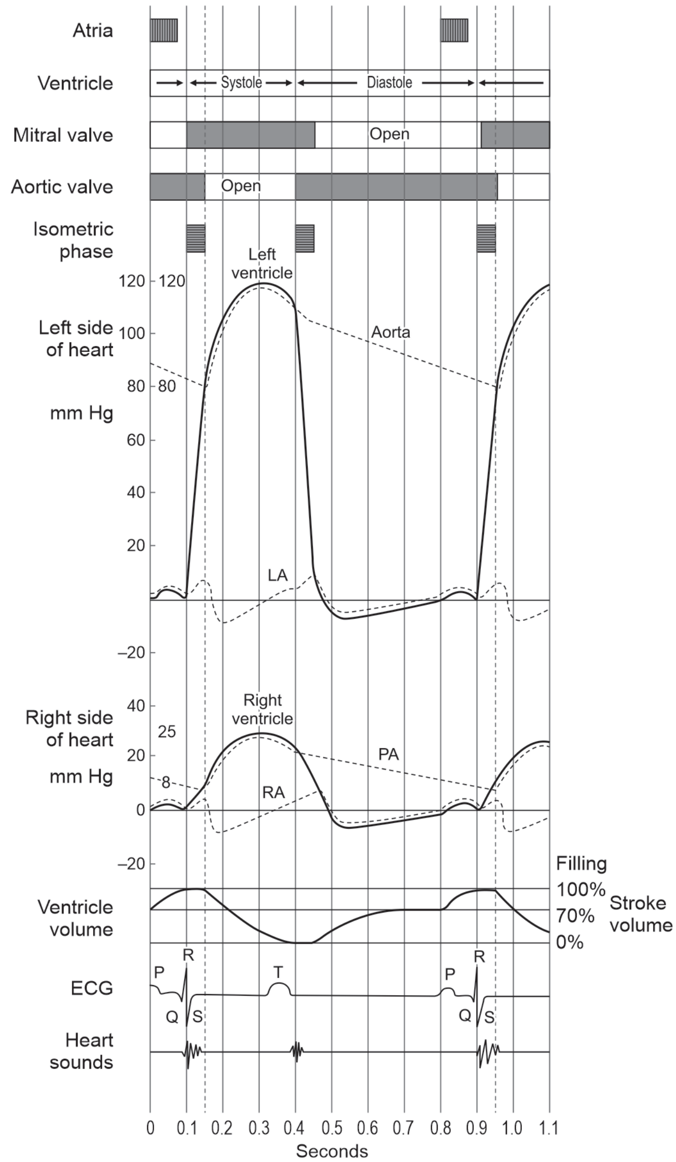


Fig. 2.5: The sequence of events in the cardiac cycle starting with the onset of atrial systole. Part of the subsequent cycle is shown. PA = Blood pressure in the pulmonary artery; RA = Right atrial pressure; LA = Left atrial pressure

bipolar and unipolar. By varying the position of the electrode, information about the passage of impulse through various parts of the heart can be obtained. The normal pattern of ECG is shown in Fig. 2.5 along with the cardiac cycle. The various peaks of ECG as 'P' wave it represents the passage of the impulse through the atria, the 'QRS' complex, the impulse passing through the ventricular recovery. Electrocardiography plays an important part in the investigation of the heart as a condition known as atrial fibrilation, the atria beats rapidly which are depicted in ECG pattern as large number of irregular, lower amplitude fibrilation.

Cardiac output: In each systole, the ventricle ejects 70 ml of blood into the aorta and this is known as stroke volume. At a normal resting heart rate 70/min, the heart pumps about 5 L of blood and this is known as cardiac output. Therefore cardiac output = stroke volume × heart rate.

Any factor affecting stroke volume and heart rate is going to affect CO (cardiac output). The stroke volume depends upon: (a) Volume of venous blood returning to the heart (venous return) and the venous return would depend upon peripheral resistance. (b) The strength of contraction, which does changes according to venous return. This relationship is known as 'Frank starling law'. Also whenever there is sympathetic stimulation the strength of contraction of heart muscle would increase at the cost of end systolic volume whereas the regulation of heart rate very much depends upon the activity of SA node, stimulation of vagal nerve would slow its (SA node) activity and impulsus from the sympathetic nervous system accelerate the heart rate as explained earlier. Thinking of exercise or actual doing the exercise would bring about the increase in heart rate as well as in strength of contraction.

Therefore, increase in cardiac output during exercise is justified as fulfilling the body demands for more oxygen. The cardiac output can be measured by dye dilution method.

THE BLOOD PRESSURE

The blood pressure is the pressure exerted by the blood on the lateral walls of the arterial vessels. The pressure is higher during left ventricular systole, around 120 mm Hg in healthy individuals. This is known as systolic blood pressure, when left ventricular systole is over, the aortic valve closes and the elastic arterial walls do recoil. Although the blood pressure falls, it does not reach zero because left ventricular systole occurs again. The lowest blood pressure is usually about 80 mm Hg and this is known as the diastolic blood pressure. The blood pressure is equal to cardiac output and peripheral resistance. The existance of normal blood pressure is quite essential as tissues of the body need an adequate blood flow and to provide this an adequate head of pressure must be available in the vessels supplying the tissues, particularly brain. The brain, in sitting or standing position, is situated at a higher level than the heart, and blood has to be pumped uphill from the heart to the brain. Unless an adequate blood pressure is maintained at the level of the heart, the cerebral blood flow will be insufficient to maintain consciousness. A person who faints due to a fall in blood pressure should be placed with his head at the same level as the heart, such as flat on the floor. The kidneys also need adequate blood pressure though for a different reason. There the pressure is needed for filtration (GTR) so that formation of urine remains to be continued.

We have studied earlier the factors affecting cardiac output. Now let us know various factors affecting peripheral resistance. The peripheral resistance depends mainly upon the smooth muscle of the arterioles and the pre-capillary sphincters, their smooth muscle is under the control of sympathetic nerve activity known as sympathetic tone or vasoconstrictor tone. The tone originates in the medulla in a collection of cells known as vasomotor center (VMC). As shown in Fig. 2.6 an increase in activity of VMC would decrease the diameter of the arterioles and would lead in the increase in peripheral resistance and arterial blood pressure. Conversely a decrease in VMC activity would cause fall in blood pressure.

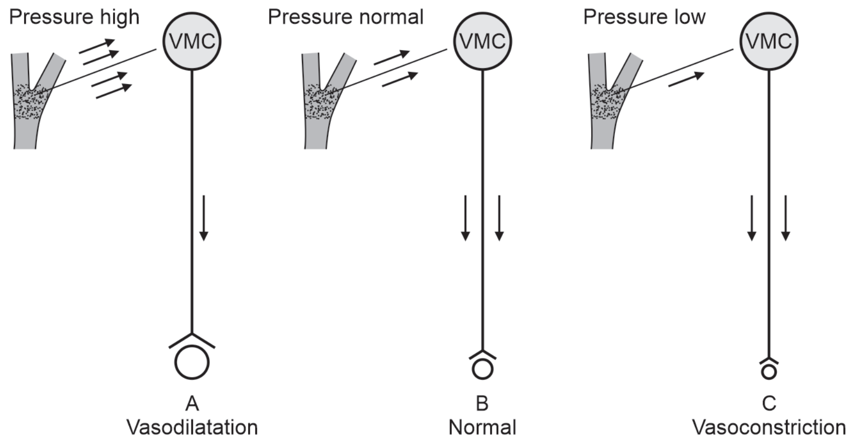


Fig. 2.6: Baroreceptor activity and arteriolar tone

A. High pressure in baroreceptor region gives increased baroreceptor activity, and a reduction in vasoconstrictor tone. This results in vasodilatation of the arterioles.
B. Normal, baroreceptor activity partially inhibits the vasomotor center (VMC) giving normal arteriolar tone.
C. A low pressure in the baroreceptor regions reduces baroreceptor inhibition of the VMC. The arteriolar tone increases giving vasoconstriction.

Baroreceptors are stretch receptors situated in aortic arch and carotid sinus, when stimulated (when blood pressure is increased) leads vasodilation via VMC as shown in Fig. 2.6 and during low blood pressure the reverse effect is observed. Baroreceptors along with other factors shown in Fig. 2.7 brings about changes in heart rate by acting on cardiac center.

The estimation of blood pressure (systolic and diastolic) in human beings can be carried out by using mercury sphygmomanometer.

BLOOD VOLUME

Blood volume which is about 75–80 ml/kg of body weight or 5L in an average adult is kept remarkably constant in health. Fluid is lost from the body in the urine, sweat, faeces and there is insensible loss through the lungs as water vapour and the skin. Fluid intake, which balances these losses is controlled by thirst. In addition, increased loss via one route is usually offset by decreased loss via another. For example, excessive sweating, caused by heat exposure is associated with a marked decrease in urine output.

Normally water deplition is prevented by the antidiuretic hormone as mentioned earlier. Conservation of sodium by the body is another important aspect to maintain the blood volumes. The mechanism by which it is maintained is known as renin-angiotensin-aldosterone system.

Therefore, blood flow through tissues and organs is dependent upon total blood volume, arterial blood pressure, the state of arterioles and blood viscosity.

THE PULMONARY CIRCULATION

The main pulmonary artery arises from the right ventricle through which venous blood is sent to lungs and from lungs arterialised blood returns to the heart via pulmonary

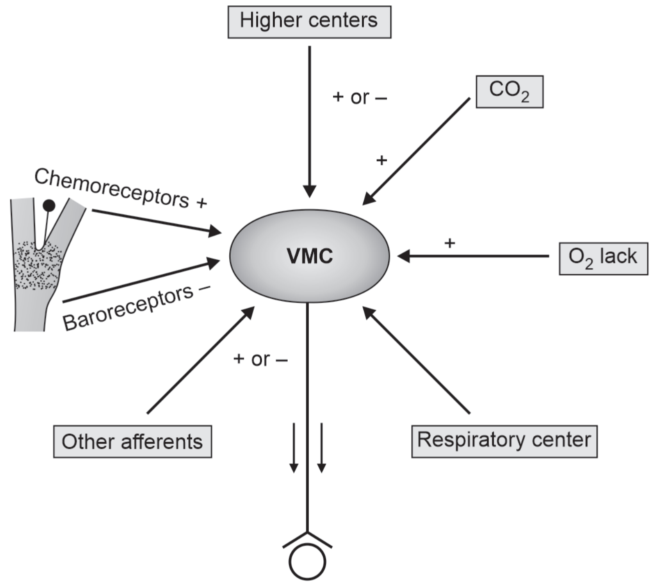


Fig. 2.7: Factors affecting the vasomotor center activity

veins to left atrium. This circulation in series with systemic circulation as shown in Fig. 2.8. It is low pressure system as there are no such resistance vessels as present in systemic circulation (the arterioles). Absence of arterioles make the blood flow through capillaries pulsatile. The blood flow in pulmonary circulation is high during systole as compared with diastole. The pressure in the pulmonary artery is only 25/5 mm Hg (systolic and diastolic respectively). Also pulmonary blood vessels are thin walled and distensible, having large capacity so that at one time it can contain one-fifth of the total blood (1 liter) volume.

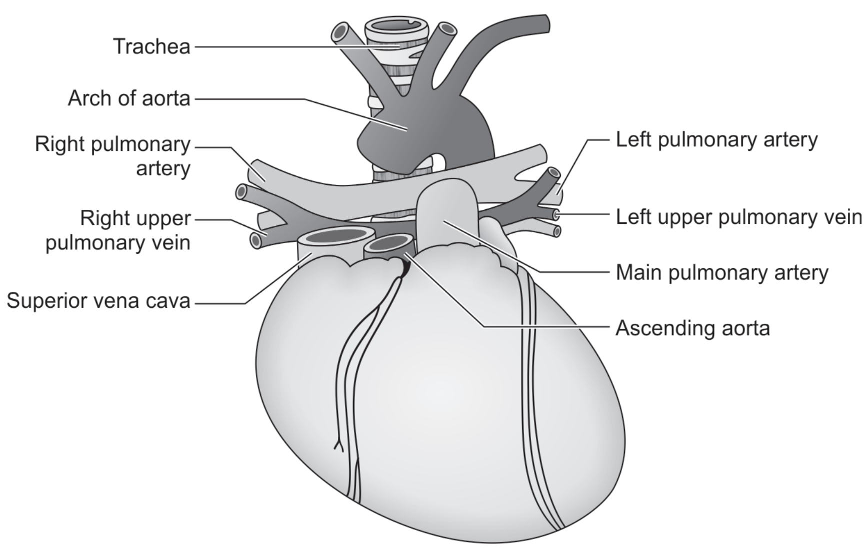


Fig. 2.8: View of the pulmonary arteries from the front. The ascending aorta and the superior vena cava have been removed

SYSTEMIC CIRCULATION

The Aorta

The aorta commences at the upper border of the left ventricle, it runs upwards and to the right for a short distance and then turns through 180° to run downwards close to the vertebral column to end at the level of the 4th lumbar vertebra by dividing into right and left common iliac arteries. Up to this point (thoracic aorta) the aorta is divided into the ascending aorta, arch of aorta, descending aorta and abdominal aorta. The ascending aorta is about 5 cm in length. It starts at the upper border of the left ventricle at the level of the lower border of the 3rd left costal cartilage behind the left half of the sternum. It runs upwards, forwards and to the right and ends at the level of the upper border of the 2nd right costal cartilage, where it is continuous with the arch of the aorta. It gives off two branches, the right and left coronary arteries. These arteries arise from the ascending aorta just above the aortic valve and supply the muscle of the heart.

The right coronary artery runs downwards in the groove between the right atrium and the right ventricle and then runs across the base of the heart to communicate with the left coronary artery (Fig. 2.9). The left coronary artery gives off a branch, called the intraventricular branch which runs in the groove between the two ventricles on the sternocostal surface of the heart, and then runs on to the posterior surface of the heart and communicates with the right artery.

The arch of the aorta connects the ascending and the descending thoracic aorta. It starts as a direct continuation of the ascending aorta and arches to the left and backward across the superior mediastinum, in front of the trachea and esophagus, to become continuous with the descending thoracic aorta on the left side of the lower border of the 4th thoracic vertebra. The lower surface of the arch (Fig. 2.10) of the aorta lies on the upper surface of the division of the main pulmonary artery into the right and left pulmonary arteries. Three branches arise from arch of the aorta—(a) the brachiocephalic artery, (b) the left common carotid artery and (c) the left subclavian artery.

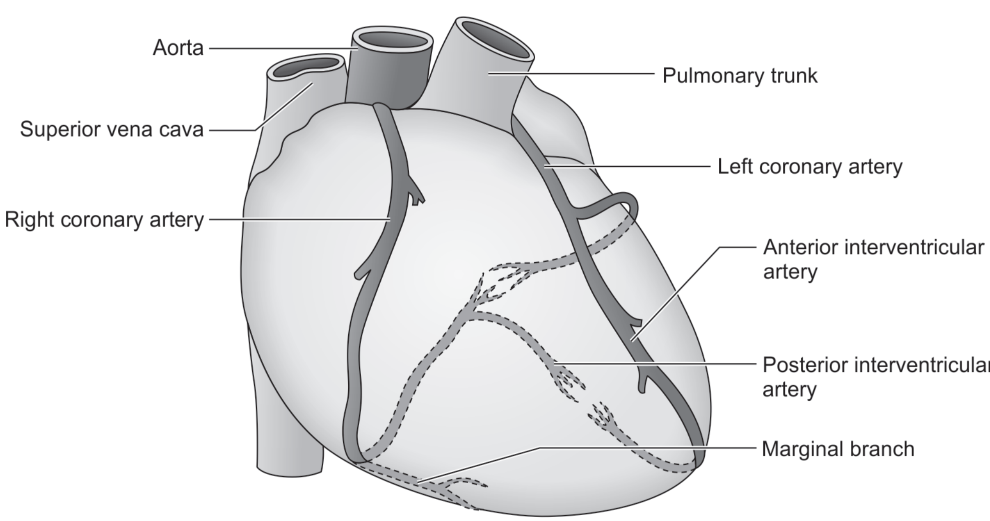


Fig. 2.9: Coronary arteries

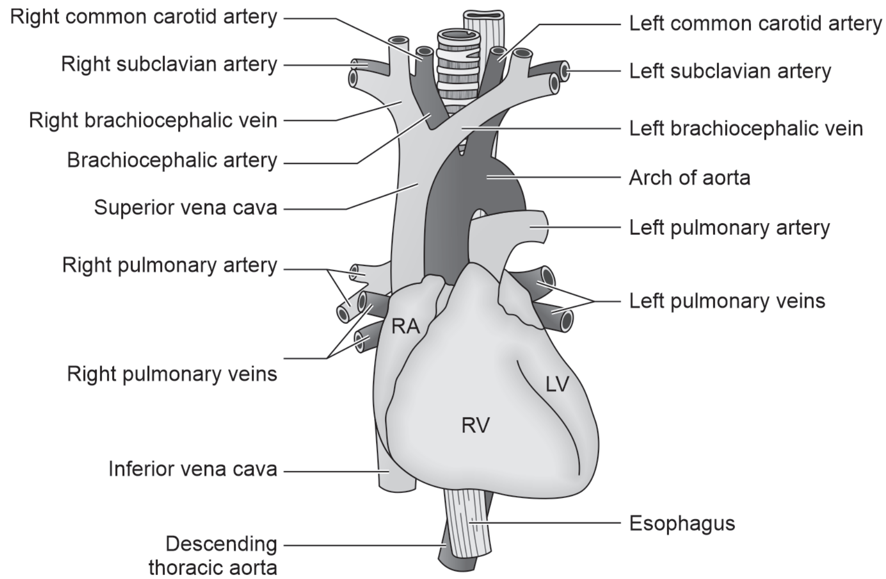


Fig. 2.10: The heart and the great vessels

The Arteries of the Head and Neck

The common carotid arteries are the main arteries of supply to the head and neck. The right common carotid artery arises from the brachiocephalic artery, whereas the left common carotid artery arises directly from the arch of the aorta. The other arteries of head, neck and brain are shown in Figs 2.11 and 2.12.

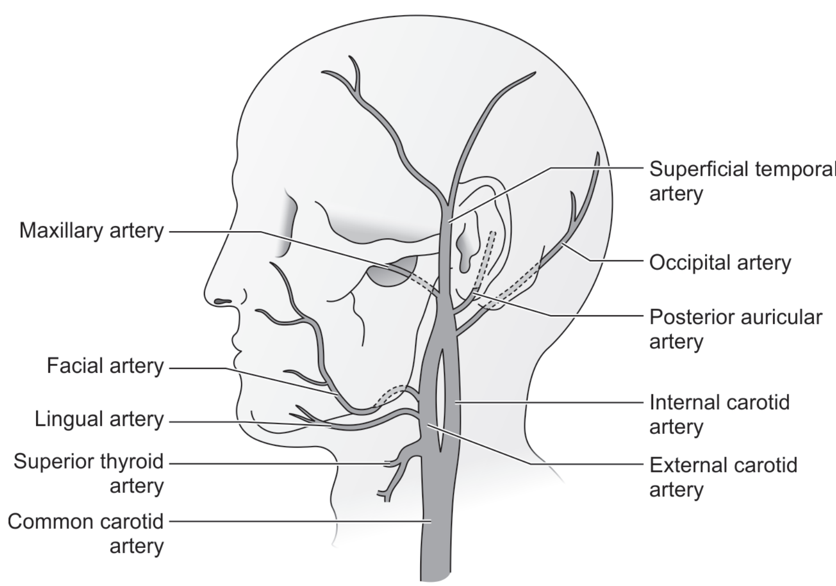


Fig. 2.11: Superficial arteries of the head

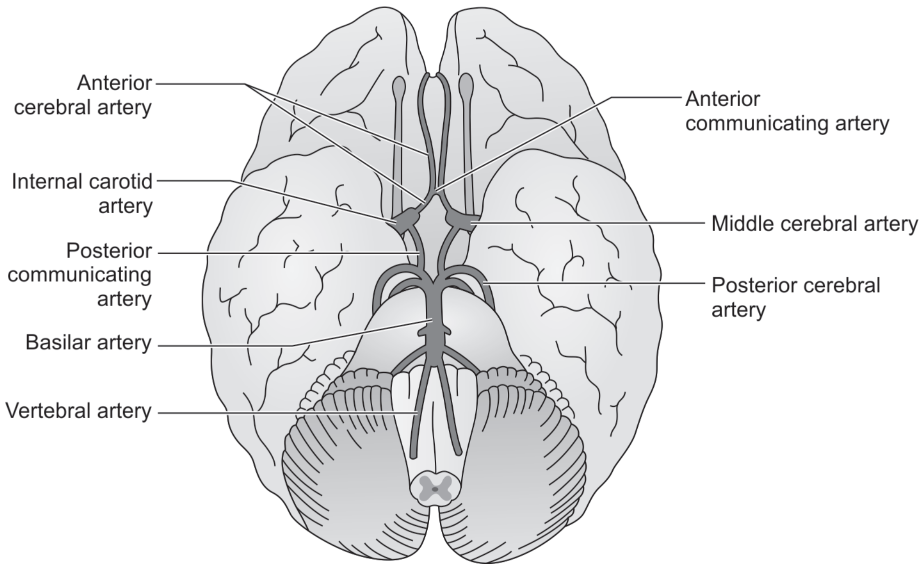


Fig. 2.12: The base of the brain, showing the Circle of Willis

The Arteries of the Upper Limb

The main arterial supply to the upper limb are the subclavian arteries and branches of brachiocephalic artery as shown in Fig. 2.13.

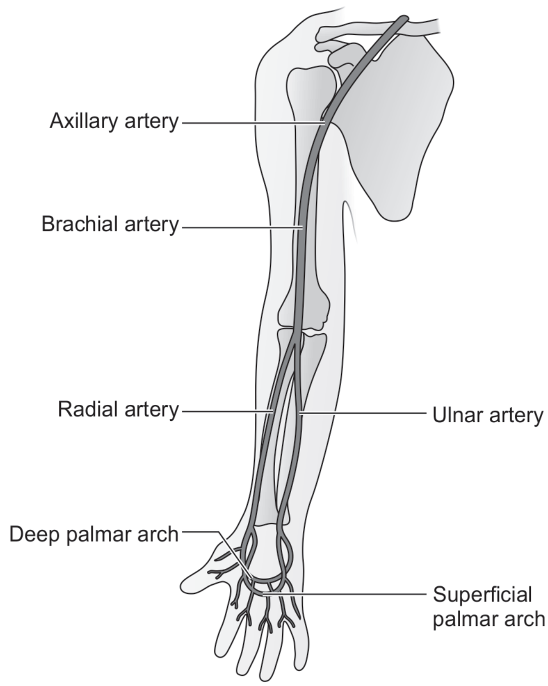


Fig. 2.13: Main arteries of the upper limb

The veins return the blood from the tissues to the heart. They start as small vessels or venules in the periphery and these gradually unite to form large trunks, until finally two main vessels called the superior and inferior venae cavae open into the right atrium of the heart. Veins are superficial and deepformer run close to the surface of the skin and are thus frequently visible. The deep veins many of which accompany the arteries and have the same name and route as the arteries. The descending thoracic aorta commences at the left side of the lower border of the 4th thoracic vertebra and runs downwards in the posterior mediastinum to enter the abdominal cavity through the aortic opening of the diaphragm at the level of the 12th thoracic vertebra. The abdominal aorta is the direct continuation of the descending thoracic aorta. It begins at the level of the lower border of the 12th thoracic vertebra and runs downwards on the left side of the anterior surface of the lumbar vertebra to end at the level of the 4th lumbar vertebra, where it divides into the left and right common iliac arteries. The inferior vena cava lies on the right side of the abdominal aorta, pancreas, duodenum and the peritoneum lie in front of it (Fig. 2.14). The arteries of the lower limb are the femoral artery, the popliteal artery, the anterior tibial artery, the posterior tibial artery and others as shown in Figs 2.15 and 2.16.

The veins return the blood from the tissues to the heart as mentioned earliar (Figs 2.17 to 2.20).

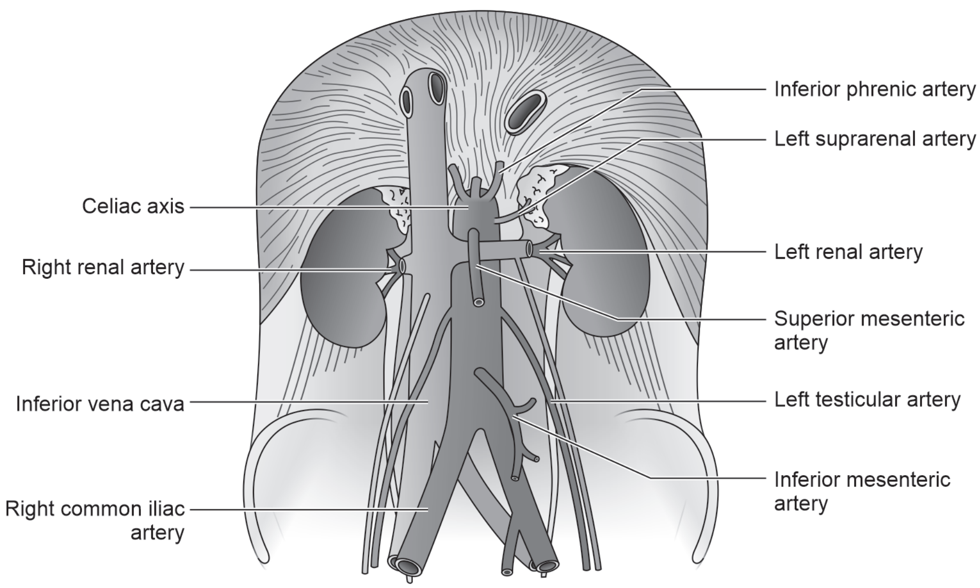


Fig. 2.14: The abdominal aorta and its main branches

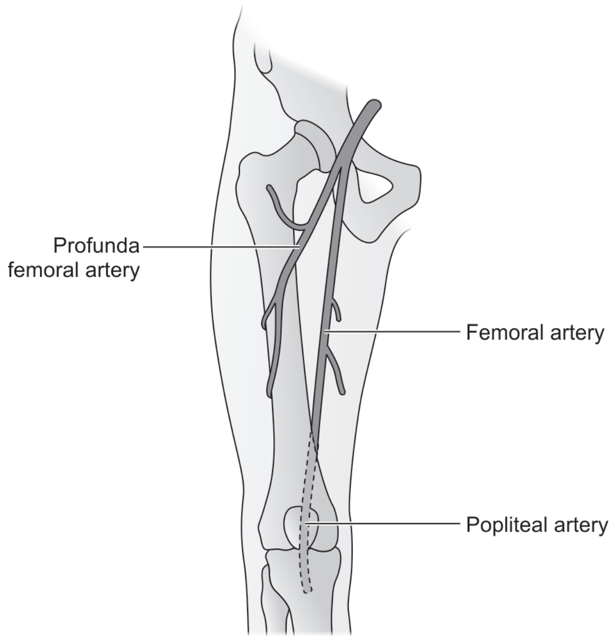


Fig. 2.15: Femoral artery

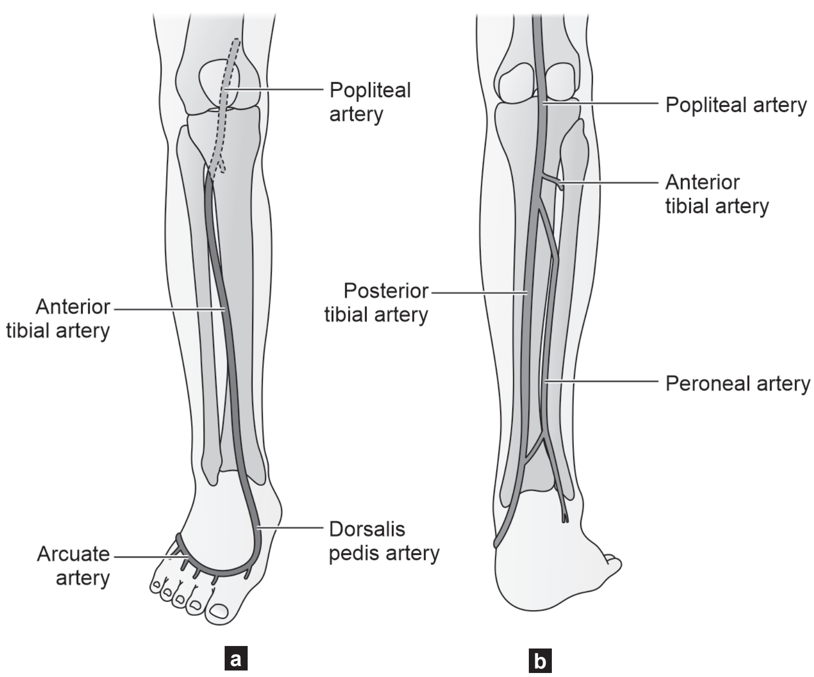


Fig. 2.16: Arteries of the leg: (a) anterior aspect, and (b) posterior aspect

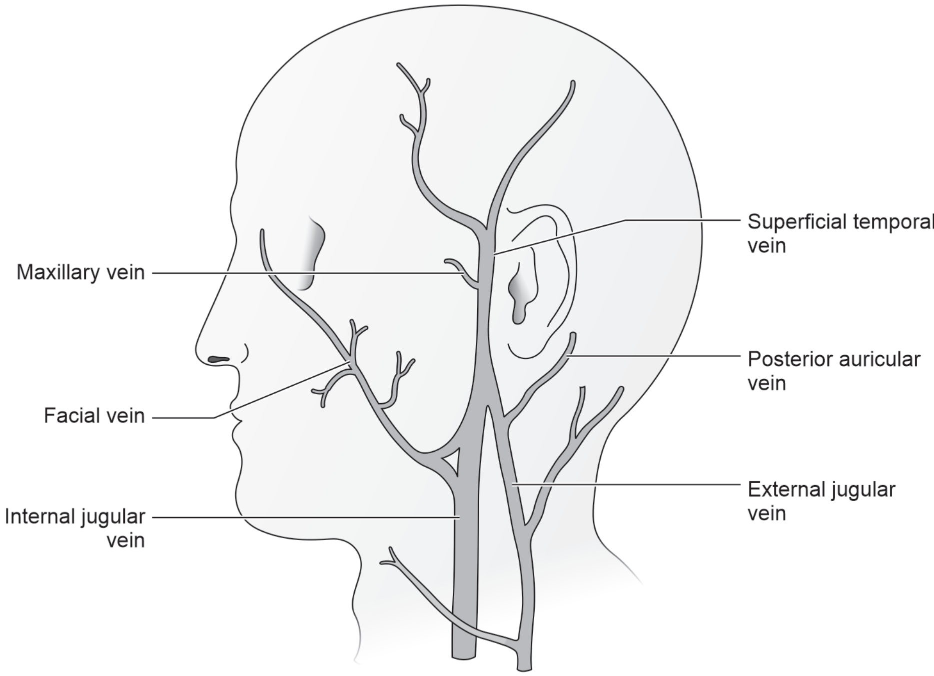


Fig. 2.17: The venous return from the head and neck

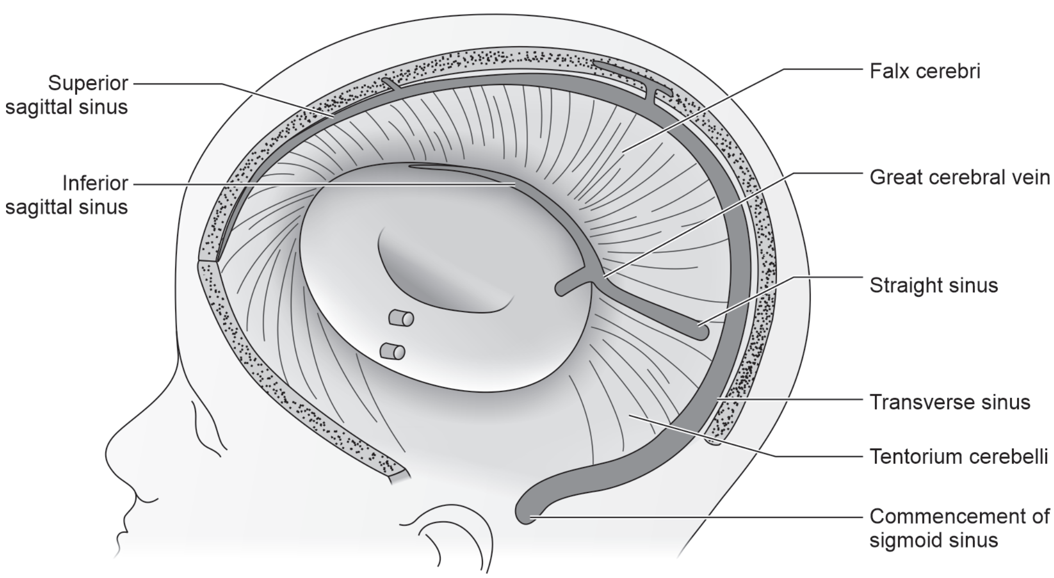


Fig. 2.18: Venous sinuses

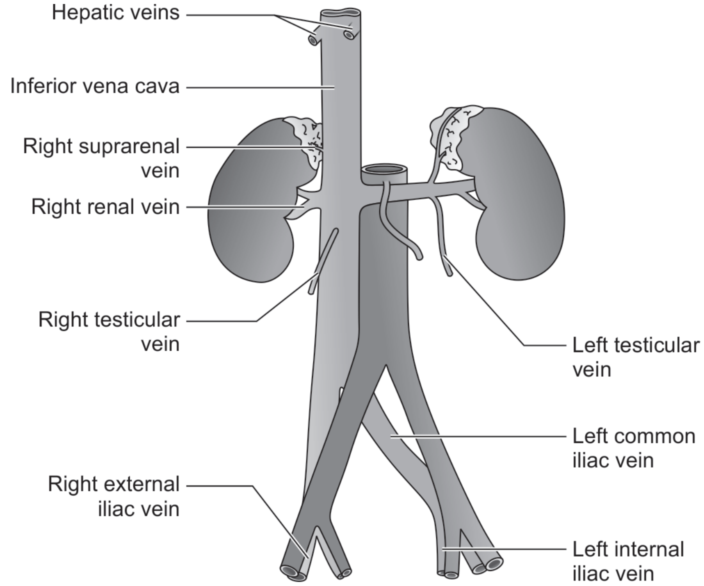


Fig. 2.19: The inferior vena cava and its tributaries

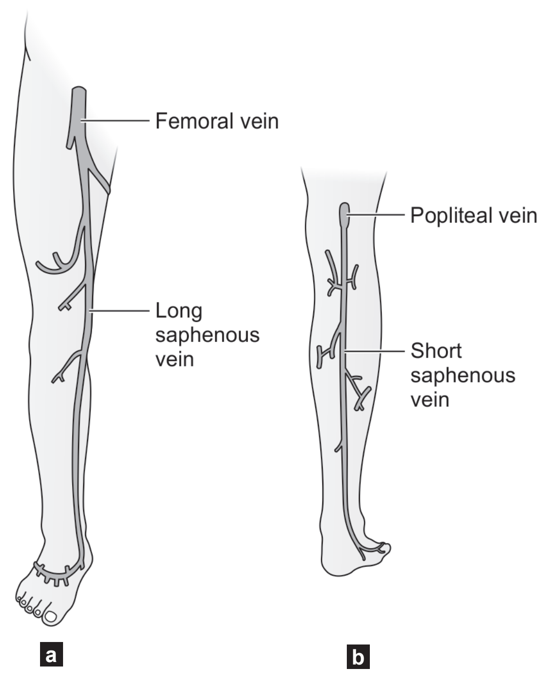


Fig. 2.20: Superficial veins of the lower limb: (a) anterior aspect, and (b) posterior aspect

THE RESPIRATORY SYSTEM

Human body is made up of billions of cells and performs a wide variety of functions. Therefore, to survive and to carry out those functions these cells requires oxygen for combustion and to provide the energy for their activities. The oxygen reaches to cells via blood which also removes the carbon dioxide produced as a waste. Product of combustion, the interchange of oxygen and carbon dioxide between the blood and the tissues is called internal respiration.

The function of respiratory system is to replenish the blood with oxygen and to remove the carbon dioxide from the blood. This interchange of gases which occurs in respiratory system between the blood and the atmospheric air is known as external respiration. The organs constituting the respiratory system are the nose, the pharynx, the larynx, the trachea, the bronchi and the lungs.

THE NOSE

The body structure of the nasal cavity has already been described. The nasal cavity is lined by ciliated epithelium containing globlets, which secrete mucus. The function of mucus is to trap dust particulates (>10 μ) and bacteria which are presented in the inhaled air. Presence of cilia is equally important as they keep on sweeping those stagnated material towards exterior. Accessory nasal sinuses are also lined by ciliated epithelium and they open into the nasal cavity. The upper part of the nose houses specific smell receptors in it.

THE PHARYNX

The pharynx is a muscular tube which in part shared by the respiratory system and the digestive system. Anatomically it lies behind the nasal cavities, mouth and larynx. It is 12–14 cm long, extending from the base of the skull to the level of the 6th cervical vertebra where it opens into the esophagus, being widest in its upper most part and gradually narrows through out its length. Anteriorly, it opens into the nasal cavity, mouth and larynx whereas separated by loose areolar tissue from the upper sixth cervical vertebrae posteriorly.

For descriptive purposes pharynx is divided into three parts—nasopharynx, oropharynx and laryngopharynx (Fig. 2.21).

The nasopharynx is the portion behind the nasal cavity and above the level of the soft palate. Anteriorly, it communicates with the nasal cavity through the posterior nares. Nasopharyngeal isthmus is an opening between the soft palate and the posterior wall of the pharynx, which connect nasopharynx and the oropharynx. This opening becomes obliterated during the act of swallowing. Opening into the lateral wall of the nasopharynx is the auditory tube. In the roof and extending posteriorly is the collection of lymphoid tissue known as pharyngeal tonsil (the adenoids). This lymphoid tissue starts to atrophy at puberty.

The oropharynx extends from the soft palate to the level of the tip of the epiglottis. It opens anteriorly into the mouth cavity through oropharyngeal isthmus, which is bounded above by soft palate, below by tongue and on either side by muscular folds, covered with mucus membrane known as pillars of the fauces. In between the folds of either side lie the palatine tonsils, which are collection of lymphoid tissue.

The laryngopharynx extends from the tip of the epiglottis to the level of 6th cervical vertebra, behind the cricoid cartilage of the larynx, where it is continuous with the esophagus. On either side of the larynx the laryngopharynx forms two pouches called the pyriform fossae.

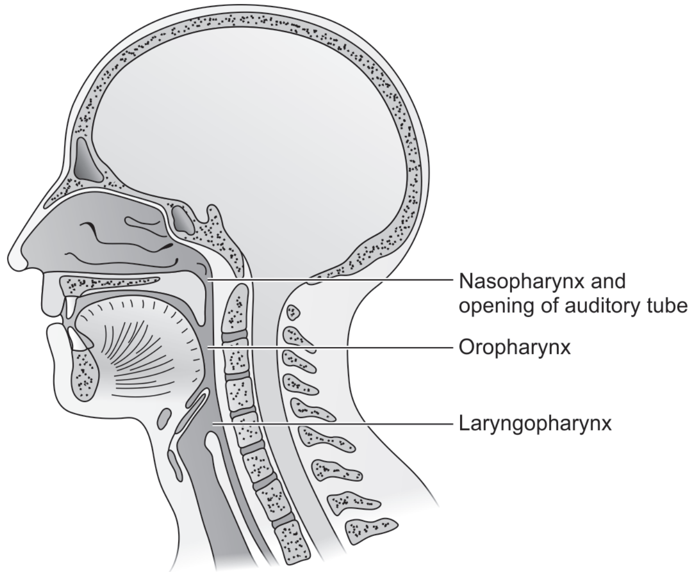


Fig. 2.21: A sagittal section through the head and neck to show the subdivisions of the pharynx

The Structure of the Pharynx

The walls of the pharynx are made up of three coats, the mucus coat, fibrous coat and the muscular coat. The arterial blood supply is from the branches of external carotid artery whereas the veins of pharynx empty into the internal jugular and the facial veins. The nerve supply derived from 9th and 10th cranial nerve and the sympathetic nervous system. The lymph vessels from the pharynx drain either directly into the deep cervical lymph node or into the retropharyngeal and paratracheal lymph nodes.

THE LARYNX

The larynx (Fig. 2.22a and b) is a box like structure which extends from the roof of the tongue to the level of the upper end of the trachea. In adult male, it lies opposite the 3rd to the 6th cervical vertebrae but it is slightly higher in children and adult females. It acts as the organ for the production of the voice and also as a valve to prevent the entry of food into trachea during the act of swallowing. It opens above into the laryngopharynx and below into the trachea.

STRUCTURE OF THE LARYNX

The larynx is consists of number of cartilages which are connected to each other by ligaments and membranes. The cartilages are *Thyroid cartilage* is the largest amongst other cartilages of larynx. It is formed of two quadrilateral plates (lamina) which are fused anteriorly in midline to form laryngeal prominence (Adam's apple). Above this there is a notch, known as thyroid notch. These two plates are widely separated posteriorly. The upper and lower angles of laminae are horn shaped and each inferior horn has a rounded facet on its inner surface which atriculates with the cricoid cartilage.

The cricoid cartilage (Fig. 2.23a) is shape like a signet ring, consisting of a quadrilateral lamina, which lies posteriorly and a narrow arch, lies anteriorly. Each lateral surface of lamina bears too articulae facets; above for the arytenoid cartilage (Fig. 2.23b) and

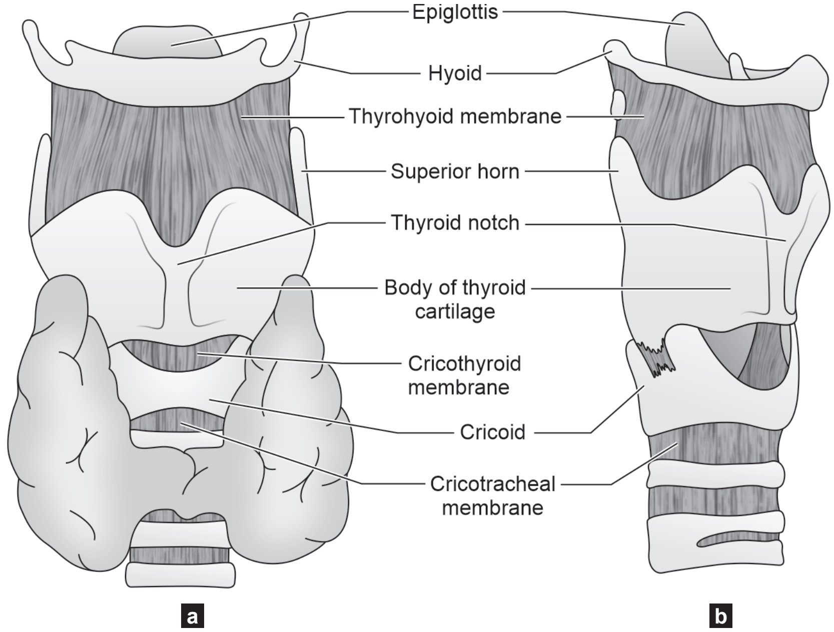


Fig. 2.22: External views of the larynx: (a) anterior aspect, and (b) lateral aspect

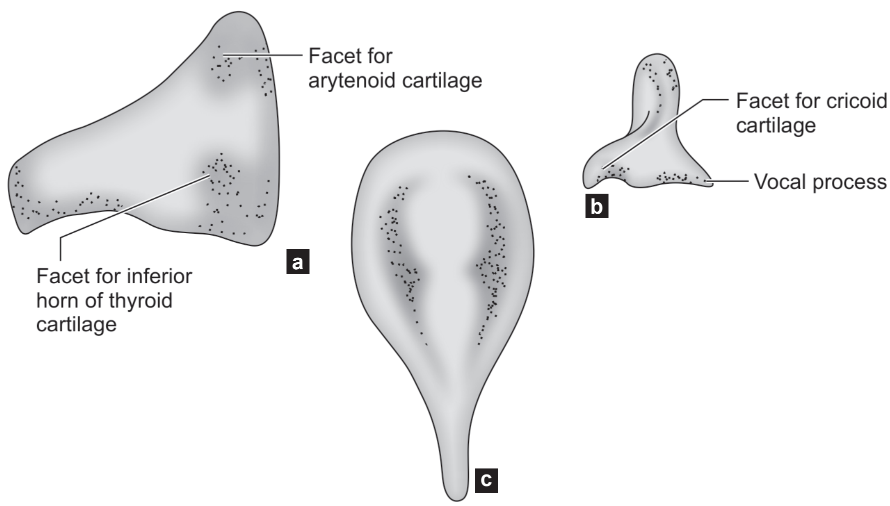


Fig. 2.23: (a) The cricoid cartilage (lateral aspect), (b) the arytenoid cartilage (lateral view) and (c) the epiglottis (posterior aspect)

below for the inferior horn of the thyroid cartilage. The arytenoid cartilage are pyramidal in shape, having an apex, a base and three surfaces as posterior, anterolateral and anteromedial.

Anterior angle is known as the vocal process and gives attachment to the vocal ligament whereas the lateral angle gives attachment to muscles. The base of arytenoid cartilage is concave and articulates with the facet on the upper part of the lateral surface of the lamina of the cricoid cartilage. The apex articulates with the corniculate cartilage. The epiglottis (Fig. 2.23c) is a leaf-shaped cartilage. Its narrow lower end is attached by the thyroepiglottic ligament, to the posterior surface of the thyroid cartilage, just below the thyroid notch. The upper end of epiglottis projects upwards behind the hyoid bone and the base of the tongue. The lower part of the anterior surface is attached to the hyoid bone by the hypoepiglottic ligament.

The Cavity of the Larynx

The larynx opens above into the pharynx and below into the trachea. The mucus membrane lining the larynx is in continuation with the mucus membrane of tongue and pharynx above. Laryngeal cavity is divided into three parts due to the two inner fold of mucus membrane. The upper fold is named as vestibular and the lower one which cover the vocal ligament forming vocal cords known as vocal folds (Figs 2.24 and 2.25).

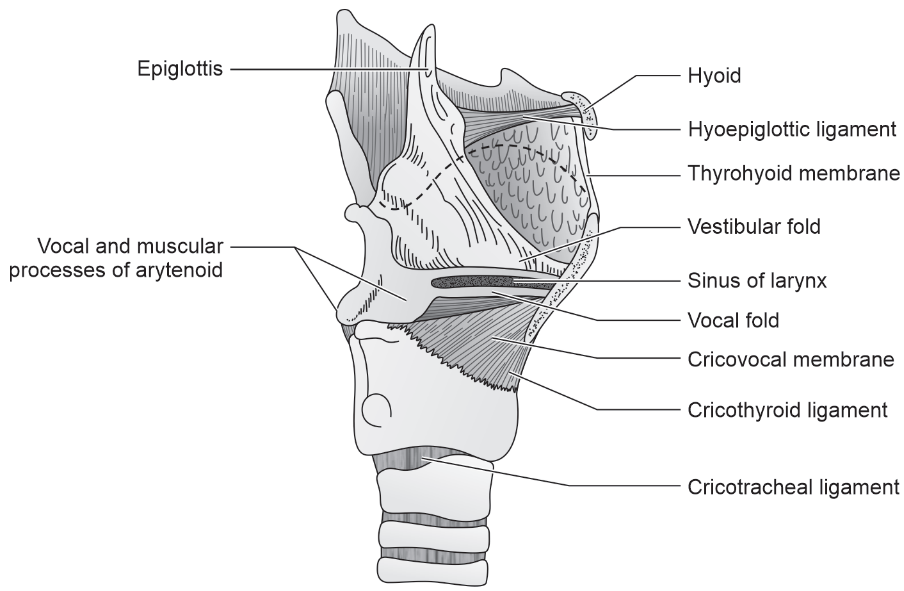


Fig. 2.24: The cartilage and ligaments of the larynx, lateral aspect

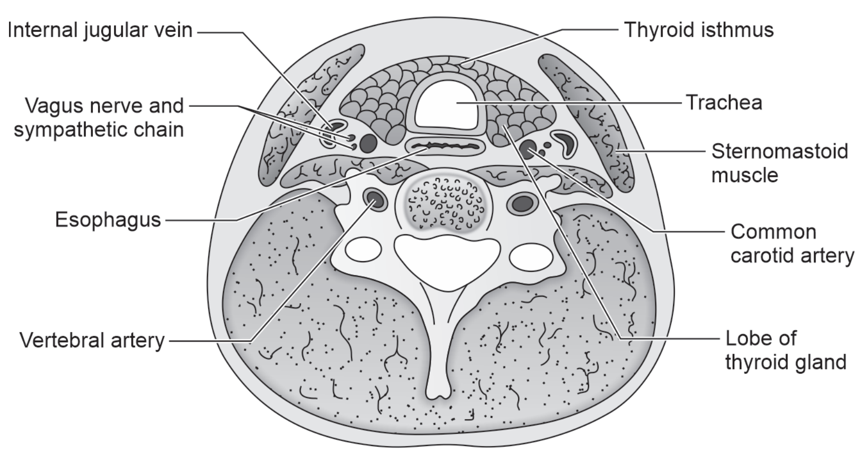


Fig. 2.25: Transverse section of the neck at the level of the lower part of the 6th cervical vertebra to show the relationship of the trachea

The arterial blood supply of larynx comes from superior and inferior thyroid arteries. The veins drain into the thyroid veins and from there into the internal jugular vein. The nerve supply to the larynx is from laryngeal and recurrent laryngeal nerves. The lymphatic vessels from the portion of larynx above the vocal cords drain into the superior deep cervical lymph nodes whereas below the vocal cords drain into the inferior deep cervical and pretracheal lymph nodes. Functions of the larynx are—(i) to allow air to pass from the pharynx to the trachea, (ii) to prevent food entering the trachea during swallowing and (iii) to produce voice.

THE TRACHEA

The trachea is a tube about 10 cm long which extends downwards from the lower part of the larynx, at the level of 6th cervical vertebrae and ends at the level of upper border of 5th thoracic vertebra by dividing into the right and left main bronchi. The portion of the trachea in the neck lies in the midline but in the thoracic cavity it is displaced slightly to the right by the arch of aorta.

Relations of the Trachea

In the neck (Fig. 2.26)**:** Anteriorly, the trachea is crossed by the isthmus of the thyroid gland which covers the 2nd to 4th cartilaginous rings, laterally the trachea is related to the lobes of the thyroid gland which separate it from the common carotid artery and posteriorly, the trachea is related to the esophagus which separates it from the vertebral column.

In the thoracic cavity: Anteriorly, the trachea is related from above downwards to the remanants of the thymus gland, the brachiocephalic artery, the left common carotid artery and with arch of the aorta. On the right side, the trachea is related to the left common carotid artery, left subclavian artery and below to the arch of aorta. Posteriorly, the trachea is related to the esophagus.

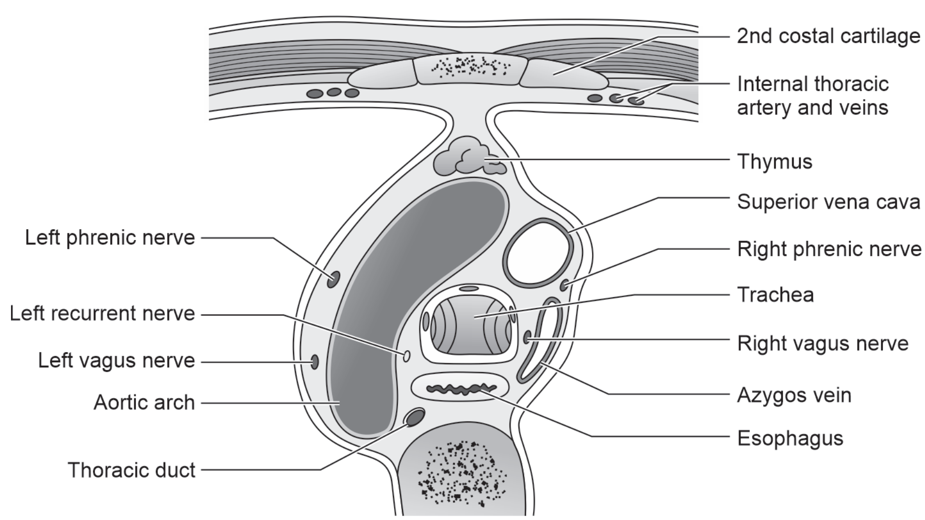


Fig. 2.26: Transverse section through the 4th thoracic vertebra to show the relations of trachea

The Structure of Trachea

It is composed of 16 to 20 'C'-shaped cartilaginous rings, incomplete and are joined by a fibrous tissue membrane contain elastic fibers and unstriped muscle fibers posteriorly. The tracheal cavity is lined by ciliated columnar epithelium along with large number of goblet cells. Beneath the mucus membrane is a loose layer of connective tissue which contains vessels and nerves. The nerve supply to the trachea is from branches of the vagus, recurrent laryngeal nerves and the sympathetic nervous system.

The arterial blood supply of trachea comes from inferior thyroid artery and veins empty into the brachiocephalic veins.

THE BRONCHI

The right and left main bronchi starts at the bifurcation of the trachea, at the level of the upper border of the 5th thoracic vertebra. The right main bronchus is broader, shorter and runs downwards more vertically as compared with left. It is about 2.5 cm in length and enters the right lung opposite the 5th thoracic vertebra. The left main bronchus is narrow than the right and it runs more horizontally. It is about 5 cm in length and it enters the left lung at the level of the 6th thoracic vertebra. In its course, it passes behind the arch of aorta and in front of the esophagus and the descending aorta. The left pulmonary artery lies first above and then in front of it. Within the lung, the two main bronchi divide and subdivide to form smaller and smaller branches till terminal bronchi (Fig. 2.27).

Structure of Bronchi

The main bronchi and larger bronchi within the lungs have same structure with that of trachea, but the cartilaginous rings are more irregularly placed. The outer coat is

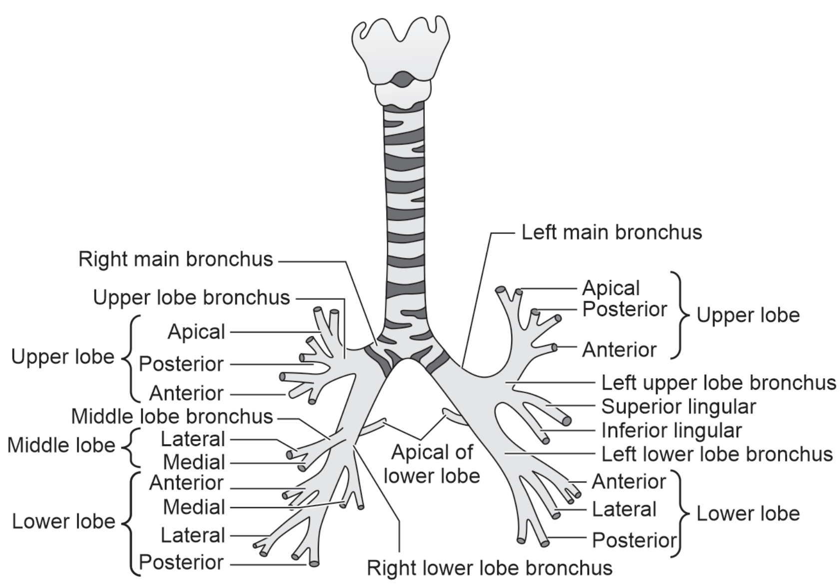


Fig. 2.27: The trachea and the main branch, anterior aspect

composed of fibrous tissue in which lie the cartilaginous plate, the middle layer is made up of circularly arranged unstriped muscle fibers and inner layer is of mucus membrane which contains mucus and serous glands (lined by columnar ciliated epithelium).

The pleura: Each lung is covered by a closed sac of serous membrane called pleura. The pleura consists of an outer layer called the parietal pleura and an inner layer called the visceral pleura. The parietal pleura is attached to the chest wall, the mediastinum and the upper surface of the diaphragm and it extends upwards into the base of the neck. The visceral layer is attached to the surface of the lungs and extends into the fissures, which divide the lungs into lobes. The two layers of the pleura are continuous around the hilum or root of each lung and the pleura extends downwards below each hilum as the pulmonary ligament. The two layers of pleura are normally in closed contact, being separated only by a thin film of serous fluid. This fluid holds the two layers of the pleura together by suction but if air is allowed to leak into pleural cavity, the two layers separate and the lung collapses. This condition is known as pneumothorax.

THE LUNGS

The right and left lungs (Figs 2.28 and 2.29) lie freely on either side of the mediastinum in the right and left pleural cavities attached only at the hila, where the bronchi, lymphatic vessels and pulmonary vessels enter and leave the lungs. Each lung is roughly conical in shape, comparing of apex, lies superiorly, a base or diaphragmatic surface, a costal surface and a mediastinal surface. The right lung is slightly larger than the left. At birth the lungs are pink in color but with advancing age they become increasingly grey or black due to deposition of inhaled carbon and other particles from the atmosphere.

The apices of the lungs extend upwards into the base of the neck for 2–3 cm above the anterior margin of the 1st rib. The base of each lung is concave and rests on the diaphragm. The right dome of the diaphragm lies higher (due to right lobe of liver)

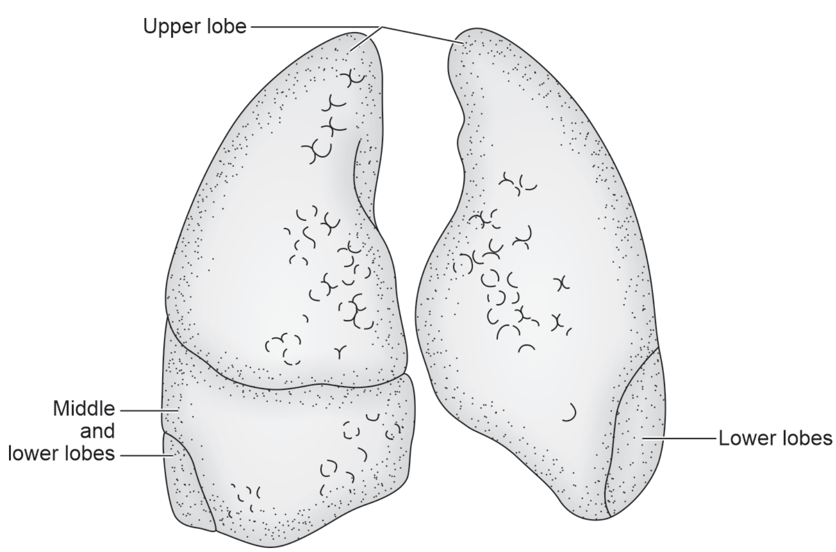


Fig. 2.28: The right and left lungs, anterior aspect

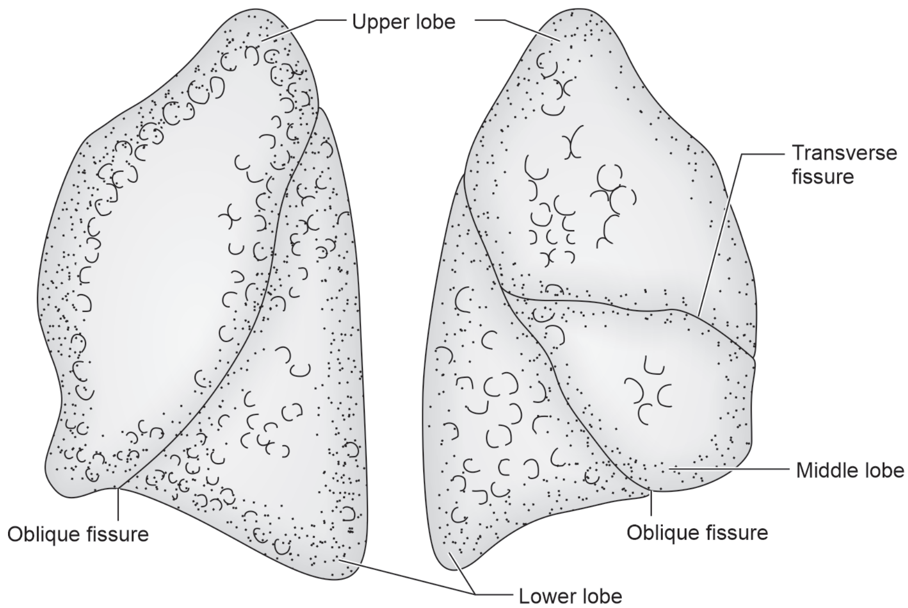


Fig. 2.29: The right and left lungs, lateral aspect

than the left (due to left lobe of liver, fundus of stomach and spleen). The costal surface of each lung is related to the chest wall. The medial surface of each lung is related posteriorly to the thoracic vertebrae and anteriorly to the mediastinum. The lower part of the mediastinal surface of each lung is concave. This concavity of right side is less (related to right atrium and part of the right ventricle) as compared to left (related to left ventricle and the left auricle). The right lung is also related to superior vena cava, lower end of the right brachiocephalic veins, the azygos veins, the right vagus nerve and the esophagus (Fig. 2.30) whereas left lung is related to the arch of the aorta, the left subclavian artery, the phrenic nerve and the esophagus (Fig. 2.31). The inferior and anterior border of each lung are sharp where it lies in the recess between the chest wall and the diaphragm and over lies the front of the pericaridum respectively. The notch in the anterior border of left lung is known as cardiac notch. The right lung is divided into three lobes by an oblique and transverse fissure whereas left lung is divided into two lobes by an oblique fissure. Each lobe is comprised of large number of lobules and each lobule is consists of terminal bronchiole air sacs, small branches of the pulmonary and bronchial arteries, lymphatic vessels and nerves. The bronchi of each lobe, divide and subdivide till bronchioles and bronchioles themselves divide to from terminal branches known as respiratory bronchioles, which are about 0.2 mm in diameter. The respiratory bronchioles contain no cartilage in their wall and they are lined by non-ciliated cuboidal epithelium. Each respiratory bronchioles divide into a number of alveolar ducts which in turn divide into atria and each atria divide into air saccules. The walls of air saccules, atria and alveolar ducts are covered by thin walled structures called pulmonary alveoli. The walls of pulmonary alveoli are lined by a layer of flat epithelium and it is this place where the exchange of gases taking place between the pulmonary alveolocapillary membrane.

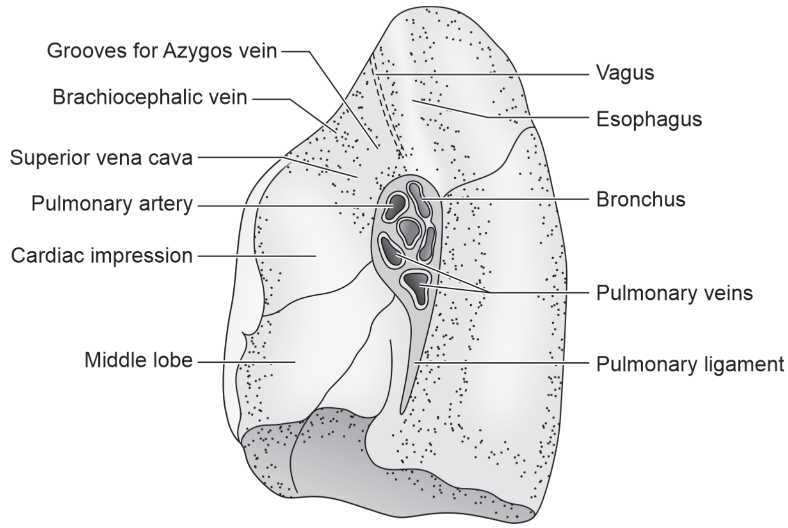


Fig. 2.30: Mediastinal aspect of the right lung

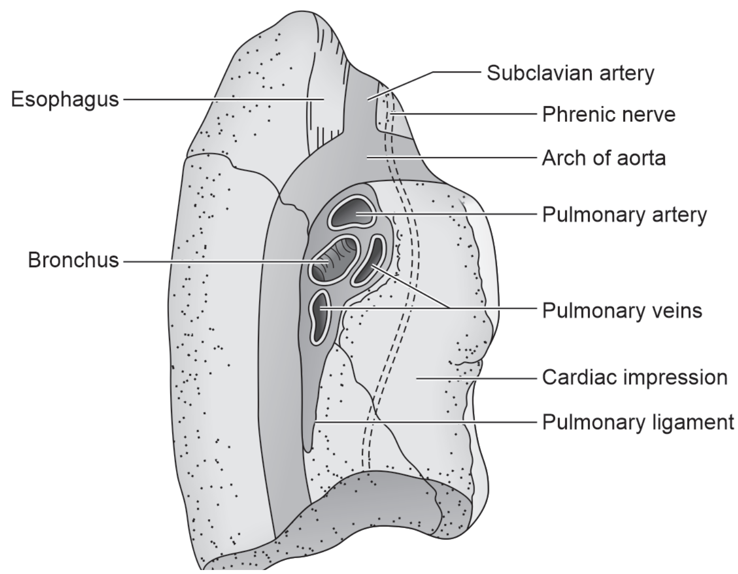


Fig. 2.31: Mediastinal aspect of the left lung

Blood Supply of the Lungs

The right and left pulmonary arteries carry deoxygenated blood from the right ventricle to the right and left lungs. Each pulmonary artery divides into branches which follow the division of the bronchi and bronchioles, finally a dense capillary network is formed around the air sacs and alveoli. The pulmonary veins, two from each lung are formed by the union of veins which return from the pulmonary capillaries. These veins open into the left atrium (oxygenated blood). The lungs are supplied with oxygenated blood by the bronchial arteries, arise from the descending aorta, the bronchial veins into the azygos vein on the right, and the hemiazygos veins on the left. The nerve supply of lungs is from vagus and sympathetic nervous system.

The lymphatic vessels of the lungs, visceral pleura and bronchi empty into the bronchopulmonary lymph nodes.

The Physiology of Respiration

The primary function of respiratory system is to make available adequate amount of oxygen (250 ml/min) to the body tissue and to remove carbon dioxide (200 ml/min) in the expired air. The air is drawn into the lungs during inspiration and expelled during expiration. During inspiration, the scalene muscle contract to prevent 1st rib moving downwards and at the same time, external intercostal muscles contract to increase anteroposterior diameter of the chest and the central tendon of diaphragm moves other muscle downwards to increase the vertical diameter of the thorax. The intercostal and diaphragm muscles are innervated by the motor neurons of T_{12}, C_3 and C_5 respectively. In quiet respiration, the major contribution to increase chest volume is shared by diaphragm whereas during force inspiration the external intercostal muscle also take part along with movement of 1st rib and manubrium sterni by the scalene and sternomastoid muscle. During quiet breathing, expiration is produced by relaxation of the scalene/external intercostal muscles and diaphragm. In the forceful expiration, abdominal muscle take part by increasing intra-abdominal pressure as well as drawing the lower ribs downwards and medially. In quiet breathing, the rate of respiration is 14 to 16/min.

Lung Volumes and Capacities

During quite breathing the volume of air breathed in or out is known as tidal volume (500 ml) out of this only 160 ml actually reaches the alveoli for gaseous exchanges, remaining 140 ml fills the air passages (dead space) during inspiration or expiration. The volume air breathed out forcefully and maximally after maximum inspiration is known as vital capacity (3.5 lit to 4.5 lit in female and males respectively). The expirogram of vital capacity when timed is known as timed or forced expiratory volume (FEV_1) in 1st second. Normally, a person should be able to expire about 80% of his total vital capacity in 1st second. It is a very sensitive indeed (Fig. 2.32), as its value and contour differs in persons having obstructive and restrictive diseases. After forceful expiration, the volume of air left in the lung is known as residual volume (RV), normally in an adult it should be 1200 ml but in old age and in some conditions where elasticity of the lung tissue is lost as bronchial asthma and omphysema, this leads into the trapping of air, resulting in an increase RV. All above mentioned lung volumes and capacity except RV can be measured/recorded by using simple spirometer (Fig. 2.33).

Control of Respiration

A resting adult takes a breath about 14 to 15 min, however in children it is somewhat higher. During exercise as body demand for oxygen and CO_2 production increases to fulfill this requirement, ventilation (respiratory rate volume/breath) brought to increase by a group neurons present in the medulla oblongata, pons and lower midbrain known as respiratory center. Rhythmic impulses pass from this center to efferent nerves, i.e. phrenic (supplying external and internal intercostal muscles to produce breathing

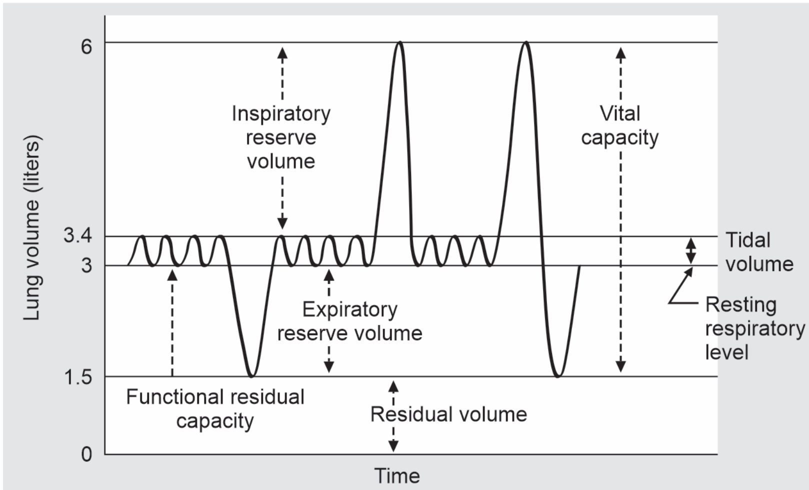


Fig. 2.32: Lung volumes

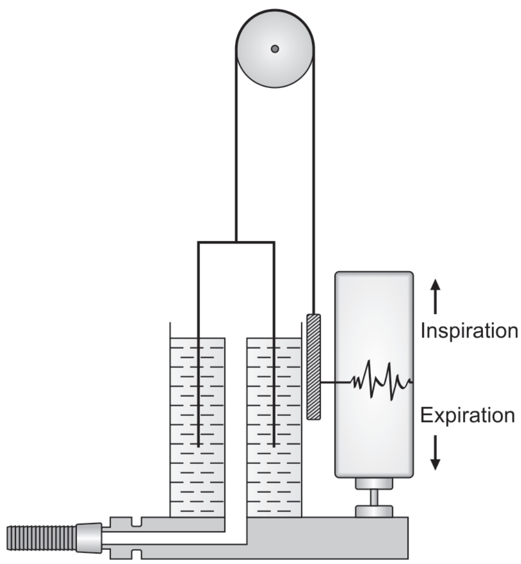


Fig. 2.33: Recording-spirometer. Inspiration causes the bell to descend and the writing lever to move upwards on the chart. The chart is calibrated so that measurements of lung volume changes may be made

without conscious (quiet breathing). However, the respiratory center is stimulated by a rise in CO_2 and fall in arterial O_2 concentration in blood, which can be during exercise (CO_2 production is increased) and when there is rise in acidity of blood (increased hydrogen ion concentration). Amongst these rise in CO_2, is a potent chemical stimulus to the respiratory center via chemical receptors in medulla oblongata. Likewise O_2 lack too is an important stimulus to respiration at high altitudes where partial pressure of oxygen is low (via receptors in aortic and carotid bodies) and also in chronic lung diseases, the afferent pathways from these receptors are branches of the vagus (Xth) nerve.

The composition of inspired air is different altogether when compared with alveolar air as shown in Table 2.2.

Table 2.2: Composition of inspired and alveolar air in percentage

	Inspired air (%)	Alveolar air (%)
O_2	20.96	14.00
CO_2	0.03	6.00
N	79.01	80.00

As the inspired air has high percentage of O_2 and alveolar air is of CO_2, therefore, the partial pressure of O_2 is high in inspired air whereas of CO_2 in alveolar air, which is one of the important factor across the alveolocapillary membrane.

Gas Transport in the Blood

The O_2 is mainly carried in red cells as oxyhemoglobin. In tissues where O_2 tension is low, oxyhemoglobin dissociates, releasing O_2 for use in tissue respiration. The dissociation of O_2 is almost complete in tissues during muscular excercise (as the demand of tissues for O_2 increases). However, CO_2 (more soluble than O_2) is transported from tissue to the lung capillaries in the blood in solution, as bicarbonates, and partly combined with hemoglobin as carbominohemoglobin. Reduced Hb has more affinity for CO_2. Therefore, in tissues where O_2 tension is low, oxyhemoglobin dissociates to yield O_2 and CO_2 is taken up by the blood in various forms as mentioned above. The exchange of gases across the alveolocapillary membrane suffers in conditions which leads either destruction of these membranes (emphysema in many occuptional diseases) or in thickening (fibrosis), of these membranes.

THE DIGESTIVE SYSTEM

The digestive system help in digesting and absorption of food which we eat (used for heat, energy, growth and repair of tissues) and with the elimination of the undigested and unabsorbed residue. The digestive system is composed of the alimentary canal, which extends from the mouth to the anus and of certain accessory organs.

Mouth and Esophagus

The mouth or oral cavity is divided into outer portion called the vestibules, and an inner portion known as mouth cavity proper. The mouth cavity proper is bounded anteriorly and laterally by teeth and gums. It communicates posteriorly with the pharynx through the oropharyngeal isthmus. The lateral margin of oropharyngeal isthums are formed by two folds of mucous membrane, one each side, lies a mass of lymphoid tissue called the palatine tonsil. The roof of mouth is formed by bony palate and posteriorly by soft palate. A small conical projection called the uvula. Anterior part of tongue forms the floor and the mylohyoid muscles forms muscular diaphragm across the arch of the mandible. The lips are two fleshy folds, surround the anterior opening of the mouth, formed by orbicularis oris muscle covered externally by skin and internally by mucous membrane.

The cheeks form the lateral margins of the vestibule of the mouth. They are continuous anteriorly with the margin of the lips and their major bulk is formed by buccinator muscle. The tongue is a muscular organ lies partly in the mouth and partly in the pharynx. It is important in perceiving taste, in speech and with act of swallowing or degutition.

The teeth are embedded in the sockets of the alveolar processes of the maxillae and mandible. There are two sets of teeth erupt in each individuals deciduous and permanent ones. The earlier ones are twenty in number, five in each half of each jaw and the permanent are usually 32 (eight in each half of the each jaw), having two incisors, one canine, two premolars and three molars. A full set of teeth would thus be written as follows:

87654321/12345678
87654321/12345678

The Salivary Glands

There are three pairs of salivary glands, the parotids, the submandibular and sublingual glands located as shown in Fig. 2.34. They secrete the saliva which passes through their ducts into the mouth. The different parts of the pharynx are already discussed along with various relationships (Fig. 2.21). The esophagus is about 25 cm in length and extends from the pharynx to the stomach. It commences in the neck at the level of the 6th cervical vertebra, where it is continuous with the lower end of the laryngopharynx. After passing through the diaphragm, slightly to the left of the midline, it opens into the cardiac orifice of the stomach at the level of 11th thoracic vertebrae (Fig. 2.35). The various anterior relation of esophagus are shown in Fig. 2.35. In the neck (A), in the thorax, (B) and abdomen. The lumen of the esophagus is not uniform but slightly narrowed at three sites, i.e. at its commencement, at the level of the left main bronchus and where it passes through the diaphragm.

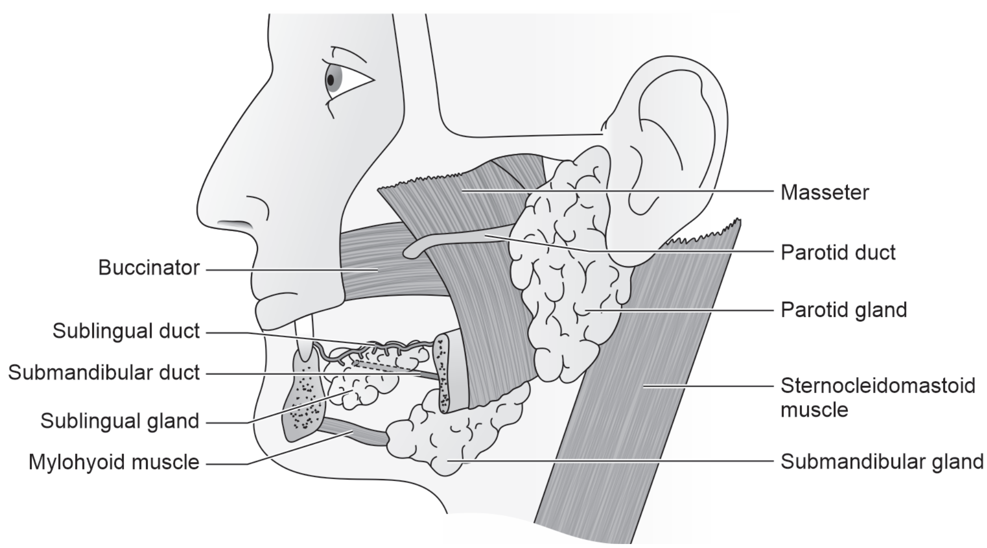


Fig. 2.34: The salivary glands: A portion of the mandible has been removed

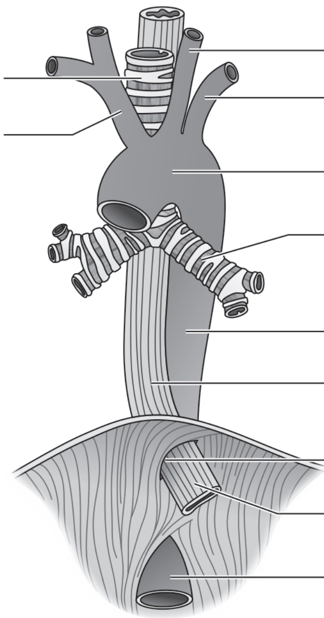


Fig. 2.35: The esophagus and its anterior relations

The Stomach

The stomach (Fig. 2.36a) is the most dilated portion of the alimentary canal. It lies in the left hypochondrium, the epigastrium and the umbilical regions of the abdomen. It communicates, above with the esophagus at the cardiac orifice and below with the duodenum at the pyloric orifice. Pyloric orifice is surrounded by a thickened band of smooth muscle called the pyloric sphincter. At cardiac orifice, the fibers of the right crus of the diaphragam compress the esophagus and prevents regurgitation of the gastric contents. The volume of the stomach in an average adult is about 1000–1500cc. The common shape of stomach seen during barium meal is 'J' shape. Though other shapes (steerhorn and fish hook) could be seen in (Fig. 2.36b).

Anteriorly, the stomach is related to the diaphragm, the left costal margin, the left lobe of the liver and the anterior abdominal wall. Posteriorly, it is related to the diaphragm, the left suprarenal gland, left kidney, pancreas, splenic artery, transverse mesocolon (Fig. 2.37), left half of the transverse colon, the splenic flexure of the colon and the spleen. These structures are frequently referred to as the stomach bed.

The Small Intestine

The length of small intestine is about 6 meter extends from the pyloric orifice of the stomach to the ileocecal valve, where it is continuous with the large intestine. It is divided into three parts—the duodenum, the jejunum and the ileum.

Duodenum is about 25 cm in length (shortest and widest part of the small intestine. It is relatively fixed in position, and forms a 'C' shape cap around the head of pancreas. For descriptive purposes, it is divided into four parts. Its relationship with other organs is shown in Fig. 2.38.