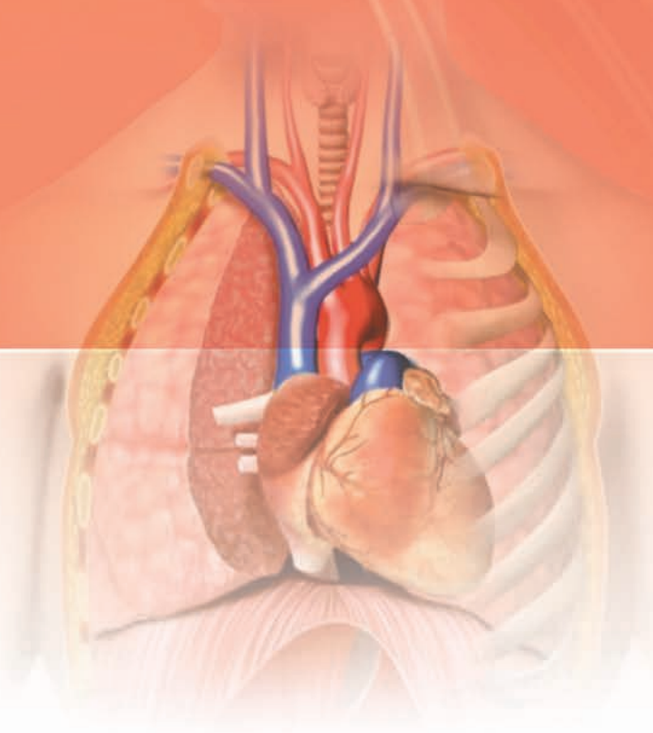
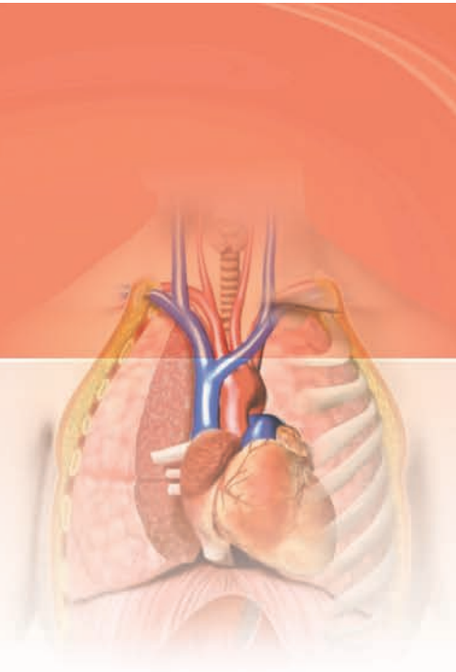


Section

8

Thorax



Chapter

39

Thoracic Wall

Competency: AN 21.1, 21.3 to 21.10

Objectives

- To list the structures forming the thoracic cage and to list the structure passing through its superior aperture
- To describe the anatomy of the sternum and to list the importance of sternal angle
- To classify the ribs into typical and atypical and discuss the features of a typical rib, first and second rib
- To name the joints of the thoracic cage, their type and movements allowed by them.
- To list the muscles of the intercostal space and to discuss their attachments, nerve supply and functions
- To discuss the anatomy of the respiration
- To define a typical intercostal space and to describe the course, branches, distribution and applied anatomy of the typical intercostal nerve
- To describe the origin, termination, branches and applied anatomy of the internal thoracic artery
- To discuss the arteries and veins in the intercostal space

The thorax includes the primary organs of the respiratory and cardiovascular system. It can be studied under thoracic wall and thoracic cavity. The thoracic cavity has a central compartment called mediastinum and pulmonary cavities on either side housing the lungs. Though mammary glands are located in the thorax, it is discussed in pectoral region of the upper limb. The thoracic wall includes thoracic cage (thoracic skeleton), muscles between the ribs, skin and fascia. The same structures covering the posterior aspect are discussed in Chapter 37.

THORACIC CAGE

The vital organs of the thorax (heart and lungs) are well protected inside the bony thoracic cage (Fig. 39.1A and B). It has following boundaries.

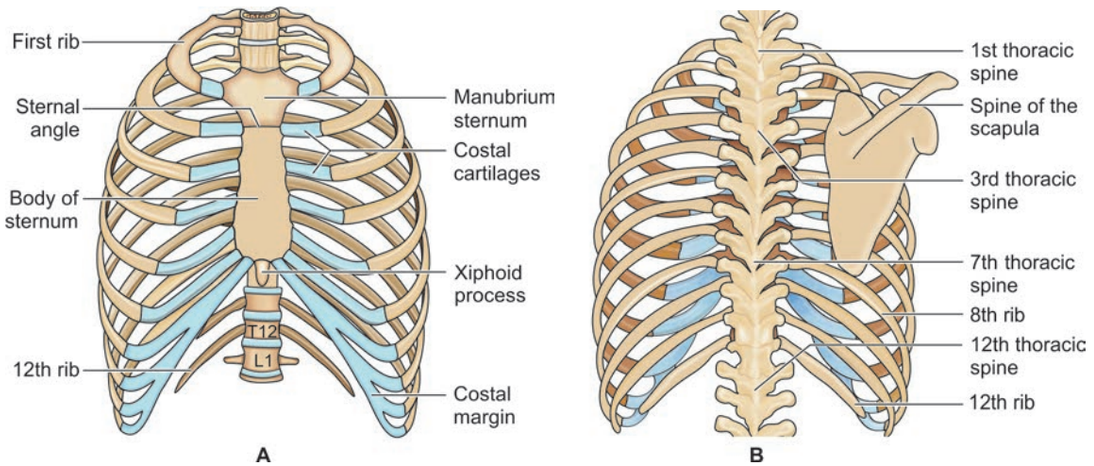


Fig. 39.1: Thoracic cage. **A:** Anterior view; **B:** Posterior view

Anteriorly: It is formed by the sternum.

On either side: The ribs and their costal cartilages.

Posteriorly: The thoracic vertebral bodies with intervertebral discs between them.

The cavity of the thoracic cage resembles a truncated cone which is narrow above and wider below. The upper end continues with the neck while the lower end is completely separated from the abdominal cavity by a dome-shaped muscular partition called diaphragm. Though the skeletal framework of the thoracic cage provides rigidity, its joints and flexibility of the ribs allow it to absorb many external blows and compressions. It is designed in such a way that it can alter the volume of thoracic cavity for respiration.

Inlet of the Thoracic Cage

Clinically it is referred as **outlet of the thorax**. When viewed from above it appears to be kidney shaped with transverse diameter ranging between 10 to 12 cm while anteroposterior diameter is only 5 cm. The inlet is not horizontal instead obliquely placed with an angle of 45°. This means the anterior wall is situated in front and below while posterior wall is situated behind and above (Fig. 39.2).

Boundaries

Anteriorly: Upper border of the manubrium sternum.

Posteriorly: Upper border of the body of first thoracic vertebra.

On each side: First rib and its cartilage.

The inlet is related to apex of the lungs covered by cervical pleura and suprapleural membrane (Sibson's fascia).

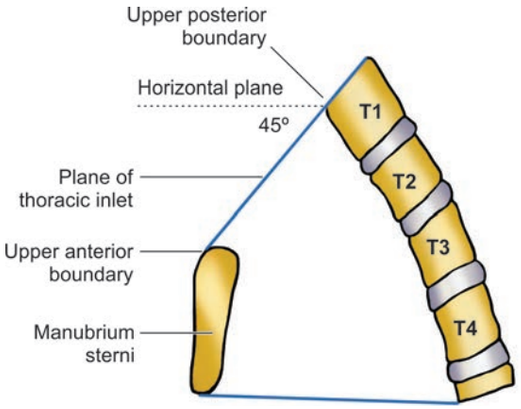


Fig. 39.2: Inlet of the thorax (lateral view)

Following are the important structures passing through the inlet of the thorax:

In the midline: Sternothyroid and sternohyoid muscles, inferior thyroid veins, trachea and the oesophagus.

On the right side of the midline: Brachiocephalic artery, right brachiocephalic vein.

On the left side of the midline: Left common carotid artery, left brachiocephalic vein, left recurrent laryngeal nerve and thoracic duct (Fig. 39.3).

Outlet of the thorax (inferior thoracic aperture): It is irregular in outline, and it is closed by the diaphragm. It is also oblique so that the posterior thoracic wall is longer than anterior.

STERNUM

Sternum is a flat bone, present in front of the thoracic cage. It presents the following parts from above

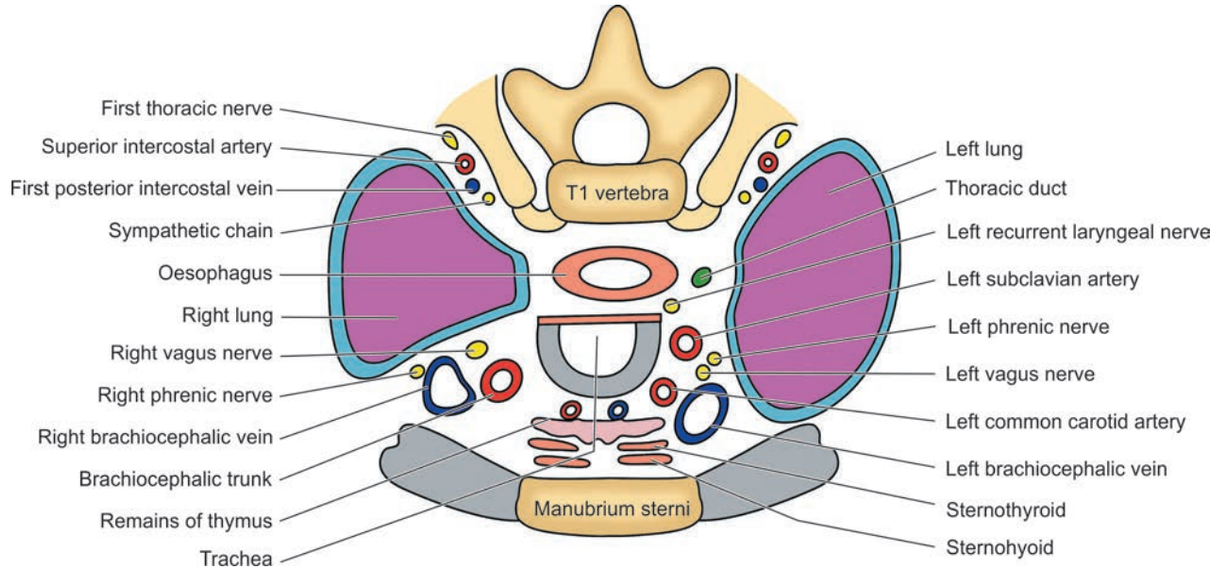


Fig. 39.3: Inlet of the thorax

downwards: Manubrium, body and xiphoid process (Fig. 39.4A and B).

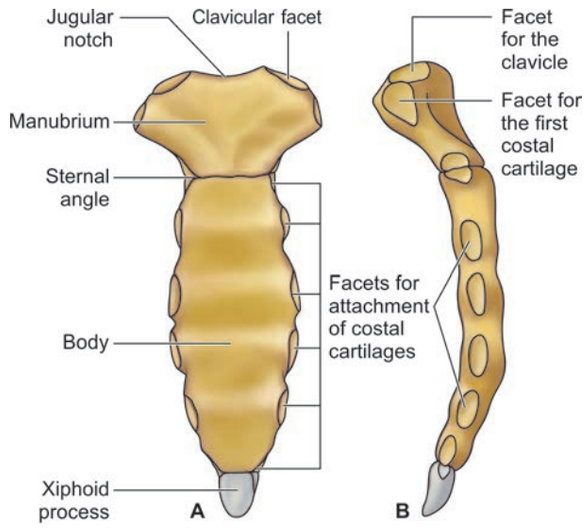


Fig. 39.4: Sternum. **A:** Anterior view; **B:** Lateral view

Manubrium: The manubrium is the upper part of the sternum. It articulates with the medial ends of clavicles and first costal cartilages. Its upper end is easily palpable and is called jugular notch (suprasternal notch). The anterior surface of the manubrium provides attachments to pectoralis major and sternocleidomastoid muscle. The upper part of the posterior surface provides attachments to sternohyoid and sternothyroid muscles. The posterior surface of the manubrium is related to the arch of the aorta.

Sternal angle (angle of Louis): It corresponds to the joint between manubrium and body of the sternum. It is an important landmark for the following reasons:

- The second costal cartilage can be felt at the sides of this angle. From this site one can count the ribs downwards.
- The ascending aorta ends, arch of the aorta begins and ends, and the thoracic aorta begins at this level.
- The trachea divides into two right and left principal bronchi.
- Azygos vein arches over the root of the right lung.
- The pulmonary trunk divides into right and left pulmonary arteries.
- The thoracic duct crosses from right to left side at this level.
- An imaginary horizontal plane passing through this level, demarcates superior mediastinum from the inferior mediastinum.

Body: The body is larger part of the sternum: On each side, it receives ribs through their costal cartilages (third to sixth ribs).

The anterior surface of the body provides attachment to pectoralis major on each side.

The lower part of the posterior surface provides attachments to sternocostalis muscle.

The posterior surface on the right half is directly related to anterior border of the right lung and pleura while the left half is related to the anterior border of the left lung and pleura in the upper part and pericardium and heart in the lower part. The posterior surface also provides attachments to sternopericardial ligament.

Xiphoid process: The xiphoid process is the most variable part of the sternum. It is a cartilaginous structure in young people but ossified in adults. Its joint with the body of the sternum (xiphisternal joint) laterally corresponds to 7th costal cartilage. Its anterior surface provides attachments to rectus abdominis, aponeurosis of external oblique abdominis and internal oblique abdominis muscles.

It is a midline marker for central tendon of diaphragm, inferior border of the heart and upper limit of the liver. Refer Chapter 38, for the development of the sternum and related anomalies.

Clinical Notes

Sternal puncture: A bone marrow sample can be obtained from sternum for hematological examination.

The fracture of the sternal body is usually a comminuted fracture (broken into several pieces), but displacement of the fragments is uncommon because of muscle attachments. Sternal fracture is common in road accidents, with its backward displacement, compressing aorta, heart or liver.

Sternum may be divided in the median plane (median sternotomy) for the surgeries of heart and its blood vessels. The flexibility of ribs and costal cartilages enables spreading of the halves of the sternum.

RIBS (COSTAE)

There are 12 pairs of ribs in the body. Each rib anteriorly articulates with the sternum, through its costal cartilage (first to seventh). The lower ribs articulate anteriorly with the higher costal cartilages (eighth to tenth). The anterior ends of the last two ribs are free and are called floating ribs (vertebral). Posteriorly each rib articulates with the thoracic vertebrae.

The third to ninth ribs present almost the same features, hence are referred as **typical ribs**. The 1st, 2nd, 10th, 11th and 12th ribs are atypical.

Typical Rib

Each typical rib has an anterior end, shaft and posterior end (Fig. 39.5).

a. Anterior end: It joins the corresponding costal cartilage by primary cartilaginous joint.

b. Posterior end: It presents head, neck and tubercle.

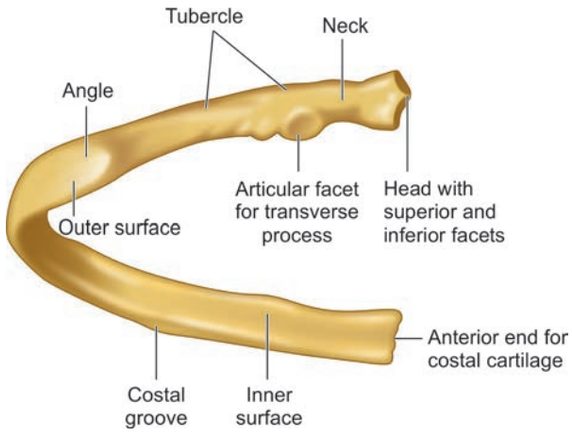


Fig. 39.5: Typical rib

Head: It comprises two facets. The lower facet of the head articulates with body of the numerically corresponding vertebra (plane synovial joint). The upper facet of the head articulates with body of the vertebra above (plane synovial joint). The two facets are separated by a crest, which corresponds to the intervertebral disc.

Neck: It is the narrow succeeding part of the head. It lies in front of the transverse process of the corresponding vertebra.

Tubercle: It is the rough portion between neck and shaft. It has medial articular and lateral nonarticular parts. The medial articular part articulates with transverse process of corresponding vertebra by a plane synovial joint (costotransverse joint). The lateral part provides attachment to lateral costotransverse ligament.

Shaft: It is the elongated flat part of the rib. It presents angulation about 5 to 6 cm lateral to the tubercle. The shaft is also twisted so that it is inner surface faces upwards behind the angle and faces downwards in front of the angle. The shaft presents upper and lower borders, outer and inner surfaces. The upper margin is smooth and rounded while lower border is sharp. From second to the tenth ribs, the distance between angle and tubercle increases. Medial to the angle, the outer surface gives attachment to levator costae and covered by erector spinae. The outer surface near the sternal end presents an indistinct line which separates the attachments of the external oblique and serratus anterior (or latissimus dorsi in case of the ninth and tenth ribs).

The external intercostal muscle is attached to inferior border. The superior border has two lips, the outer lip receives attachments of external intercostal while the inner lip receives internals intercostal muscles. The floor of the costal groove provides attachment to internal intercostal muscles. The innermost intercostal muscles are attached to inner surfaces of the shaft.

Costal groove: The lower part of the inner surface presents a costal groove, which is occupied by posterior intercostal vein, posterior intercostal artery and intercostal nerve from above downwards. You can remember these arrangements using a mnemonic VAN (Vein, Artery and Nerve). ☺

First Rib

- It is the shortest, broadest and most curved among all the ribs (Fig. 39.6A).
- The head presents only one facet for the body of first thoracic vertebra.
- The neck is rounded and directed laterally. Following important structures are related in front of the neck of the first rib from medial to lateral side.
  a. Sympathetic chain
  b. First posterior intercostal vein
  c. Superior intercostal artery
  d. Ventral ramus of the first thoracic nerve
  (You can recall these structures using a mnemonic —chain pulling a VAN) ☺

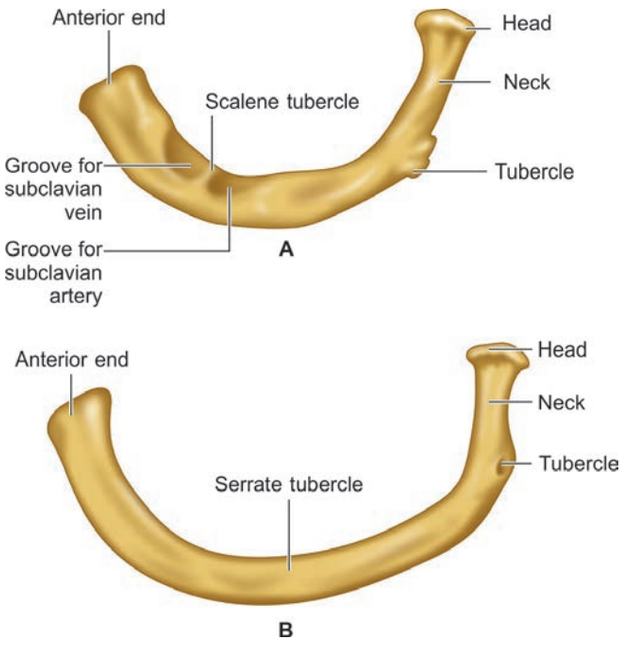


Fig. 39.6: Atypical ribs; **A:** First rib (superior view); **B:** Second rib (superior view)

- The clinical relevance of these relations is discussed in Chapter 41.
- The shaft has no twisting hence presents superior and inferior surfaces, outer and inner borders.
- The inner border and the upper surface present **scalene tubercle** for the insertion of scalenus anterior muscle. The inner border provides attachment to suprapleural membrane.
- The outer border is convex and receives attachment of first digitation of serratus anterior muscle.
- Its superior surface is grooved by subclavian vein in front of the scalene tubercle and subclavian artery behind the scalene tubercle.
- The anterior part of the superior surface provides attachment to subclavius muscle.
- The shaft has no costal groove.

Second Rib

- The second rib is also highly curved like first rib (Fig. 39.6B), but the length is twice that of the first rib.
- Shaft has no twisting and presents outer convex and inner concave surface.
- The head presents two articular facets for the bodies of 1st and 2nd thoracic vertebrae.
- It has a rough area on its upper surface called **serrate tubercle** providing attachment to serratus anterior muscle.
- A short costal groove is present on the posterior part of the inner surface.
- The posterior part of the upper border of the shaft receives insertion of scalenus posterior muscle.

Tenth Rib

The 10th rib has one facet—for articulation with its numerically corresponding vertebra.

11th and 12th Ribs

- There is no neck and tubercle.
- The head presents only one facet.
- Their anterior end is pointed.
- Costal groove and angle are absent in 12th rib, however in 11th rib it may be ill defined.

Clinical Notes

- The middle ribs are most commonly fractured from blows or from crushing injuries (automobile injuries). The weak point of the rib is near (anterior) its angle, however direct violence may fracture a rib anywhere. Fracture involving this site can penetrate the lungs or spleen. Fractures of the lower ribs may tear the diaphragm and result in diaphragmatic hernia. Rib fractures are painful.
- Ribs may be fractured occasionally during muscular strains (coughing).
- Rib dislocation can occur where costal cartilage articulates with sternum.
- Rib separation is the dislocation at the articulation between costal cartilage and ribs.
- In coarctation of aorta, X-ray shows notching of the ribs due to pressure by intercostal arteries.
- Supernumerary ribs: Presence of cervical or lumbar ribs is also known. Presence of cervical rib can lead to compression of neurovascular structures. Absence of 12th pair of ribs is also known.

Cervical Rib Syndrome/Scalenus Anterior Syndrome/Thoracic Outlet Syndrome

- Presence of cervical rib (Fig. 39.7) or a congenitally hypertrophied scalenus anterior muscle can compress the subclavian artery or lower trunk of the brachial plexus.
- Compression of the subclavian artery causes pallor and coldness of the upper limb and reduced radial pulse.
- Compression of the subclavian vein causes distension of the superficial vein, oedema and pain in the upper limb.
- Compression of the lower trunk of the brachial plexus causes numbness, tingling and pain along the medial border of the hand (C8 and T1) and little finger, wasting of small muscles of the hand.

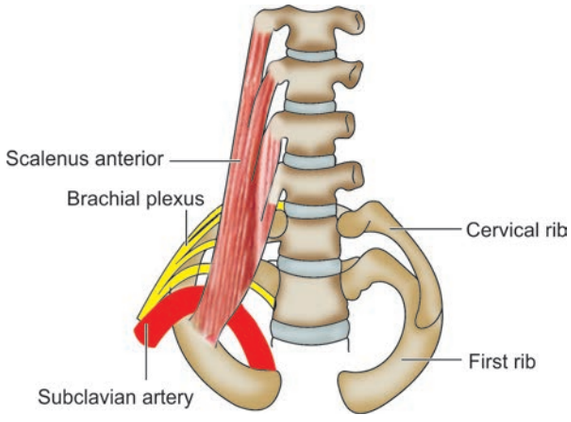


Fig. 39.7: Cervical rib

Costal Cartilages

The anterior ends of the ribs continue as costal cartilages, providing elasticity to thoracic wall. The cartilages increase in length through first seven and then gradually decrease. The first seven costal cartilages directly articulate with sternum. The eighth, ninth and tenth articulates with costal cartilages superior to them forming **costal margin.** The 11th

and 12th costal cartilages form caps on the anterior ends of the corresponding ribs.
Costal cartilages provide resilience to the thoracic cage and prevent fractures of ribs and sternum. Because of its elasticity, chest compression may produce injury within the thorax without fractures in children. In elderly people, the costal cartilages become brittle, and they may undergo calcification. They become radiopaque in X-rays.

CASE 1
On examining, a routine posteroanterior chest radiograph of an 85-year-old woman, it was noticed that many of the costal cartilages showed scattered radiopaque areas. What is the likely explanation for these opacities?

CASE 2
A 60-year-old man and a 10-year-old boy were both involved in a severe automobile accident. In both cases the thorax has been badly crushed. On X-ray examination, the man was seen to have five fractured ribs, but the boy had no fractures. Comment on these findings.

CASE 3
A 32-year-old patient presents with pain associated with taking a deep breath. Palpation reveals tenderness over midaxillary region of ribs 5 and 6 on the right side. Radiologic findings confirm fractures of these ribs:
1. How did you determine the correct rib numbers?
2. Do the ribs move during breathing?
3. How do you explain the pain?
4. What other structures may be at risk?

Thoracic vertebrae: The thoracic vertebrae are 12 in number of which second to eighth thoracic vertebrae are typical, while first and 9th to 12th thoracic vertebrae are atypical.
The further details are discussed in Chapter 37.

JOINTS OF THE THORAX

Manubriosternal Joint

It is the joint between the body and the manubrium of the sternum. It is a secondary cartilaginous joint. It permits slight movements during respiration.

Costovertebral Joint

As we studied before the head of the typical rib presents two facets. Of which the lower facet articulates with the numerically corresponding vertebra (with upper facet on the body). The upper facet on the head of the rib articulates with the vertebra above (with lower facet on the body). It is a plane synovial joint with capsular ligament and triradiate ligament.

Costotransverse Joint

The tubercle of a typical rib articulates with the facet on the anterior aspect of the transverse process of the numerically corresponding vertebra. It is a synovial joint. In addition to the capsular ligament the joint has three costotransverse ligaments (Fig. 39.8A and B).

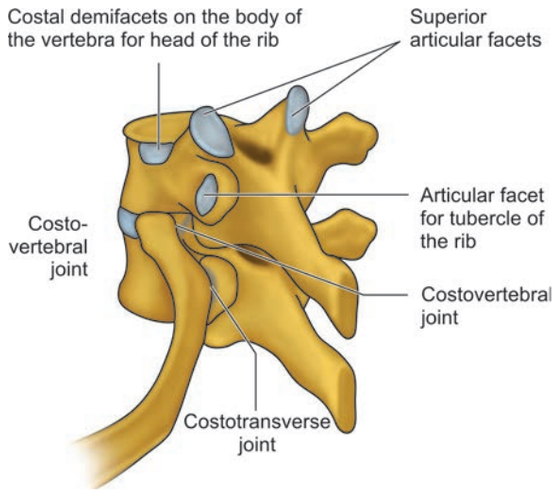


Fig. 39.8A: Joints of the ribs and vertebrae

a. Superior costotransverse ligament: It extends from the crest of the neck of the rib to the transverse process of the vertebra above.
b. Inferior costotransverse ligament: It extends from the posterior surface of the neck of the rib to the transverse process of its own vertebra.
c. Lateral costotransverse ligament: It extends from the lateral non-articular part of the tubercle of the rib to the tip of the transverse process of its own vertebra.
d. Radiate ligament: It connects the anterior part of the head of each rib with the side of the bodies of two vertebrae, and the intervertebral fibrocartilage between them.

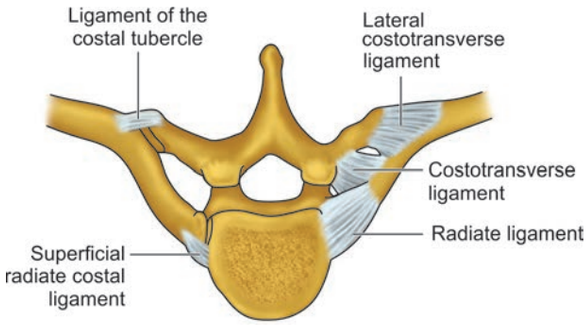


Fig. 39.8B: Joint between rib and vertebra (superior view)

It is interesting to note that the articular facets of the ribs vary and accordingly they bring different types of movement. For instance, the articular facets on the tubercles of the upper six ribs are convex and they permit the rotation of the neck of the rib for pump-handle movement. Their backward rotation helps in the forward and upward movement of the sternum which increases the anteroposterior diameter of the thorax.

Costochondral Joint

Each rib continues anteriorly with its cartilage. It is a primary cartilaginous joint. These joints do not allow any movement.

Chondrosternal Joint (between Costal Cartilages and Sternum)

The first chondrosternal joint is primary cartilaginous, and it does not permit any movement. The remaining second to seventh costal cartilages articulate with the sternum by synovial joints.

MUSCLES OF THE THORACIC WALL

Thoracic wall muscles include intercostal, subcostal, sternocostalis, levator costae and serratus posterior. The thoracic cage forms the skeletal framework of the walls of the thorax. The gaps between the ribs are called **intercostal spaces**, which are filled up by intercostal muscles (Figs 39.9 and 39.10A to C). The intercostal muscles are a group of intrinsic thoracic cage muscles that occupy the 11 intercostal spaces. They are divided into three groups, from superficial to deep are:

1. External intercostal muscles
2. Internal intercostal muscles
3. Innermost intercostal muscles

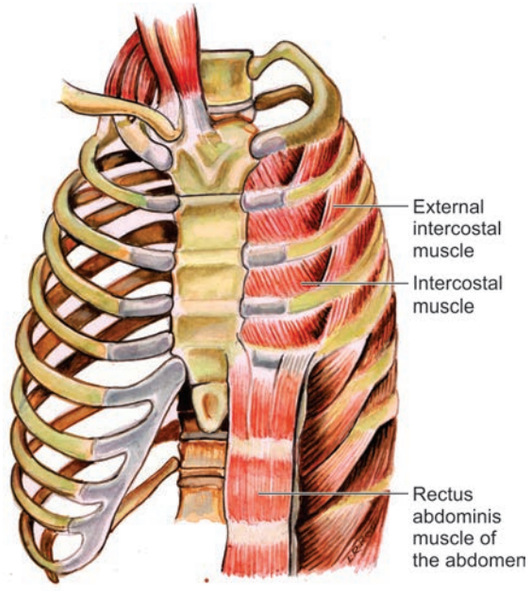


Fig. 39.9: Intercostal muscles

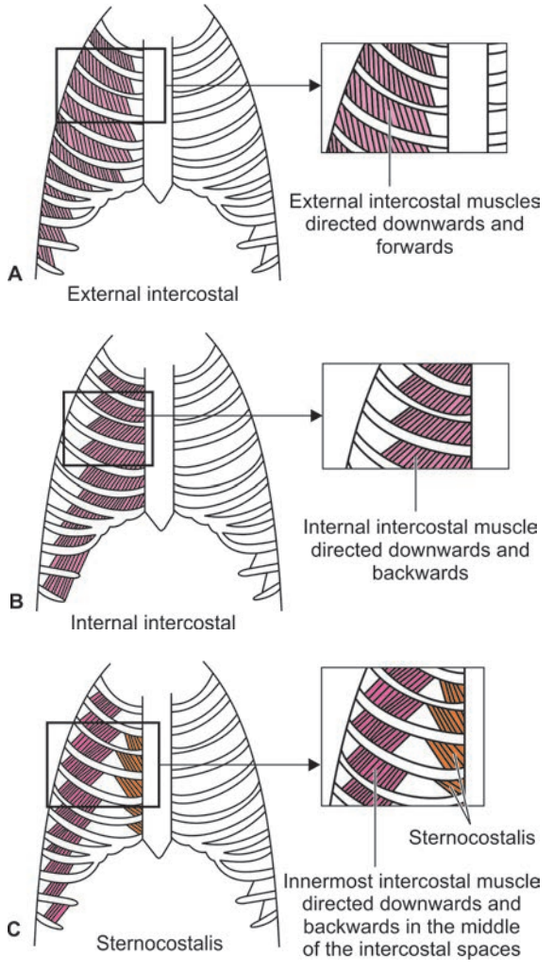


Fig. 39.10A to C: Intercostal muscles: Anterior view

All three groups of muscles support the rib cage. Moreover, they participate in the process of forced breathing.

1. External Intercostal Muscles

- In each intercostal space they extend from the angle of the ribs posteriorly to costochondral junction anteriorly.
- Between the lateral margin of the sternum and costochondral junction it is represented by an external intercostal (anterior intercostal) membrane.
- Each muscle arises from inferior border of upper ribs to the outer lip of the superior border of lower ribs.
- The directions of the muscles are downwards and medially in front and downwards and laterally in the posterior part (Fig. 39.10A).

2. Internal Intercostal Muscles

- They are present deep to the external intercostal muscle and its fibres are directed at right angle to the direction of external intercostal muscles (Fig. 39.10B).

- In each intercostal space the muscle extends from the angle of the ribs posteriorly to lateral border of the sternum anteriorly.
- In the posterior part of the intercostal space (beyond the angles of the ribs) it is represented by internal intercostal (posterior intercostal) membrane.
- Each muscle arises from the floor of the costal grooves to inner lip of the superior borders of the ribs inferior to them.

Subcostalis, sternocostalis and intercostalis intimi muscles are often grouped as transversus thoracis.

3. Innermost Intercostal Muscles (Intercostalis intimi)

- They are present deep to the internal intercostal muscle in the middle and lateral part of the intercostal spaces but separated from them by intercostal nerves and vessels (Fig. 39.11).
- The direction of the muscle fibres are same as internal intercostal muscles (downwards and backwards) (Fig. 39.10C).
- They extend from inner surface of the upper ribs to inner surface of the lower ribs.

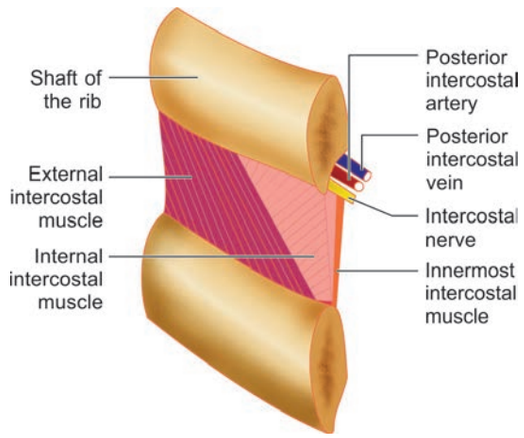


Fig. 39.11: Arrangements of intercostal muscles

Subcostalis

They arise from inner surface of lower ribs near their angles and extend to superior borders of 2 or 3 ribs below. They are better defined in lower intercostal spaces only.

Sternocostalis

It arises from the posterior surface of the lower part of the sternum. It extends **upwards** to inner surface of second to sixth costal cartilages (Fig. 39.10C).

It pulls ribs 2–6 towards the sternum during forced expiration, which results in depression of those ribs. This action consequently decreases the anteroposterior diameter of the thoracic cavity.

All these muscles are supplied by the intercostal nerves (thoracic spinal nerves).

Action of the Intercostal Muscles

a. The main action of the intercostal muscles is to prevent retraction of the intercostal spaces during inspiration and bulging during expiration. Such movements are an indication of the paralysis of the intercostal muscles.
b. The role of intercostal muscles in producing the movements of the ribs appear to be related mainly in forced respiration, the diaphragm being primary muscle of inspiration and expiration is passive (due to elastic tissues of the lungs).
c. It is believed that external intercostal and interchondral portions of the internal intercostal and levator costae may elevate the ribs during forceful inspiration.
d. The internal intercostal (except the interchondral part) and innermost intercostal may depress the ribs during forceful expiration.

Levator costarum: It extends from transverse processes of T7 to T11 vertebrae to subjacent ribs between tubercle and angle. It is supplied by posterior primary rami of C8–T11, nerves, and they elevate the ribs.

Serratus posterior superior: It arises from spinous process of C7 to T3 vertebrae and is inserted into upper borders of 2nd to 4th ribs. It is supplied by intercostal nerves (T2–T5) and known to elevate the ribs.

Serratus posterior inferior: It arises from spinous processes of T11 to L2 vertebrae and inserted into lower border of 8th to 12th ribs near their angles. They are supplied by lower intercostal and subcostal nerves (T9–T12) and are known to depress the ribs.

RESPIRATORY MOVEMENTS

In the medical world, breathing is defined as pulmonary ventilation. It is described as the movement of air between the atmosphere and the alveoli of the lung. It involves two events: inspiration, when the air moves into the lungs and expiration, when the air leaves the lungs.

Inspiratory Movement

Increase in thoracic volume (decrease in intrapulmonary pressure/pressure inside the lung) is achieved by movement of thoracic wall and diaphragm.

a. The increase in vertical diameter is due to contraction of the diaphragm. When diaphragm contracts, it descends, which leads to increase in vertical diameter of the thorax.
b. The increase in anteroposterior diameter of the thorax is due to contraction of intercostal

Table 39.1: Muscles of the thoracic wall—summarized

Name of the Muscle	Origin	Insertion	Nerve Supply	Actions
External intercostal Their fibres are directed downwards, forwards and medially when seen from the front	Lower border of the upper rib	Outer lip of the upper border of the rib below	Intercostal nerves	Elevate the ribs during forced inspiration
Internal intercostal Their fibres are directed obliquely, right angle to those of the external intercostals	From the floor of the costal groove	Inner lip of the upper border of the rib below	Intercostal nerves	Depress the ribs during forced expiration but interchondral part elevates the ribs during forced inspiration
Innermost intercostal The fibres are directed similar to that of the internal intercostals	Inner surface of the upper rib	Inner surface of the rib below	Intercostal nerves	Depress the ribs during forced expiration
Subcostales They are confined to the lower intercostal spaces only	Inner surface of one rib near the angle	Inner surface of the second or third rib below	Intercostal nerve	Depresses the ribs
Sternocostalis	Lower part of the posterior surface of the sternum and xiphoid process and costal cartilages	The fibres ascend laterally and inserted into lower border and inner surfaces of second to sixth ribs	Intercostal nerves	It pulls ribs 2–6 towards the sternum during forced expiration, which results in depression of those ribs.

muscles. Movement of the ribs (2nd to 6th) at the costovertebral joints around an axis passing through necks of the ribs causes anterior ends of the ribs to rise. Since anterior ends of the ribs are directed downwards, their elevation results in anteroposterior movement of the sternum. This is called **pump handle movement** (Fig. 39.12A).

c. The increase in transverse diameter of the thorax is also due to contraction of intercostal muscles. Movements of lower ribs rise the middle part of the ribs, thus increasing transverse diameter. This is called **bucket handle movement** (Fig. 39.12B).

With increase in the thoracic volume, the pressure inside the lung is reduced. So, air is drawn into the lungs through, nose, mouth, larynx and trachea.

Expiratory Movement

The air is expelled out from the lung, due to elastic recoiling tendency of the lungs. It is a passive act. The diaphragm and intercostal muscle relax, thus decreasing the thoracic volume and increasing the pressure inside the lungs.

Muscles involved: Muscles that are helpful in expanding the thoracic cavity are called

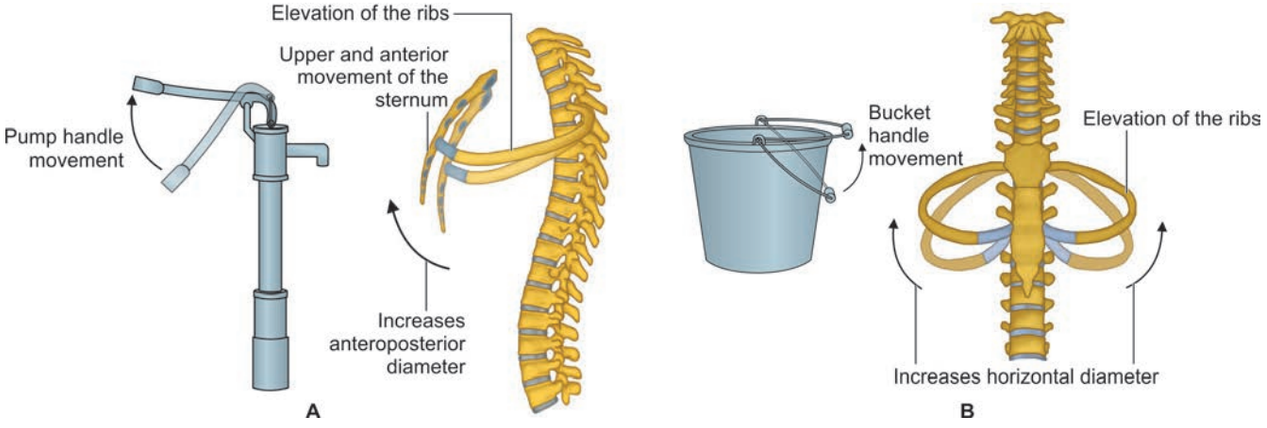


Fig. 39.12: Respiratory movements. **A:** Pump handle movement; **B:** Bucket handle movement

the inspiratory muscles because they help in inhalation, while those that compress the thoracic cavity are called expiratory muscles and they induce exhalation. The specialty of these muscles are that they are composed of fatigue resistant muscle fibres, they are controlled by both voluntary and involuntary mechanisms (if we want to take a breath we can, even if we do not think about breathing the body automatically does it). The muscles of inspiration elevate the ribs and sternum, and the muscles of expiration depress them.

Chief muscles of inspiration: Diaphragm

Deep inspiration: External intercostal and interchondral portion of the internal intercostal.

Accessory muscles of inspiration: The accessory inspiratory muscles are the sternocleidomastoid, the scalenus anterior, medius, and posterior, the pectoralis major and minor, the inferior fibres of serratus anterior and latissimus dorsi, the serratus posterior superior.

Chief muscles of forceful expiration: Interosseous part of the internal intercostal muscle and anterior abdominal wall muscles.

CASE 4

A mother, on looking at her newborn baby lying on its back in a cradle, was astonished and horrified to see its anterior abdominal wall bulging in and out with each respiration. Can you explain this in anatomical terms?

Endothoracic fascia: The thoracic cage is internally lined by a thin fibroareolar membrane called endothoracic fascia. It connects the costal part of the parietal pleura to the inner aspect of the thoracic wall. It is better defined over the apices of the lungs as the suprapleural membrane.

Suprapleural membrane (Sibson's fascia): It is the thicker part of the endothoracic fascia (or from scalenus minimus/pleuralis muscle) covering the cervical pleura and the apex of the lung which lies deep to it. It is attached to the inner border of the 1st rib and its costal cartilage and tip of the transverse process of 7th cervical vertebra. It prevents puffing off of lung apex during expiratory phase of respiration.

CASE 5

A carpenter who had received a knife wound in the neck two years before now noticed that when he blew his nose or sneezed, the skin above the clavicle bulged upward. Explain this upward bulging of the skin in anatomical terms.

TYPICAL INTERCOSTAL SPACE

The spaces between the typical ribs and traversed by intercostal nerves supplying only thorax are known as **typical intercostal spaces**. The 3rd, 4th, 5th and 6th intercostal spaces are typical.

Each space is directed downwards and forwards. It is narrow at the posterior part (towards vertebra) and wider at the anterior part (towards sternum).

Contents: Intercostal muscles, nerves and vessels.

Intercostal Nerves

The 12 pairs of thoracic spinal nerves supply the thoracic wall after dividing into anterior and posterior primary rami. The posterior rami of thoracic spinal nerves pass posteriorly to supply the muscles of the back and skin of the back. The anterior primary rami of 1st to 11th thoracic spinal nerves are called **intercostal nerves** since they course through intercostal space. The anterior primary ramus of 12th thoracic spinal nerve is called subcostal nerve.

First thoracic ventral ramus: The anterior/ventral primary ramus of first thoracic spinal nerve divides into two branches. The larger branch joins with anterior primary ramus (ventral ramus) of 8th cervical spinal nerve to form lower trunk of the brachial plexus. It means T1 fibres are distributed through upper limb. The smaller branch of anterior primary ramus of 1st thoracic spinal nerve form 1st intercostal nerve, **which courses along the under surface of the 1st rib. It does not give any cutaneous branch**.

The 2nd intercostal nerve gives lateral cutaneous branch and is called 'intercostobrachial nerve', which supplies skin of the floor of the axilla. The 7th to 11th intercostal nerves in addition to intercostal spaces, also supply anterior abdominal wall.

Typical Intercostal Nerves

The 3rd to 6th intercostal nerves, which are confined only to thoracic wall, are called typical intercostal nerves (Fig. 39.13).

Course

a. At the posterior ends of the intercostal space (vertebral end), each intercostal nerve travels between parietal pleura and posterior intercostal membrane, crossing behind the sympathetic chain.
b. Each nerve, medial to the angle of the rib enters the costal groove to occupy with intercostal vessels. The arrangement of the structures from above downwards is '**VAN**'—**v**ein, **a**rtery and **n**erve.
c. The nerve proceeds between internal intercostal and innermost intercostal muscles.

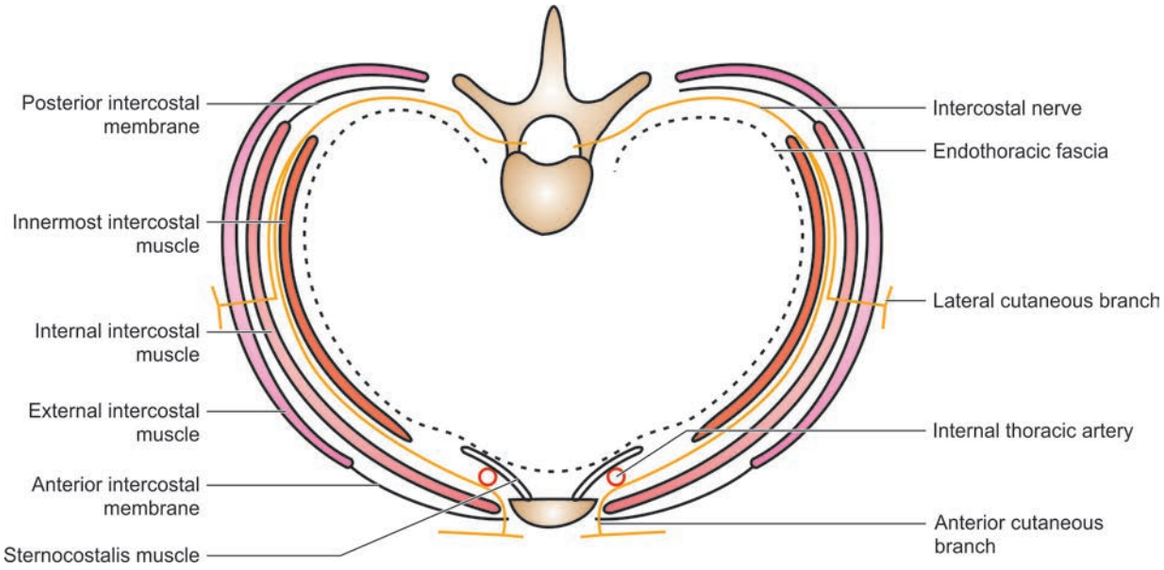


Fig. 39.13: Typical intercostal nerve (a schematic cross sectional view)

d. Near the anterior ends of the intercostal space (sternal end), each nerve crosses in front of the internal thoracic artery, pierces internal intercostal muscle, anterior intercostal membrane, pectoralis major muscle. It terminates as anterior cutaneous nerve.

Branches and Distribution

1. **Collateral branch:** It arises near the angle of the rib and proceeds in the lower part of the same intercostal space (upper margin of the lower ribs). It may join the main trunk in the anterior part of the intercostal space. It supplies intercostal muscles and parietal pleura.
2. **Lateral cutaneous branch:** It arises near the angle of the rib, runs with main trunk. At the midaxillary line it pierces the intercostal muscles and becomes superficial. It divides into anterior and posterior branches, which supply skin of the lateral thoracic wall.
3. **Muscular branches:** It supplies intercostal muscles, subcostal, sternocostalis, and the 4th and 5th typical intercostal nerve also supplies serratus posterior superior.
4. **Sensory branches:** The intercostal nerves apart from supplying skin and muscles, it also carries sensory (pain) fibres from parietal pleura. (The atypical, thoracoabdominal intercostal nerves, apart from supplying skin and muscles of the anterior abdominal wall. It also supplies parietal peritoneum.)
5. **Anterior cutaneous branches:** They are the continuation of intercostal nerves, pierces typical intercostal nerve (a schematic cross sectional view) on either side of the sternum to become superficial. After dividing into medial and lateral branches, supply the skin of the anterior aspect of the sternum.

Components of Intercostal Nerve

- Afferent: Cutaneous sensation from thoracic and abdominal wall
- Afferent: Sensation from costal and peripheral part of the diaphragmatic pleura
- Efferent: Motor fibres to intercostal muscles
- Efferent: Sympathetic fibres present in it, supplies sweat glands (sudomotor), Arrector pili muscles of the dermis (pilomotor) and the smooth muscles present at the wall of the blood vessels (vasomotor).

Clinical Notes

Intercostal nerve block: To produce anesthesia in one or two intercostal spaces, anesthetic solution is injected around the intercostal nerve. The intercostal nerve can be blocked anywhere proximal to the midaxillary line, where the lateral cutaneous branch originates. In children, the block is commonly carried out at the posterior axillary line. In adults, the most popular site for intercostal nerve block is at the angle of the rib (6–8 cm from the spinous processes). Just **lateral to the angle** of the rib, the rib is relatively superficial and easy to palpate, and the costal groove is the widest, theoretically reducing the probability of pleural puncture. Blockade medial to the angle of the rib is not recommended because the nerve lies deep to the posterior intercostal membrane with very little tissue between it and the parietal pleura, while the overlying sacrospinalis muscle makes rib palpation difficult. Blockade distal to the anterior axillary line is more difficult because the nerve has left the costal groove and re-entered the intercostal space and lies in the substance of the internal intercostal muscle.

Intercostal nerve block is used in a great variety of acute and chronic pain conditions affecting the thorax and upper abdomen. Complete loss of sensation usually does not occur unless two or more intercostal nerves are anesthetized.

Herpes zoster infection: Herpes zoster (or simply zoster), commonly known as shingles is a viral disease characterized by a painful skin rash with blisters in a limited area on one side of the body, often in a stripe. Years or decades after a chickenpox infection, the virus may break out of nerve cell bodies (example; dorsal root ganglia) and travel down through axons to cause viral infection of the skin in the region, supplied by that particular spinal nerve (dermatome). It can also be associate with muscular weakness.

The diseases of the thoracic vertebrae may irritate the intercostal nerves and pus from the tuberculous thoracic vertebrae may track along the neurovascular plane.

Blood Vessels of Thoracic Wall

Internal thoracic artery (internal mammary artery)

Origin: It arises from the under surface of the first part of the subclavian artery.

Course: The artery is crossed by phrenic nerve near its origin. It descends lateral to the sternum, deep to the costal cartilages, anterior to sternocostalis muscle. At the sixth intercostal space, it ends by dividing into two terminal branches; superior epigastric artery and musculophrenic artery (Fig. 39.14). Internal thoracic artery is accompanied by venae commitantes (pair of veins).

Branches

1. **Anterior intercostal arteries:** In the upper six intercostal space, there are two anterior intercostal arteries. The upper branch, anastomose with main trunk of the posterior intercostal artery, whereas the lower branch anastomoses with collateral branch of the posterior intercostal artery.
2. **Pericardiophrenic artery:** It accompanies the phrenic and descends in front of the root of the lungs. The artery is located between the fibrous pericardium and the parietal pleura in the middle mediastinum and extends inferiorly into the diaphragm. It supplies diaphragm and also phrenic nerve.
3. Pericardial, thymic, sternal and mediastinal branches.
4. Perforating branches in 2nd and 3rd intercostal space in females supply mammary gland.
5. The superior epigastric artery enters rectus sheath through xiphoid and sternal origins of diaphragm. It anastomoses with inferior epigastric artery (a branch from the external iliac artery).
6. The musculophrenic artery descends obliquely parallel to costal margin. Apart from supplying diaphragm, it also gives anterior intercostal arteries of 7th to 9th intercostal space. It anastomoses with inferior phrenic, lower two posterior intercostal arteries and ascending branch of the deep circumflex iliac arteries.

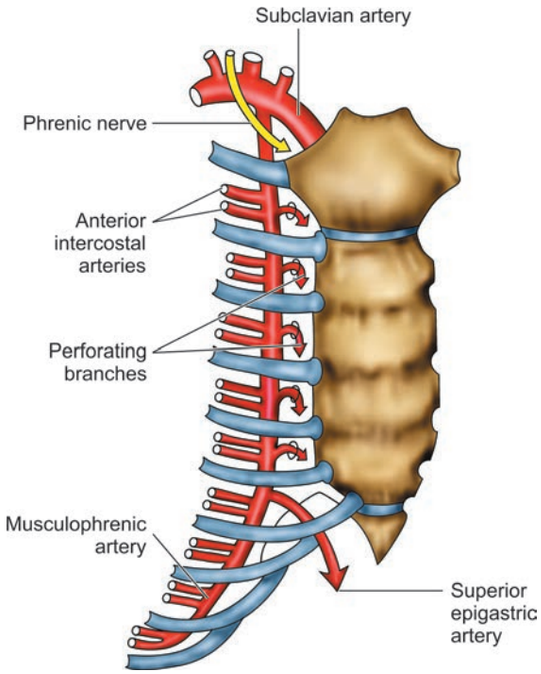


Fig. 39.14: Internal thoracic artery

Clinical Notes

The internal thoracic artery is the cardiac surgeon's artery of choice for coronary artery bypass grafting. It has superior long-term patency compared to saphenous vein grafts. Several histological (more elastic tissue), physiological (release more nitric oxide, which inhibits proliferation of smooth muscles in tunica intima) and anatomical (nearer to the coronary artery) advantages of internal thoracic artery is claimed.

Intercostal Arteries

In each intercostal space there are two anterior intercostal arteries and one posterior intercostal artery (with exception of 10th and 11th intercostal spaces).

In the upper six intercostal space, anterior intercostal arteries are branches of internal thoracic artery, while in 7th to 9th intercostal spaces-, they are branches of musculophrenic artery.

Posterior Intercostal Arteries

In the upper two intercostal spaces, it arises from superior intercostal artery (a branch of the costocervical trunk of the subclavian artery). In the remaining spaces it arises from descending thoracic aorta (Fig. 39.15).

The right posterior intercostal arteries are longer since thoracic aorta is slightly to the left of the vertebral column and have to cross in front of the vertebral bodies. Each posterior intercostal artery is accompanied by posterior intercostal vein and intercostal nerve in the costal groove. Anteriorly they end by anastomosing with upper anterior intercostal arteries. The third right posterior intercostal artery can give origin to right bronchial artery.

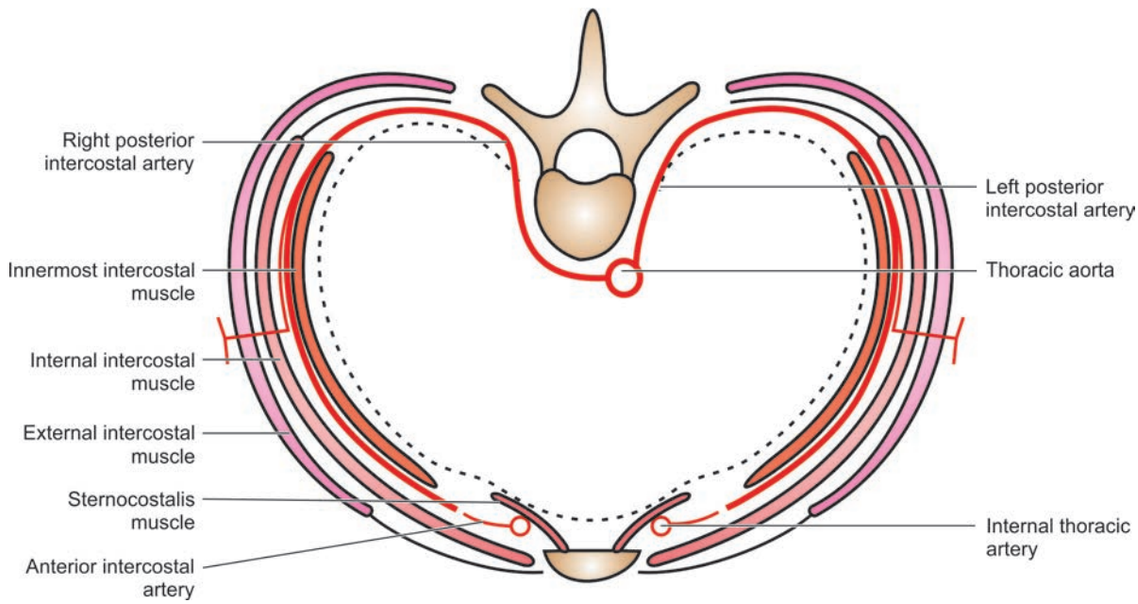


Fig. 39.15: Posterior intercostal artery (a schematic cross-section view)

The anastomoses between anterior and posterior intercostal arteries provide a connection between subclavian artery and thoracic aorta. These anastomoses become important in case of coarctation of aorta providing collateral circulation, which is discussed in detail in Chapter 46.

Superior Intercostal Artery

It is a branch arising from the costocervical trunk of the subclavian artery. It descends between the pleura and neck of the first and second ribs and anastomose with the third posterior intercostal artery. While crossing the neck of the first rib. It is closely related to ventral ramus of first thoracic nerve and stellate ganglion. It gives posterior intercostal artery to the first intercostal space and then continues as second posterior intercostal artery.

The venous drainage of the thoracic wall is discussed in Chapter 45.

Lymphatic Drainage of the Thoracic Wall

Parasternal nodes: These are placed along the internal thoracic vessels. They drain deeper tissue of the anterior thoracic wall and anterior abdominal wall (up to the level of umbilicus) and also mammary gland. The efferent lymphatic vessels arising from them join bronchomediastinal trunk (refer to lymphatic drainage of lungs).

Posterior intercostals nodes: These are located at the posterior ends of the intercostals spaces. They drain part of the mammary gland and posterolateral wall of the thoracic wall. Their efferent vessels drain into thoracic duct.

Clinical Notes

Clinical Examination of Thoracic Wall

Inspection and palpation: Usually inspection and palpation are discussed together because there is an intimate relationship between these two processes in the chest examination. Palpation not only confirms the results in inspection but also discovers diagnostic signs. Through careful palpation, the examiner should aim to determine the location and size of the cardiac apex impulse, characterize its contour, and identify any abnormal precordial pulsations.

Percussion: The chest is percussed to confirm the cardiac borders, size contour and position in the thorax.

Auscultation: The purpose of auscultation of the heart is to find the normal and abnormal sounds of the heart. It plays a very important role in the diagnosis of heart disease.

Solutions to the clinical case studies

Case 1: In old age the costal cartilages may undergo ossification. They then become radiopaque and may give rise to some confusion when examining a chest radiograph of an elderly patient.

Case 2: The thoracic wall of the child is very elastic, and fractures of ribs in children are rare. But in aged people the ribs become brittle and more prone to be fractured.

Case 3:

1. The ribs are usually counted from the level of sternal angle which corresponds to second costal cartilage. There are other bony landmarks which also help to determine the correct rib number like, xyphisternal joint corresponds to seventh costal cartilage.
2. Ribs move during respiratory movements (*refer* to bucket handle and pump handle movement in respiratory movements)
3. Pain is due to fracture of the ribs
4. Lungs

Case 4: A newborn does not breathe evenly like adults do, in and out. Instead, they breathe in clusters of many breaths followed by long pauses that can be terrifying for new parents.

Case 5: The suprapleural membrane was damaged by knife and was not repaired during surgery. Subsequently, herniation of the cervical pleura and apex of the lung took place, which resulted in the skin above the clavicle bulging upward during forced expiration.

MCQs

1. The second costal cartilage can be located by palpating which of this structure?
A. Costal margin
B. Sternal angle
C. Sternal notch
D. Sternoclavicular joint

2. The tubercle of the 7th rib articulates with which structure?
A. Body of vertebra T6
B. Transverse process of vertebra T7
C. Body of vertebra T7
D. Transverse process of vertebra T6

3. Which of this bony structure can be palpated below the inferior margin of the medial portion of the clavicle?
A. Acromion
B. Atlas
C. First rib
D. Second rib

4. A wrestler's chest is compressed during a match, causing a posterior displacement of the clavicle at the sternoclavicular joint. Which of the following structures would be most at risk?
A. Aorta
B. Oesophagus
C. Trachea
D. Superior vena cava

5. A medical student inserting an intercostal drain for the first time forgets her anatomy and passes it at the lower border of the rib. Which of this structure is most likely to be damaged?
A. Intercostal artery
B. Intercostal nerve
C. Intercostal vein
D. Internal intercostal muscle

6. A 21-year-old female college student is involved in a road accident. She sustains a blunt force injury to the chest, resulting in fracture of the left seventh rib. The patient is experiencing severe pain from this fracture. To relive this pain, a resident administers a local anesthetic. Which of the following sites would be the most appropriate site for this injection?
A. 7th intercostal space immediately below the 7th rib in the midclavicular line
B. 7th intercostal space immediately below the 7th rib just lateral to the angle of the rib
C. 7th intercostal space immediately below the 7th rib just medial to the angle of the rib
D. 6th intercostal space immediately above the 7th rib in the midclavicular line

7. Which of the following layers provides a natural cleavage plane for surgical separation of the costal pleura from the thoracic wall?
A. Deep fascia
B. Endothoracic fascia
C. Parietal pleura
D. Visceral pleura

8. A patient rush into the hospital complaining of dyspnea (shortness of breath). He complains that breathing in air is difficult. Which of the following is a muscle of inspiration?
A. Rectus abdominis
B. Internal intercostais
C. Innermost intercostals
D. Interchondral part of internal intercostals

9. A doctor informs his colleagues to insert a catheter in patient at the 7th intercostal space. Which of the following is the correct insertion point of catheter?
A. Just above 7th rib
B. Just below 7th rib
C. Just above the 8th rib
D. Just below the 8th rib

ANSWERS TO THE MCQs

1. B	2. B	3. D	4. C	5. B
6. B	7. B	8. D	9. C	

JUST BEFORE THE EXAM

Thoracic cage → Boundaries: anteriorly by the sternum, posteriorly by the 12 thoracic vertebrae with intervertebral discs between them and on either side by 12 pairs of ribs and their costal cartilages.

Ribs → There are 12 pairs of ribs, of which the 3–9 ribs are typical ribs. Each rib articulates posteriorly with the body and transverse process of the thoracic vertebrae through synovial joints.

Intercostal space → The spaces between the ribs are called intercostal space. The third to sixth intercostal spaces are considered as typical intercostal space.

Contents of the intercostal space → Mainly three muscles—external intercostals, internal intercostals and innermost intercostals, intercostal nerves and vessels.

External intercostals → These are directed downwards forwards and medially and they elevate the ribs during forced inspiration.

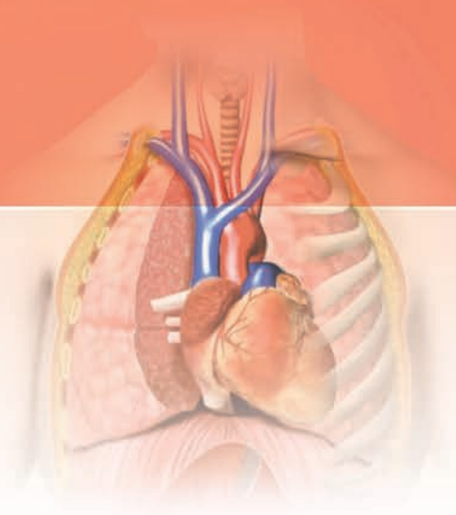
Internal intercostals → These are directed right angle to the direction of external intercostal (downwards and laterally). The interchondral part of the muscle elevates the ribs in forced inspiration while interosseous part of the muscle depresses the ribs during forced expiration.

Innermost intercostals → These are confined to the middle part of the intercostal space. The muscles are directed similar to that of the internal intercostals. They depress the ribs during forced expiration.

Neurovascular structure of the intercostal space includes → Posterior intercostal vein, posterior intercostal artery and intercostal nerves (their arrangements in the costal groove of the ribs from above downwards is VAN —Vein, Artery and Nerve).

Intercostal nerves → The ventral ramus of T1 to T11 spinal nerves are called intercostal nerves, of which third to sixth intercostal nerves are typical intercostal nerves. Each intercostal nerve supplies intercostal muscles, skin of the anterolateral chest walls, parietal pleura and also sensory fibres to the diaphragm.

Internal thoracic (internal mammary) artery → A branch from the first part of the subclavian artery. It terminates by dividing into superior epigastric and musculophrenic arteries. In each of the upper six intercostal spaces they give two anterior intercostal arteries which anastomose with posterior intercostal arteries.



Chapter

40

Pleura

Competencies: AN 24.1 and 25.9

Objectives

- To define the pleura, pleural cavity and to name its two layers
- To name the different parts of the parietal pleura, its nerve supply and clinical relevance
- To surface mark, the pleural reflection
- To name the pleural recesses, their extent, relations and clinical relevance

PLEURA AND ITS SUBDIVISION

It is a fibroserous membrane covering the lungs. The term fibrous refers to connective tissue fibres (collagen and elastic fibres) and serous refers to mesothelial cells which secretes fluid into the pleural cavity. The pleural cavity is the fluid filled space which surrounds the lungs except at its hilum. The pleura is formed by inner visceral pleura and outer parietal pleura which are in continuity. This is because each pleural sac is invaginated by the lung from the medial side; hence it consists of an inner visceral and outer parietal layer with pleural cavity in between them. Both these layers are lined by mesothelial cells (facing the pleural cavity), which secrete serous fluid into the pleural cavity (Fig. 40.1).

1. **Visceral (pulmonary) pleura:** It closely invests the lungs, except at the hilum.
2. **Parietal pleura:** It lines inner aspect of the thoracic wall, upper surface of the diaphragm, mediastinum and under surface of the suprapleural membrane. It is named according to the structures it lines. They are given as follows.

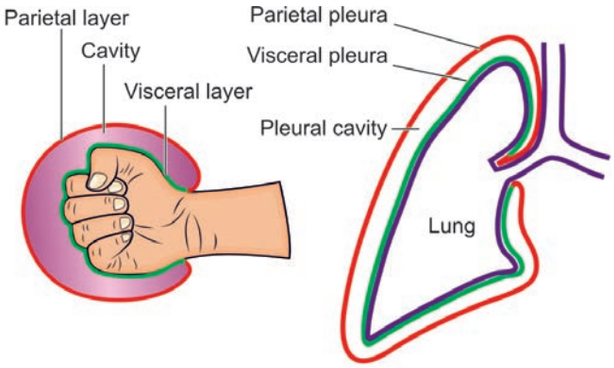


Fig. 40.1: Parietal and visceral layers of the pleura (schematic)

Costal Pleura

It lines the inner surface of the sternum, ribs and their costal cartilages and intercostal muscles. All these structures are separated from it by endothoracic fascia. At the first intercostal space, the internal thoracic artery is directly related to it. Posteriorly it is reflected in front of the sympathetic chain.

Diaphragmatic Pleura

It covers the upper surface of the diaphragm (Fig. 40.2A).

Cervical Pleura

The costal pleura, above the level of first rib forms cervical pleura. It extends to the root of the neck covering the apex of the lung. Its upper surface is covered by a suprapleural membrane.

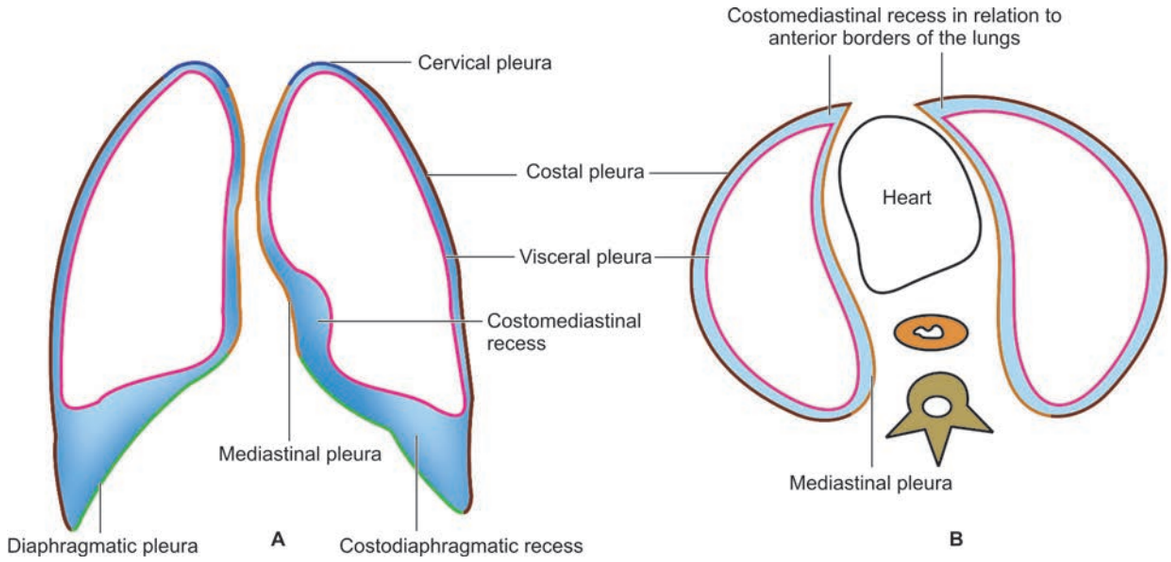


Fig. 40.2: Pleural recesses; **A:** Anterior view; **B:** Superior view

Mediastinal Pleura

It covers the lateral aspect of the mediastinum. The heart with pericardium is separated from medial surface of lung by mediastinal pleura (Fig. 40.2B). It is reflected over the root of the lung and extends below the root as a double-layered fold called **pulmonary ligament**. Through this the parietal pleura continues with visceral pleura. There is a potential space between the two layers of the pulmonary ligament, which provides a dead space for expansion of inferior pulmonary veins during increased venous return and also for descent of root of the lung during inspiration.

Pleural cavity: The space between the visceral and parietal pleura forms the pleural cavity (or pleural space). Normally it contains a small volume of pleural fluid and is a narrow space. The fluid allows the lungs to glide freely without friction over thoracic wall during breathing movements. The lymphatic vessels drain the pleural fluid continuously. The pressure inside the pleural cavity is negative (**about –2 mm Hg and during inspiration it drops to about –8 mm Hg**), which is necessary to retain the visceral pleura in contact with parietal pleura. When the negative pressure collapses (entry of air or fluid), the lungs will collapse because of its elastic recoiling tendency. It pulls the visceral pleura away from the parietal pleura.

The lungs are comparable to an inflated balloon when they are distended. If the distension is not maintained, their inherent elasticity will cause them to collapse. An inflated balloon remains (lungs) distended even when the airway passages are open because the outer surface of the lungs (visceral pleura) adhere to the inner surface of the thoracic walls (parietal pleura) as a result of surface tension provided by the pleural fluid.

PLEURAL REFLECTIONS

Costomediastinal Line

Anteriorly the costal pleura becomes continuous with the mediastinal pleura and is called costomediastinal pleural reflection. It is related to anterior border of the lungs extending from the apex of the lung.

Surface marking: A line connecting the following points will mark the costomediastinal reflection.

- A point behind the sternoclavicular joint
- A point near the midpoint of the sternal angle.
- Further the costomediastinal line differs on right and left side. On right side the third point is xiphisternal angle near the midline.
- On left side the third point is at the level of 4th costal cartilage. From this point, draw an oblique line descending close to the lateral margin of the sternum up to the left 6th costal cartilage (Fig. 40.3).

Costodiaphragmatic Line

Inferiorly the costal pleura continues with the diaphragmatic pleura along the costodiaphragmatic pleural reflection.

Surface marking: On the right side, the marking begins from xiphisternal angle.

- It crosses **8th rib in the midclavicular line, 10th rib in the midaxillary line** and ends at a point **2 cm lateral to 12th thoracic spine.**

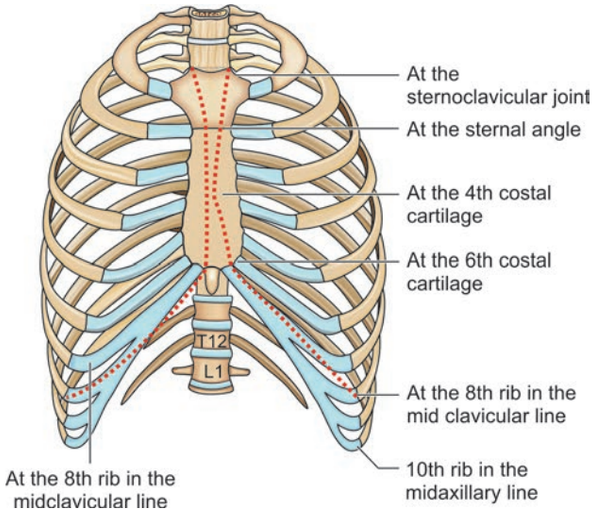


Fig. 40.3: Pleural reflection (anterior view)

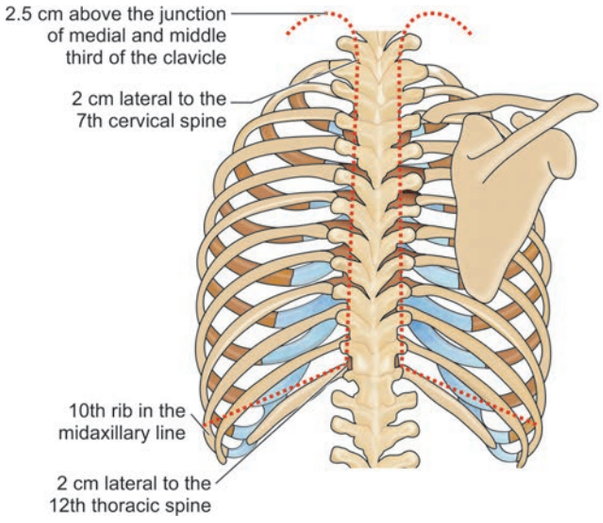


Fig. 40.4: Pleural reflection (posterior view)

- It suggests that the lower limit of pleura in the midclavicular line is 8th rib and 10th rib in midaxillary line (Fig. 40.3).

Costovertebral Line

Posteriorly the costal pleura continues with the mediastinal pleura by the side of the vertebral column and is called costovertebral pleural reflection.

Surface marking: A vertical line connecting a point 2 cm lateral to the 12th thoracic spine to a point 2 cm lateral to the 7th cervicalspine (vertebra prominence) (Fig. 40.4).

Cervical Pleura

It is marked by a curved line extending posteriorly from a point 2 cm lateral to the 7th cervical spine, a point 2.5 cm above the junction of medial and middle third of the clavicle and finally to a point at the sternoclavicular joint.

PLEURAL RECESSES

The pleural recesses are extended part of the pleural cavity along the lines of pleural reflections. The lungs do not extend into these spaces during quiet breathing. There are two pleural recesses:

1. Costomediastinal Recess

This space is present along the costomediastinal pleural reflection (junction of the costal and mediastinal pleura). It is related to anterior borders of the lungs (during deep inspiration). The right costomediastinal recess is narrow and uniform in size. The left costomediastinal recess is well defined between 4th to 6th costal cartilages due to the cardiac notch of the left lung (deviation in the anterior border of the left lung). Because of this cardiac notch, a small portion of the right ventricle is not covered by lung and pleura, this area is dull on percussion (area of superficial cardiac dullness) (Figs 40.2 and 40.5).

2. Costodiaphragmatic Recess

- This space is present along the costodiaphragmatic pleural reflection (between costal and diaphragmatic pleura).
- During deep inspiration this space gets obliterated due to downward movement of the lung.
- The recess is deep along the midaxillary line, where it extends up to 10th rib (Figs 40.2 and 40.6).
- It is the most dependent part of the pleural cavity. **If fluid appears in the pleural cavity, it collects first in the costodiaphragmatic recess.** In plane radiographs of chest, these cavities appear as dark shadows on either side of the opaque diaphragm. Hence, during examination of a chest X-ray, observing this area is important.
- Excess pleural fluid is drained from costodiaphragmatic recess (thoracocentesis), hence the relation of this recess is very important.
- On right side it is related to liver and posterior surface of the right kidney and on the left side to spleen, fundus of the stomach and posterior surface of the left kidney.

NERVE AND BLOOD SUPPLY TO THE PLEURA

Nerve Supply to Pleura

- The costal pleura and peripheral part of the diaphragmatic pleura are supplied by intercostal nerves.
- The central part of the diaphragmatic pleura and mediastinal pleura are supplied by phrenic nerve

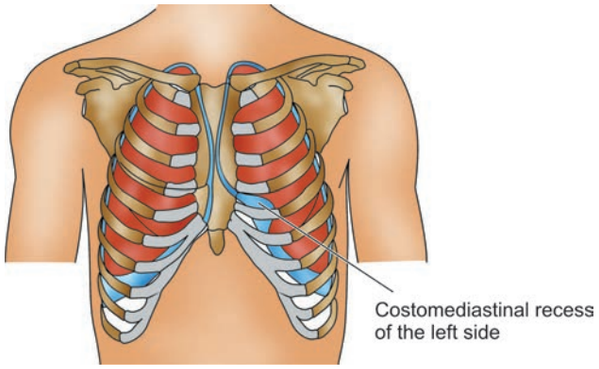


Fig. 40.5: Costomediastinal recess: Anterior view

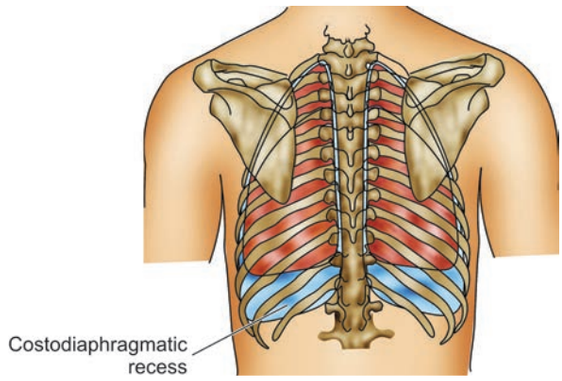


Fig. 40.6: Costodiaphragmatic recess: Posterior view

(C3, 4, 5). Remember the phrenic nerve also supplies the fibrous pericardium, diaphragm and peritoneum lining the under surface of the diaphragm.

- These somatic nerves carry pain sensation from the pleura when it is infected. Irritation of the parietal pleura may produce local pain or referred pain projected to dermatomes supplied by the same spinal segment. For example, irritation of the mediastinal or central part of the diaphragmatic pleura results in referred pain to the root of the neck and over the shoulder (phrenic nerve/C3, 4 and supraclavicular nerve/C3, 4 shares same root value and the pain fibres while passing through the dorsal root ganglia of these nerves get mixed and cause referred pain).
- The visceral pleura is innervated by autonomic (sympathetic and parasympathetic) nerves supplying the lungs. The visceral pleura is not sensitive to pain or other general sensations. The diseases of the lung do not cause pain until the parietal pleura is involved.

CASE 1

A 12-year-old boy was rescued from the swimming pool. The next day he developed a severe cold, and three days later his condition deteriorated. He became more febrile and started to cough up blood-stained sputum. At first, he had no chest pain, but later, when he coughed, he experienced severe pain over the right 5th intercostal space in the midclavicular line. The diagnosis of lobar pneumonia was made. Explain the following:

1. Why did he not experience chest pain early in the disease?
2. What is the pain due to and why is it worse on coughing?

Blood Supply to the Pleura

The blood supply to the parietal pleurae is the same vessels supplying thoracic wall (anterior and posterior intercostal vessels) and visceral pleurae is supplied by bronchial vessels.

Clinical Notes

Pleurisy (pleuritis): It is the inflammation of the pleura. It is characterized with sharp, stabbing pain, which gets aggravated with increased respiratory movements (exertion, such as climbing stairs). During normal respiratory movements, the sliding between parietal and visceral pleura is smooth, without any sound during auscultation of the lungs, but in pleurisy, there will be **friction (pleural rub)**, which is detectable with a stethoscope. It sounds like a clump of hair being rolled between the fingers. The inflamed surfaces of the pleura may also cause the parietal and visceral layers of pleura to adhere.

Pneumothorax (air in the pleural space): The entry of the air into the pleural cavity can result from either penetrating wound of the parietal pleura (bullet entry) or rupture of lung substance into the pleural cavity. The air in the pleural cavity leads to collapse of the lungs on the affected side. Fractured ribs may also tear the visceral pleura and lung, thus producing the pneumothorax.

The lowering of oxygen tension in blood gives rise to shortness of breath and cyanosis. The mediastinum shifts to the opposite (normal) side compressing the normal lung also. **The mediastinal shift can be confirmed by palpating the trachea just above the suprasternal notch.** Shift of the mediastinum to the same side is also possible due to the absorption while to the opposite side is due to collapse.

When the lung collapses, it occupies less volume within the pulmonary cavity and the size of the pulmonary cavity is reduced. This can be confirmed with a radiographic picture, with elevation of diaphragm on the affected side, narrowing of the intercostal spaces (ribs closer together) and displacement of the mediastinum (Fig. 40.7A and B).

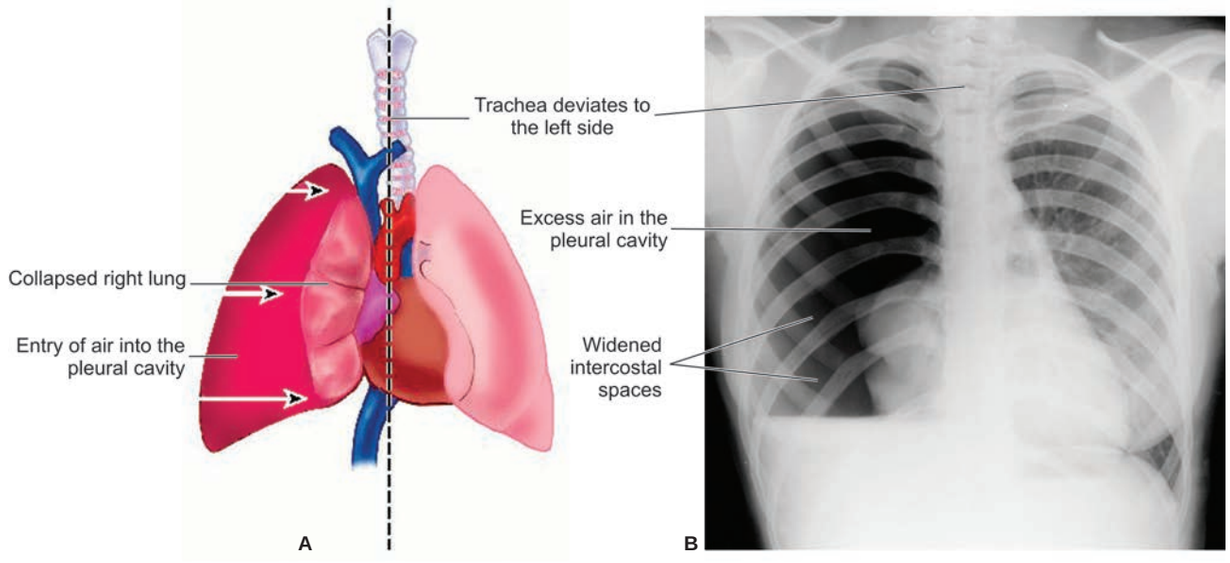


Fig. 40. 7: A: Pneumothorax of right side; **B:** Radiograph showing pneumothorax (right-sided)

CASE 2

A 38-year-old patient with a known history of emphysema (dilatation of alveoli and destruction of alveolar walls with tendency to form cystic spaces) suddenly experiences severe pain in the chest, and he is breathless, and is in a state of shock. On examination, the trachea is found displaced to the right in the suprasternal notch and the apex beat of the heart can be felt in the left 5th intercostal space **just** lateral to the sternum. Assuming the patient has had a spontaneous pneumothorax, explain the following:

1. Why are the trachea and apex beats displaced to the right?
2. Why has the left lung collapsed?

Clinical Notes

Tension pneumothorax: It is the presence of air in the pleural space under pressure. The lung collapses, and a mediastinal shift interferes with the expansion of the contralateral lung and compromises venous return to the heart via the inferior vena cava (Fig. 40.8). This condition is extremely dangerous and requires urgent intervention. The signs and symptoms of tension pneumothorax are tachypnea (abnormally rapid respiration rate), contralateral tracheal deviation, distended veins of the neck, dyspnea (difficulty in breathing), and hypotension. It is treated with a needle thoracocentesis, followed by chest tube placement.

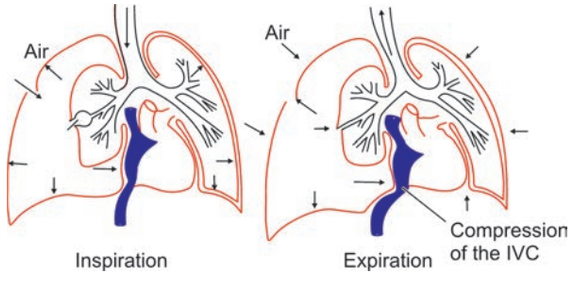


Fig. 40.8: Tension pneumothorax

CASE 3

A 25-year-old man was brought to the emergency department of the hospital after sustaining a single gunshot wound to the right side of his chest. The patient is awake with a palpable pulse, systolic BP of 100 mm Hg, and respiratory rate 30/ minute. An occlusive dressing was done over the entry site in the 5th intercostal space of the midaxillary line to prevent bleeding. Later on arrival at the hospital, the patient's vital signs deteriorated. The trachea is deviated to the left, the jugular veins are distended, no breathing sounds on the right side of the chest, had palpable crepitus (cracking or popping sounds and sensations experienced under skin) and on percussion he has hyper-resonance on the right side of the chest. The physician diagnoses this as tension pneumothorax and inserts a 14-gauge needle in the right midclavicular line at the second intercostal space and the air is heard escaping. A chest tube is inserted at the 5th intercostal space in the midaxillary line and connected to a chest drainage device. The patient was stabilized and transferred to the intensive care unit.

1. What might have created the tension pneumothorax?
2. Why did the physician insert the chest tube into the 5th intercostal space?
3. What structures did the chest tube pass through to enter the pleural cavity?
4. What is tension pneumothorax?
5. What are the signs and symptoms of tension pneumothorax?

Clinical Notes

Pleural effusion (escape of fluid into the pleural cavity): It is the accumulation of a significant amount of fluid in the pleural cavity. It is associated with the **disappearance of friction rub.** The condition gives rise to dullness on percussion and reduction in the intensity of the breath sounds. The lung on the affected side with the mediastinum shifts to the opposite (normal side), which can be confirmed by shift of the trachea. The fluid level in hydropneumothorax can be confirmed by radiographic examination (instead of horizontal fluid level line, it will be curved) (Fig. 40.9A and B). Accumulation of a significant amount of fluid in the pleural cavity is called **hydrothorax** and it may result from pleural effusion. The accumulation of blood in the pleural cavity is called **hemothorax**, which is due to rupture of intercostal or internal thoracic vessels or even from laceration of lungs. The accumulation of pus in the pleural cavity is referred as **pyothorax**. The accumulation of lymph fluid in the pleural cavity is called c**hylothorax**, usually due to rupture of the thoracic duct or interference in lymphatic drainage from the pleural cavity.

Thoracocentesis or pleural tap: It is a procedure to remove the excess fluid or blood or pus from the pleural cavity. This is performed with the patient in sitting posture. Usually the needle is inserted in the posterior axillary line or the midaxillary line through the lower part of **8th or 9th intercostal space.** The excess fluid accumulates in costodiaphragmatic recess. Performing thoracocentesis in either of these spaces **during expiration** will avoid the injury to the lung. The needle passes in succession through the skin, fasciae, serratus anterior, intercostal muscles, endothroacic fascia and the costal pleura. To avoid damage to the intercostal nerve and vessels, the needle is inserted along the superior border of the lower rib, high enough to avoid the collateral branch, which runs along the upper border of the rib (Fig. 40.10).

CASE 4

A postgraduate medical student obtained a sample of pleural fluid from a patient's right pleural cavity. He inserted the needle close to the lower border of the eighth rib in the anterior axillary line. The next morning, he was surprised to hear that the patient has a complaint of altered skin sensation extending from the point where the needle was inserted downward and forward to the midline of the abdominal wall above the umbilicus.

Can you explain the cause of altered sensation in anatomical terms?

Clinical Notes

Insertion of a chest tube: This is a procedure to remove a major amount of air, blood, fluid, pus or any combination of these substances from the pleural cavity. A short incision is made in the 5th or 6th intercostal space in the midaxillary line. The tube inserted is directed upwards towards

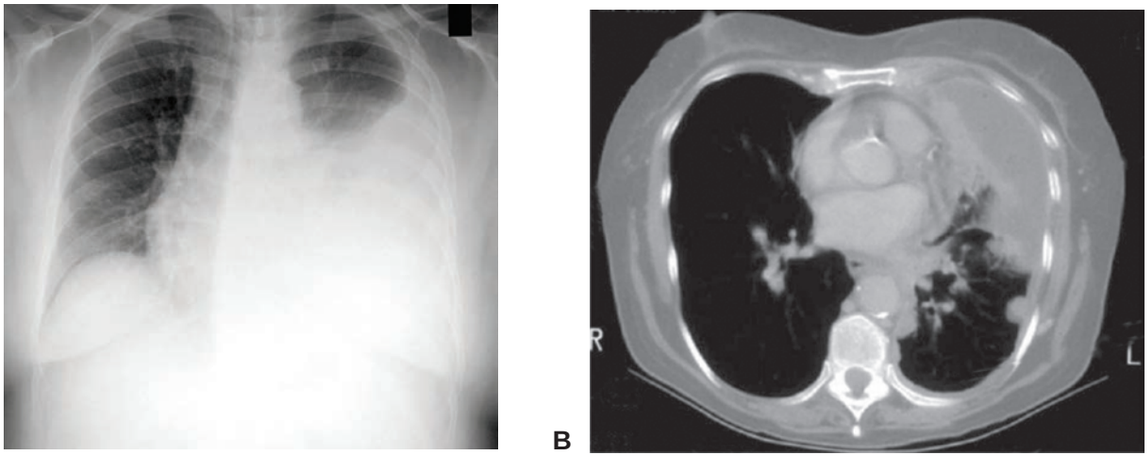


Fig. 40.9: A: Radiograph showing left-sided pleural effusion; **B:** CT showing left-sided pleural effusion

cervical pleura for removal of air or the tube can be directed downwards for fluid drainage. The outer end of the tube is connected to a controlled suction (or under water seal), to prevent air from being sucked back into the pleural cavity. Failure of removal of fluid may cause the lung to develop a resistant fibrous covering that inhibits expansion unless it is peeled.

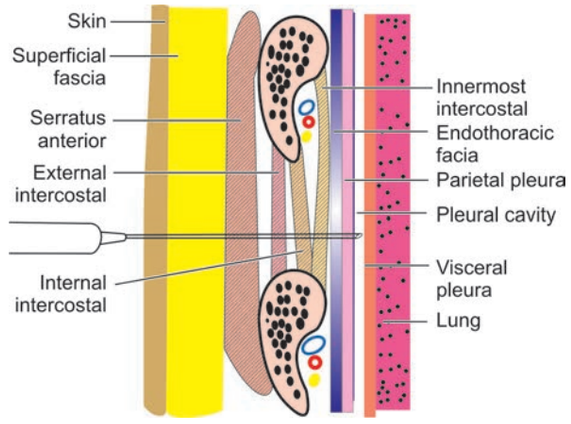


Fig. 40.10: Thoracocentesis—schematic

Solutions to the clinical case studies

Case 1

1. Diseases of the lung do not cause pain until the parietal pleura is involved. Lung tissue and visceral pleura are not innervated with pain fibres. The costal pleura is innervated by intercostal nerves, which have nerve endings in the pleura. The boy had pneumonia of the right middle lobe, which later spread to the pleurae, causing pleurisy. Once the parietal pleura was involved, he experienced pain he could localize.
2. Movement of the inflated pleural surfaces against one another, as in deep inspiration or coughing, accentuated the pain.

Case 2

1. The patient has had a left-sided pneumothorax. The air has entered the left pleural cavity as the result of rupture of one of the emphysematous cysts of the left lung. The air in the left pleural cavity displaced the mobile mediastinum over to the right.
2. The left lung collapsed immediately when air entered the left pleural cavity, since the air pressures within the bronchial tree and in the pleural cavity were then equal. The elastic recoil of the lung tissue caused the lung to collapse.

Case 3

1. The nature of some injuries to the chest wall may create an opening that acts like a one-way valve. Trauma may create an inward swinging flap in the chest wall. Air is sucked into the pleural cavity during inspiration, but during expiration the chest wall closes on itself, preventing air from escaping.
2. Insertion of the chest tube at the 5th intercostal space allows the release and escape of air from the pleural space into the chest drainage device. In addition, it allows the physician to intervene immediately and prevent a potentially life-threatening event by arresting further damage to a potentially injured diaphragm.
3. Skin, superficial fascia, external intercostal muscle, internal intercostal muscle, innermost intercostal muscle, endothoracic fascia and parietal pleura.
4. It is the presence of air in the pleural space under pressure. The lung collapses, and a mediastinal shift interferes with the expansion of the contralateral lung and compromises venous return to the heart via the inferior vena cava. This condition is extremely dangerous and requires urgent intervention. Other possible injuries leading to tension pneumothorax are explained.
5. Tachypnea, contralateral tracheal deviation, hyper-resonance, distended neck veins, dyspnea, and hypotension.

Case 4: The needle was inserted incorrectly and thereby it damaged the 8th intercostal nerve. This produced altered sensation (paresthesia) in the 8th thoracic dermatome. Needles should always be inserted close to the upper border of a rib, i.e. as far away from the neurovascular bundle as possible.

MCQs

1. A 68-year-old male is admitted to the hospital due to acute pleurisy. In sitting posture, where would the fluid tend to accumulate in the pleural cavity?

A. Costodiaphragmatic recess
B. Costomediastinal recess
C. Cupola
D. Hilar reflection

2. A needle inserted into the 9th intercostal space along the midaxillary line would enter which space?

A. Cardiac notch
B. Costodiaphragmatic recess
C. Costomediastinal recess
D. Cupola

3. Where does the costomediastinal recess is best identified?

A. At the anterior border of the right lung
B. At the apex of the lung

C. At the inferior border of the left lung
D. At the anterior border of the left lung

4. You have been asked to remove fluid from the pleural cavity in a patient with hydrothorax. You decide to insert the aspiration needle over the top of a rib, into an intercostal space inferior to the lower border of the lung in the midaxillary line at the end of normal expiration. In which highest intercostal space, the procedure can be performed safely without injuring the lung?

A. 4th intercostal space B. 5th intercostal space
C. 6th intercostal space D. 8th intercostal space

5. While performing the thoracentesis, the lower border of the lung will lie at the level of which rib in the midclavicular line?

A. 5th B. 6th
C. 7th D. 8th

6. A 24-year-old patient suffering from lobar pneumonia complains of severe pain during breathing, suggesting the involvement of the parietal pleura. Which of the following combinations of nerves carry pain fibres from parietal pleura?

A. Phrenic nerves and intercostal nerves
B. Vagus and phrenic nerves
C. Greater splanchnic and phrenic nerves
D. Intercostal and vagus nerves

7. A patient with pleurisy develops referred pain in the shoulder region. Which of these pleurae is most likely to be affected?

A. Peripheral part of the diaphragmatic pleura
B. Mediastinal pleura
C. Visceral pleura
D. Costal pleura

8. While performing the thoracocentesis, the lower border of the lung will lie at the level of which rib in the midaxillary line?

A. 5th B. 6th
C. 7th D. 8th

ANSWERS TO MCQs

1. A 2. B 3. D 4. D 5. B
6. A 7. B 8. D

JUST BEFORE THE EXAM

Pleura → It is a fibroserous membrane which surrounds the lungs. It has an outer parietal layer and inner visceral layer with pleural cavity in between the two layers. The pleural cavity is filled with thin amount of fluid and the pressure inside the pleural cavity is negative.

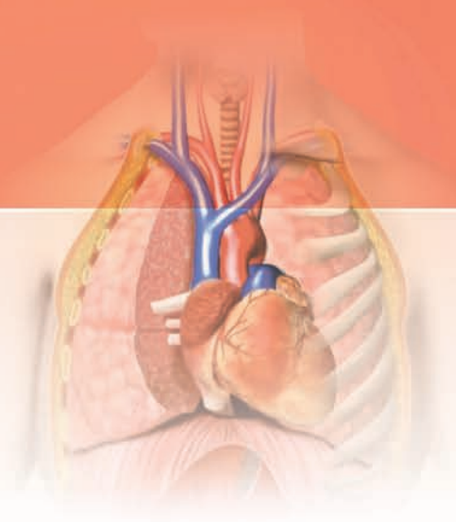
Parts of the parietal pleura → It is divisible into costal pleura, cervical pleura, mediastinal pleura and diaphragmatic pleura. The parietal pleura is supplied by phrenic nerve (C3, 4, 5) and intercostal nerves and is pain sensitive, while visceral pleura which closely surrounds the lungs are supplied by autonomic nerves and are not sensitive to pain.

Pleural cavity → Presents two better defined spaces called costomediastinal recess and costodiaphragmatic recess. The costomediastinal recess is occupied by the anterior border of the lungs and it is better defined on the left side where cardiac notch of left lung is present.

Costodiaphragmatic recess → It is better defined on each side (pocket-like space between costal and diaphragmatic pleura) in the midaxillary line where fluid tends to accumulate in pleurisy.

Lower limit of the pleura → On the midclavicular plane is 8th rib, in the midaxillary line is 10th rib while on the posterior aspect, it extends up to a horizontal line at the level of T12 spine. The lower limit of the lung in the midclavicular line is 6th rib, in the midaxillary line is the 8th rib and posteriorly it extends up to a horizontal line at the level of T10 spine.

Thoracocentesis → A needle can be inserted into the pleural cavity to drain the excess fluid. This is often performed at the anterior axillary line or midaxillary line through the lower part of the 8th or 9th intercostal space.



Chapter

41

Lungs

Competencies: AN 24.1 to 24.3, 24.5, 25.1, 25.7, 25.9

Objectives

- To describe the external features of right and left lungs and correlate the differences between them
- To mark the position of fissures of the lung on a cadaver or a patient (surface marking) and explain how you auscultate different lobes of lungs in a patient
- To describe the relations of the apex of the lung and its clinical relevance
- With the help of a diagram, be able to explain the relations of medial surface of right and left lungs
- To define bronchopulmonary segments and be able to explain their clinical relevance
- To describe the source of sympathetic and parasympathetic nerve supply to the lung and list the effect of their stimulation on lung functions
- To describe the lymphatic drainage of the lung and its clinical relevance
- To describe the microscopic structure of lung

Lungs are a pair of respiratory organs. Its main function is to oxygenate the blood by bringing the inspired air into close relation with venous blood within the lungs. The healthy lungs in living are light, soft, porous, highly elastic and spongy in texture. In the newborn, it is rosy pink in colour. In adults, it is dark slaty grey due to the deposition of carbonaceous particles.

Each lung occupies the pulmonary cavities (space on either side of the mediastinum) and is covered by pleura (or invaginates into pleural sac). Because of the negative intrapleural pressure, the parietal and visceral pleurae can slide over each other during respiration.

EXTERNAL FEATURES OF THE LUNGS

Each lung presents an apex, a base, three surfaces (costal, medial and inferior/base) and three borders (anterior, posterior and inferior). The apex is directed superiorly towards the neck while base rests on the diaphragm (Fig. 41.1). The right lung is larger and heavier than the left, but it is shorter and wider because the right dome of the diaphragm is higher.

Anterior Border

The anterior border of the right lung is relatively straight. The anterior border of the left lung has a deep cardiac notch (an indentation consequent to the deviation of the apex of the heart to the left side). The portion of the superior lobe of the left lung below the cardiac notch resembles a tongue and is called **lingula.** It moves across the costomediastinal recess during full inspiration.

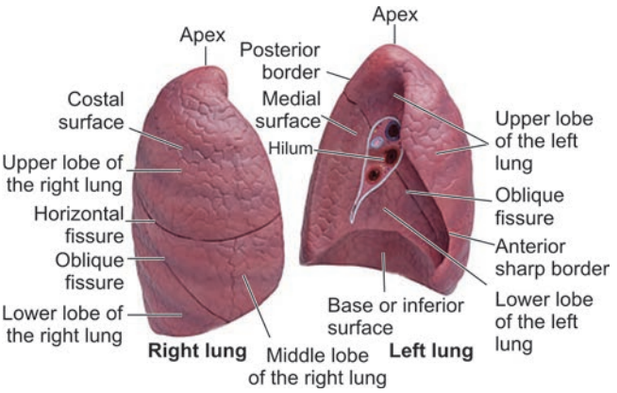


Fig. 41.1: External features of the lungs

Posterior Border

The posterior border is ill-defined and separates vertebral part of the medial surface from costal surface.

Inferior Border

The inferior border separates costal surface from the inferior surface or base.

Fissures and Lobes of the Lung

The right lung is divided into three lobes by oblique and horizontal fissure, while left lung has only oblique fissure, dividing it into superior and inferior lobes (Fig. 41.1).

Surface Marking of Oblique Fissure

It roughly corresponds to medial border of the scapula in the fully abducted position of the arm. Connecting the following three points mark the oblique fissure (Fig. 41.2A to D).

- The first point is at 2 cm lateral to the T3 spine.
- The second point is at 5th rib in midaxillary line.
- It reaches 6th costal cartilage 7–8 cm lateral to the midline (6th costochondral junction).

Surface Marking of Horizontal Fissure

It begins at the anterior border of right lung at right 4th costal cartilage, then it meets the oblique fissure in midaxillary line (Fig. 41.2A to D). These surface markings are important during auscultation. For example, the upper lobe of the right lung is best heard anteriorly in the area extending from the clavicle to the level of 4th costal cartilage, while that of the left lung is best heard in the area up to the level of 6th costal cartilage. The middle lobe is heard anteriorly between right 4th and 6th ribs in front of the midaxillary line.

Variations in Lobes of Lung

The oblique and horizontal fissures may be incomplete or absent in some lungs, with consequent reduction in number of lobes. The left lung sometimes has three lobes and right lung only two. The most common accessory lobe is '**azygos lobe**', which appears in right lung in approximately 1% of people. It appears above the hilum of right lung, separated by the rest of the lung by a deep groove lodging the arch of the azygos vein.

APEX OF THE LUNG

It is the blunt superior end of the lung above the level of first rib. It extends into the root of the neck about 2.5 cm above the medial end of the clavicle. Apex is covered by cervical pleura and suprapleural membrane.

Relations of the Apex

Anteriorly: The subclavian artery, scalenus anterior muscle and subclavian vein are present in front of the apex.

Medially: The trachea, oesophagus, phrenic and vagus nerves (left recurrent laryngeal on the left side) are related to its medial surface.

Laterally: Scalenus medius muscle.

Posteriorly: It is related to structures present in front of the neck of the first rib (from medial to lateral)—sympathetic chain, first posterior intercostal vein, superior intercostal artery, ventral ramus of first thoracic nerve forming lower trunk of the brachial plexus (Fig. 41.3).

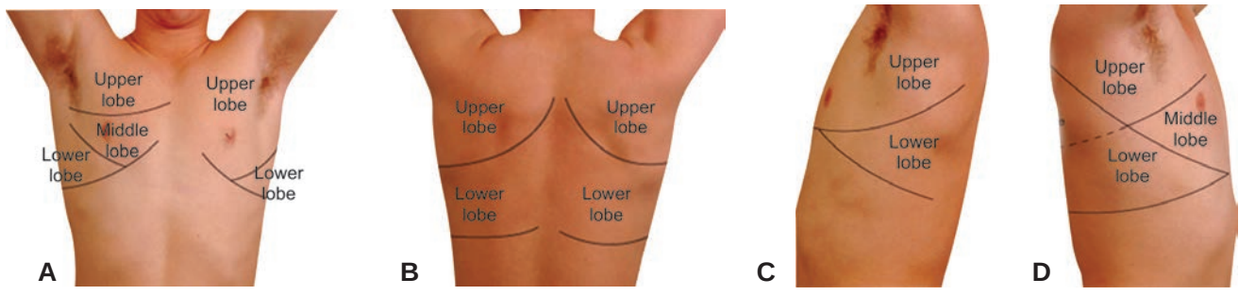


Fig. 41.2: Surface markings of the fissures of the lungs. **A:** Anterior view; **B:** Posterior view; **C:** Left lateral view; **D:** Right lateral view

Clinical Notes

- The malignancy of the apex of the lung may present as symptoms and signs produced due to spread of cancer to neighboring structures.
- The compression of subclavian vein results in venous engorgement and edema in the arm or neck and face (involvement of brachiocephalic vein or SVC).
- The diminished radial pulse is due to the compression of the subclavian artery supplying upper limb.
- Infiltration of phrenic nerve cause paralysis of the diaphragm on the affected side (hemi-diaphragm).

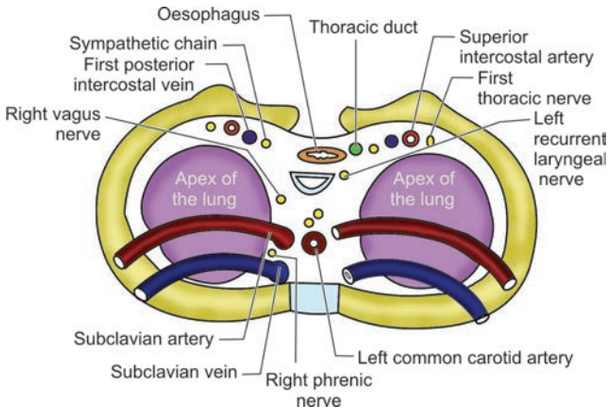


Fig. 41.3: Relations of the apex of the lung—superior view

Pancoast tumor: Further the erosion of the 1st or 2nd ribs causes pain in the ulnar distribution and wasting of hand muscles (T1 fibres of lower trunk of the brachial plexus). The compression of the sympathetic chain can cause Horner's syndrome.

Base

It is concave inferior surface of the lung and rests on upper surface of the diaphragm. The diaphragmatic pleura and diaphragm separate the base of the right lung from right lobe of the liver, and left lung from left lobe of the liver, fundus of stomach and spleen.

Costal Surface

It is related to thoracic wall (ribs, costal cartilages and intercostal spaces) and presents impressions of ribs and costal cartilages. It is covered by costal pleura and endothoracic fascia.

MEDIAL SURFACE OF THE LUNG

It is further divided into an anterior mediastinal part and posterior vertebral part.

The posterior vertebral part is related to bodies of the thoracic vertebrae and intervertebral discs between them. The **mediastinal part** is related to mediastinum. It presents hilum of the lung, cardiac impression. There are many structures related to mediastinal surface and some of them leave impressions on the cadaveric lungs (except the heart, which is evident during surgery or fresh cadaveric or postmortem specimens) and are shown in Figs 41.4 and 41.5.

Mediastinal surface of the Right Lung

1. Cardiac impression: It is located anterior and inferior to the hilum and related to right atrium and anterior part of the right ventricle (Figs 41.4 and 41.6A).
2. Arch of the azygos vein: It is related superior to the hilum as a prominent arched groove.

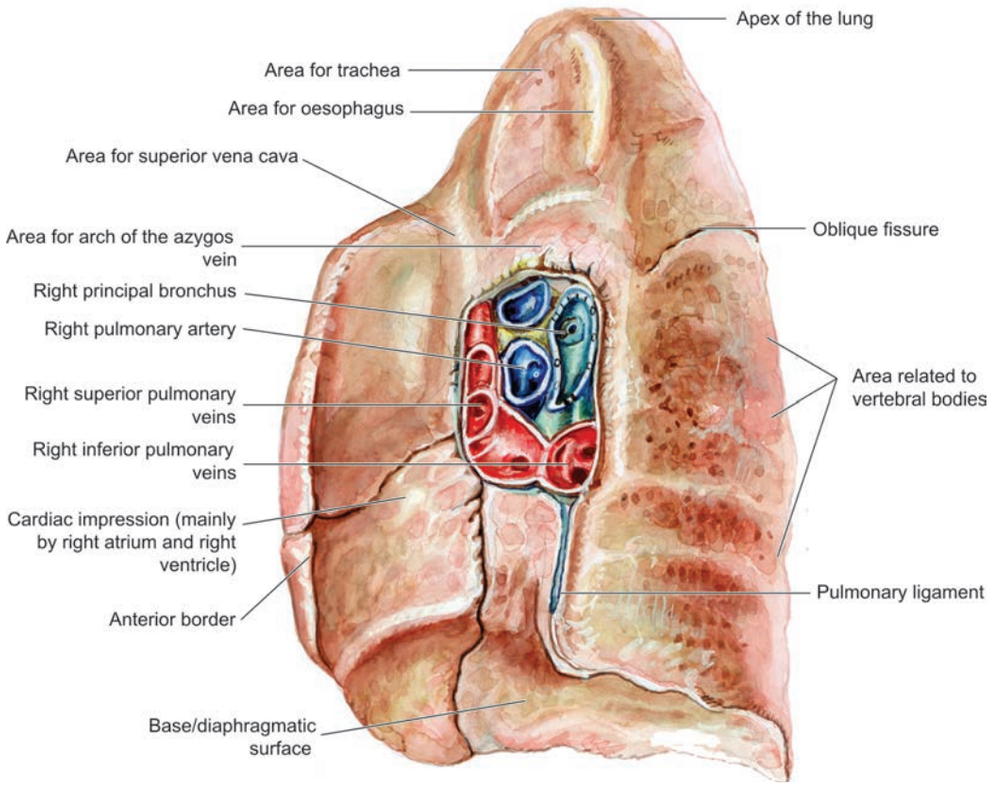


Fig. 41.4: Medial surface of the right lung

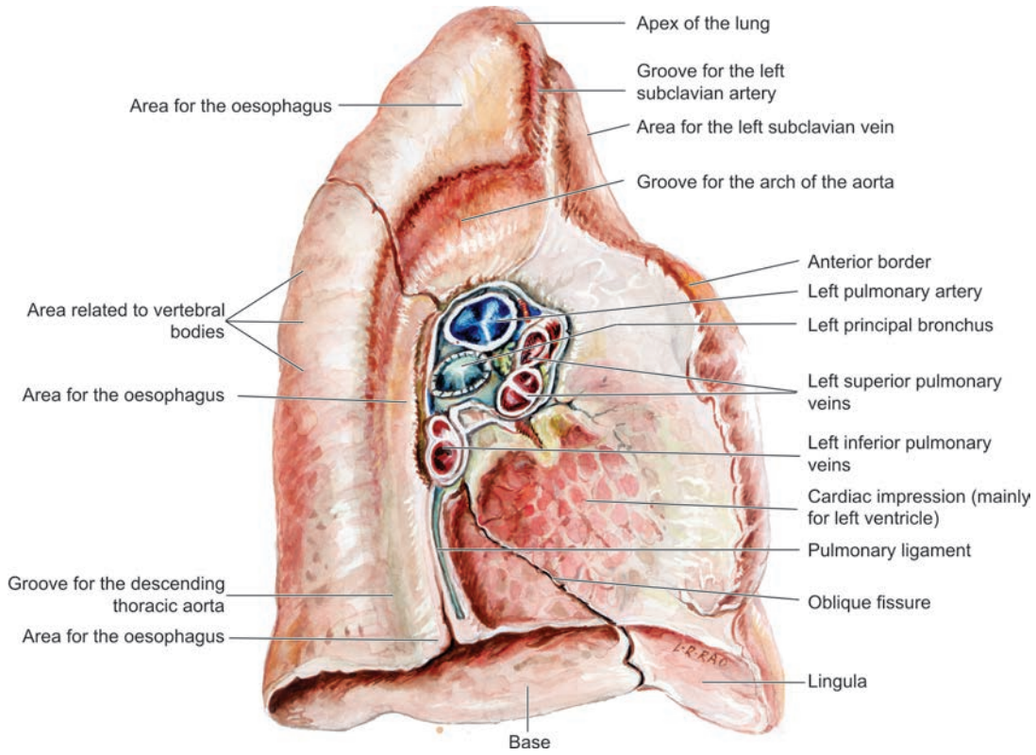


Fig. 41.5: Medial surface of the left lung

3. Groove for superior vena cava: The upper part of the cardiac impression continuous with groove for superior vena cava.
4. Groove for the inferior vena cava: It is placed posteroinferior to the cardiac impression.
5. Trachea: It is related posterior to the groove for superior vena cava.
6. Oesophagus: It makes a shallow groove posterior to the trachea, hilum and pulmonary ligament, but this shallow groove does not extend up to the inferior margin of the lung.
7. Phrenic nerve **descends anterior to the hilum**, along the right margin of the superior and inferior vena cava.
8. Vagus nerve descends along the trachea, then **descends posterior to the hilum**.
9. The right subclavian artery may produce a notch just below the apex and the right first rib produces a notch just inferior to the pulmonary artery at the anterior border.

Mediastinal Surface of the Left Lung

1. Cardiac impression: A large cardiac impression is present anterior and inferior to the hilum related to left ventricle (Figs 41.5 and 41.6B).
2. Pulmonary trunk: It is related just anterior to the hilum (between cardiac impression and hilum).
3. Arch of aorta: It is related to a deep groove immediately superior to the hilum.
4. Descending thoracic aorta: The groove for arch of aorta continues posterior to the hilum and pulmonary ligament for descending thoracic aorta, up to the inferior border of the lung.
5. Left subclavian artery: The groove for the left subclavian artery begins from groove for arch of aorta and extends upwards just anterior to the apex.
6. Oesophagus: It is related just posterior the groove for left subclavian artery along with the thoracic duct. The oesophagus is related again, **anterior to the descending thoracic aorta**, posterior and below the lower end of the pulmonary ligament.
7. Nerves: The left vagus and left phrenic nerve cross each other above the hilum, deep to the groove for the arch of aorta. Then the vagus descends behind the hilum along with the oesophagus and phrenic descends in front of the hilum. The left recurrent laryngeal nerve winds around the arch of aorta, is also related to medial surface of the upper lobe of the left lung.

A schematic diagram showing relations of the right and left lungs are shown in Fig. 41.6A and B. Students are suggested to practice this simple line diagram (Fig. 41.6A and B). Compare the relations between right and left lungs using the Table 41.1.

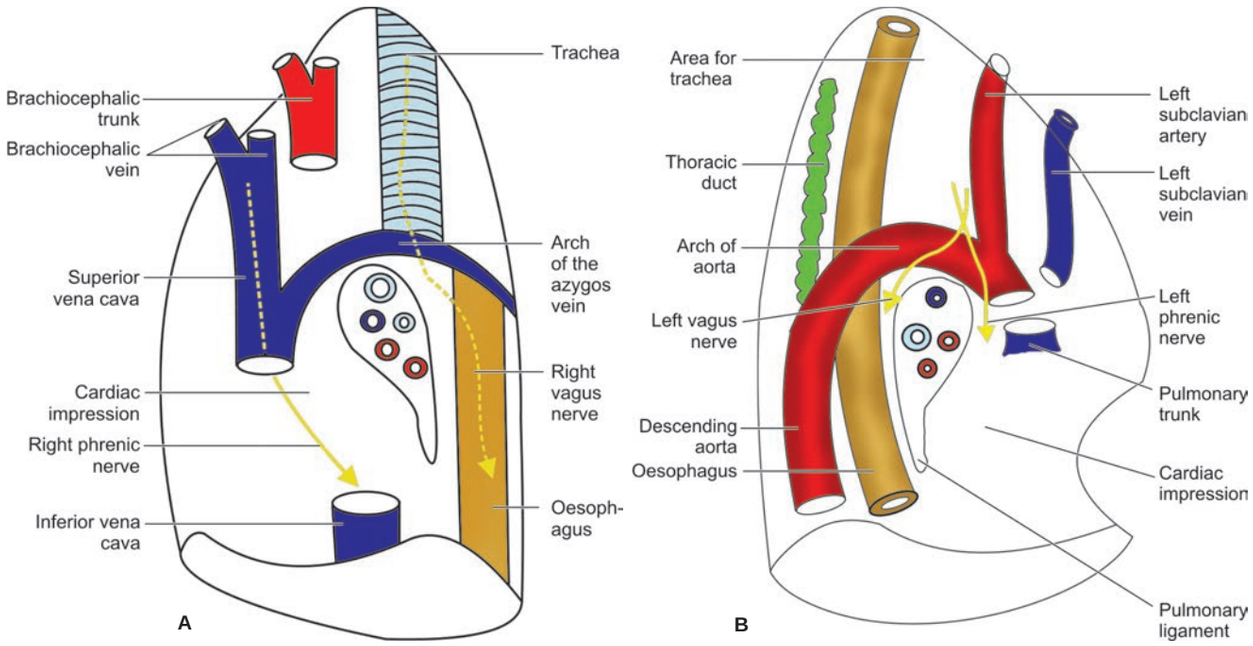


Fig. 41.6: Medial surface of the lungs (schematic). **A:** Right lung; **B:** Left lung

Root of the Lung

It connects the hilum of the lung to the mediastinum. The root contains the principal bronchus on the left side, eparterial and hyparterial bronchus on right side pulmonary vessels, bronchial vessels, lymphatics and nerves (Fig. 41.7). It extends from the level of T5 to T7 vertebra.

Relations of the Root of the Lungs

Anteriorly: Phrenic nerve, pericardiophrenic vessels and anterior pulmonary plexus. In addition, on right side, the superior vena cava.

Posteriorly: Vagus nerve, posterior pulmonary plexus. In addition, on the left side, the descending thoracic aorta.

Superiorly: On right side the arch of the azygos vein and on the left side the arch of the aorta.

Hilum of the Lung

Hilum is an area through which the structures enter or emerge out from the lung. It consists of a pair of pulmonary veins, one pulmonary artery, two bronchi on the right side and one bronchus on the left side, bronchial vessels, lymphatics, lymph nodes and nerve fibres. The arrangement of the structures at the hilum from above downwards is as follows (Fig. 41.8):

Right Lung

- Eparterial bronchus (located superior to the pulmonary artery)
- Pulmonary artery
- Hyparterial bronchus (located inferior to the pulmonary artery)
- Inferior pulmonary vein

Table 41.1: Structures related to the mediastinal surface of the right and left lungs

Right Lung	Left Lung
Cardiac impression: Right atrium and right ventricle	Cardiac impression: Left ventricle
Above the hilum: Arch of the azygos vein	Above the hilum: Arch of the aorta
Oesophagus: Related posterior to trachea, hilum and pulmonary ligament and not related in the lower part	Oesophagus: Related in the upper part just posterior to the left subclavian artery and again the lower part posterior to the thoracic aorta. It is not related in the middle part
Right subclavian artery: May produce a notch just inferior to the apex	Left subclavian artery: The groove begins from the arch of the aorta and extends upwards, anterior to the apex
Trachea: Related posterior to the groove for the superior vena cava	Trachea is not directly related
Phrenic nerve descends in front of the hilum while vagus nerve descends behind the hilum	Phrenic nerve descends in front of the hilum while vagus nerve descends behind the hilum

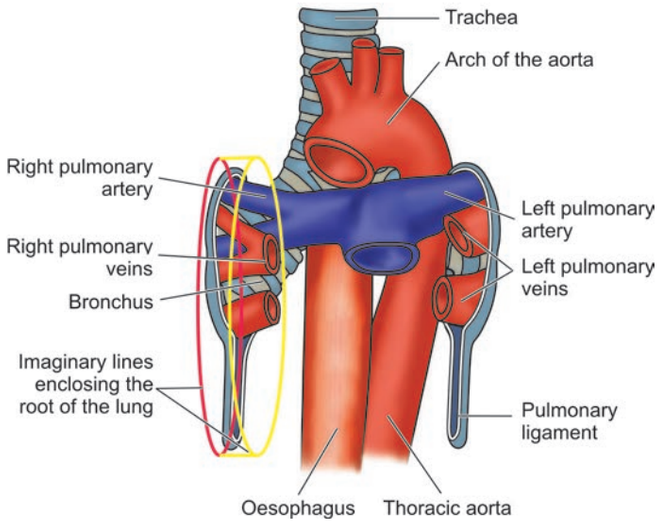


Fig. 41.7: Root of the lungs (schematic)

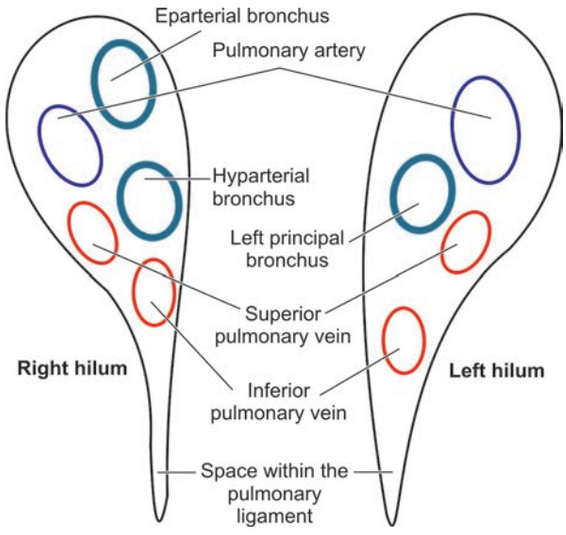


Fig. 41.8: Hilum of the lungs

Left Lung

- Pulmonary artery
- Left principal bronchus
- Inferior pulmonary vein

The arrangement of the structures from anterior to posterior (on both sides) are: Superior pulmonary vein, pulmonary artery and the bronchus.

How to identify these structures in a cadaveric specimen?

The bronchus is identified by the presence of rigid cartilage in its wall. The anterior most structure is superior pulmonary vein and the inferior most is the inferior pulmonary vein.

Clinical Notes

The hila of the lungs consist of vessels, bronchi, and lymph nodes, changes in a chest X-ray will present as a change in position, size, and/or density of the hilar region. The common causes of these changes will include—**bilateral and symmetrical hilar enlargement.** This can be due to sarcoidosis, especially in the presence of paratracheal enlargement, pulmonary arterial hypertension, or lymphoma, metastatic disease, or infection. **Asymmetric hilar enlargement** is often the result of cancer. The **change in position** could be due to haemothorax or pneumothorax.

Bronchial Tree

Trachea divides into right and left principal bronchus at the root of the lung (usually at the level of the 4th to 5th thoracic vertebrae).

- Each principal bronchus again divides into secondary (or lobar) bronchi, one for each lobe (3 on right lung and 2 on left lung).
- Each secondary bronchus subdivides into tertiary or segmental bronchi. There are 10 such tertiary bronchi in each lung.
- The tertiary bronchi divide repeatedly to form terminal and further respiratory bronchioles.
- **The wall of the bronchus is made up of cartilages while they are absent in bronchioles**.
- The respiratory bronchiole terminates in alveoli where oxygenation of blood takes place (Fig. 41.9).
- The right principal bronchus is shorter, wider and more vertical than the left principal bronchus. Therefore, an aspirated foreign body is more likely to enter the right lung than left. The right principal

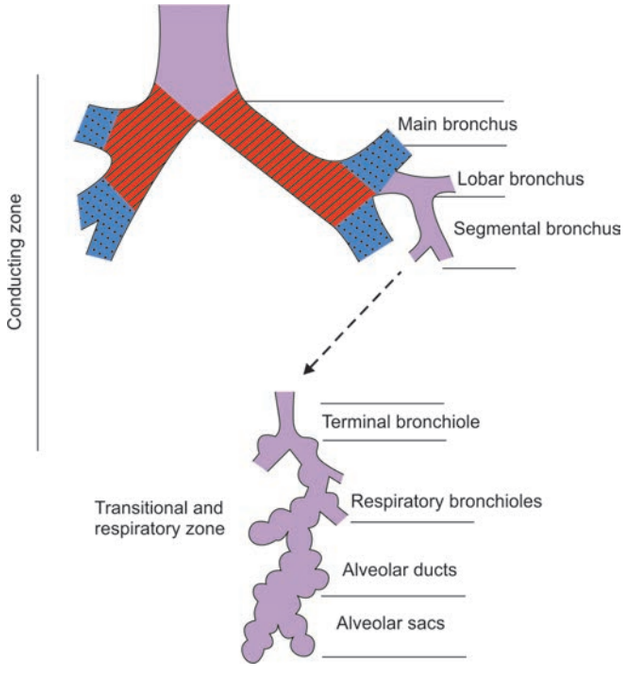


Fig. 41.9: Bronchial tree

bronchus is 2.5 cm long, soon divides into two, the upper lobar bronchus (eparterial) passes above the pulmonary artery, and the lower (hyparterial) bronchus enter the lung below the pulmonary artery at the level of T5 vertebra.

BRONCHOPULMONARY SEGMENTS

Definition: These are well-defined pyramidal shaped independent units of the lung aerated by **tertiary (segmental) bronchi** with separate branch of pulmonary artery accompanying it (Fig. 41.10).

- The apex of each segment is directed towards the hilum and base towards lung surface.
- Each segment is separated from the other by connective tissue septa.

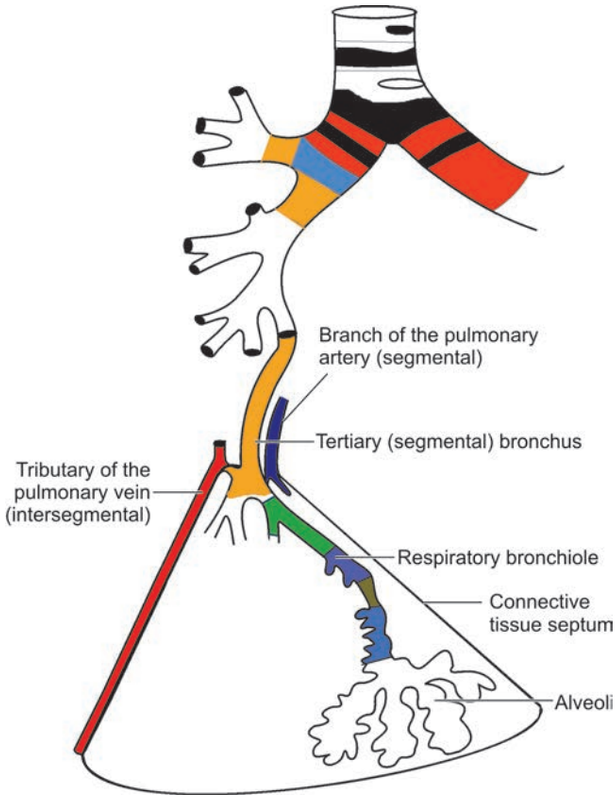


Fig. 41.10: Bronchopulmonary segment

- The tributaries of the pulmonary veins carrying oxygenated blood traverse the connective tissue septa placed between the bronchopulmonary segments.
- However, the branches of the bronchial artery follow the segmental bronchus.
- There are 10 bronchopulmonary segments in each lung (Figs 41.11 and 41.12 and Table 41.2).
- Sometimes it is possible to have 8 segments on the left lung due to absence of medial basal segment of the lower lobe and or posterior segment of the upper lobe.

Clinical Notes

1. Though the spreading of infection from one segment to the other is prevented to some extent by this connective tissue septum, the tuberculosis or carcinoma of the lung can break this barrier.
2. The **apical basal (superior) segment of the lower lobe and posterior segment of the upper lobe are common sites (more commonly on right side) for lung abscess due to aspiration of infected material.** These are the most dependent segments in supine position.
3. Being independent units of the lung, the diseased bronchopulmonary segments can be surgically removed. During surgical resection of certain bronchopulmonary segments, the diseased segmental bronchus is identified by dissection, and it is clamped along with the blood vessels. This helps to identify the segment, as the surface of the segment will darken due to loss of blood supply and air.
4. It is important to note that the apical (superior) segmental bronchus is directed backwards. In supine position of the body, this segmental bronchus is directed posteriorly (most dependent) and foreign bodies entered into the right lung is most likely to enter through this segmental bronchus into **superior (apical) bronchopulmonary segment of the lower lobe** (Fig. 41.13).

CASE 1

A 62-year-old male who had been a heavy cigarette smoker for nearly 50 years was diagnosed with lung cancer. Radiologic and bronchoscopy examinations revealed a relatively small tumour in one of the tertiary bronchi of the middle lobe of the right lung. This segment of the patient's lung was removed. As there was no evidence of metastasis of the tumour, no further treatment was prescribed. He quit smoking and 5 years after the surgery he was free of any detectable cancer.

Why was it possible to remove only a portion of the diseased lung rather than a lobe or the entire structure?

Clinical Notes

Auscultation of Lungs and Percussion of the Thorax

These are important techniques used during physical examinations. The auscultation is listening to the sounds with the help of a stethoscope. It assesses the airflow through the tracheobronchial

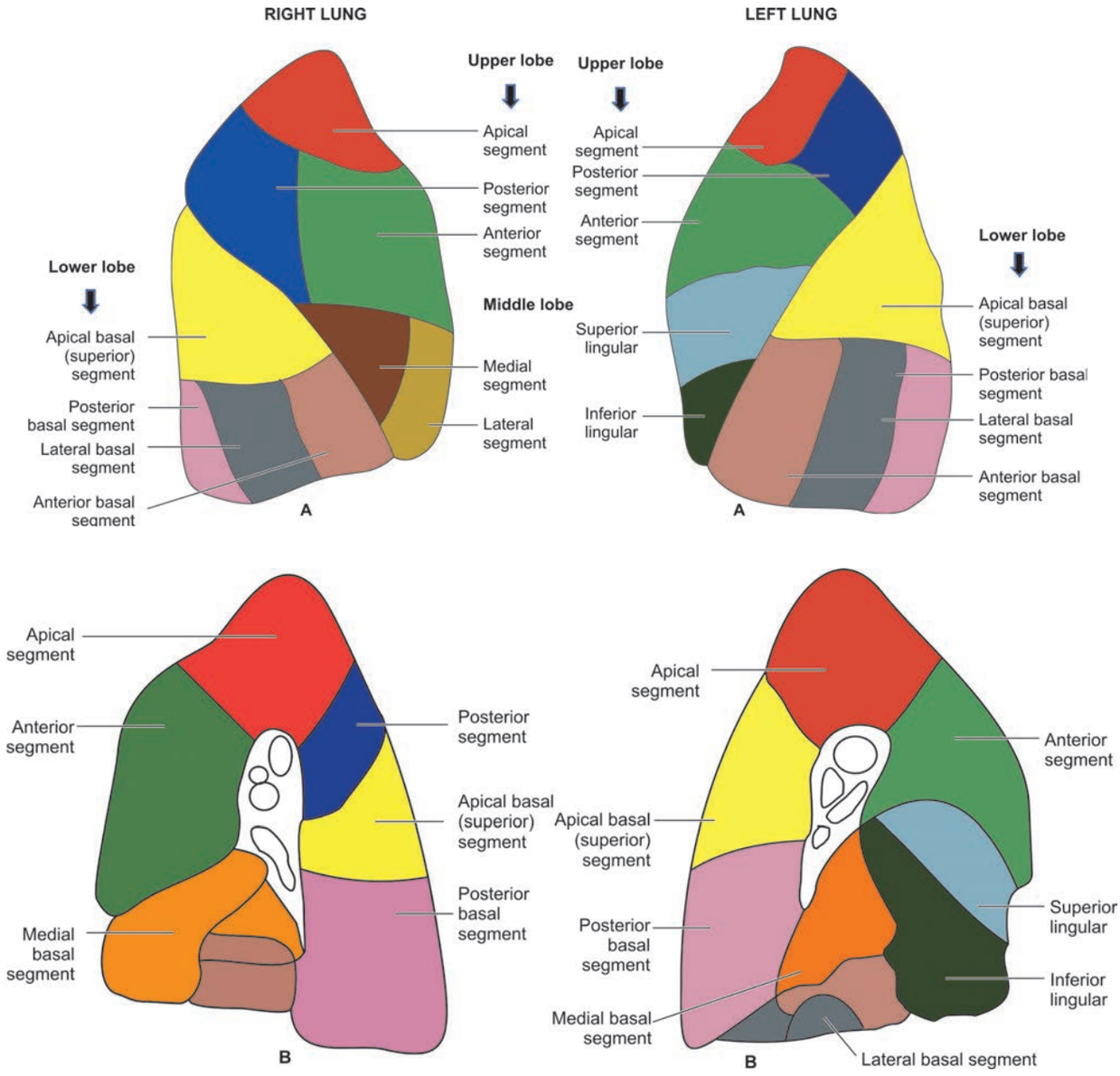


Fig. 41.11: Bronchopulmonary segments of the right lung. **A:** Lateral view; **B:** Medial view

Fig. 41.12: Bronchopulmonary segments of the left lung. **A:** Lateral view; **B:** Medial view

Table 41.2: Bronchopulmonary segments in right and left lungs

Right Lung	Left Lung
Upper lobe • Apical • Posterior • Anterior	**Upper lobe** • Apicoposterior • Anterior • Posterior (may be separate) • Superior lingular • Inferior lingular
Middle lobe • Lateral • Medial	
Lower lobe • Superior (apical basal) • Medial basal • Anterior basal • Lateral basal • Posterior basal	**Lower lobe** • Apical basal • Anterior basal • Lateral basal • Posterior basal • Medial basal (may be suppressed)

tree. The percussion refers to tapping the thorax over the chest wall with the fingers to detect the resonance sounds of the lungs. It helps to know whether the underlying tissue is air filled (resonant sound), fluid filled (dull sound), or solid (flat sound). The knowledge of normal anatomy of the lung and its projections, portions covered by the bones (example scapula), muscles is important to know where flat and resonant sounds should be expected.

Auscultation Sites

- Apex of the lung is auscultated above the medial third of the clavicle anteriorly and upper part of suprascapular region posteriorly.

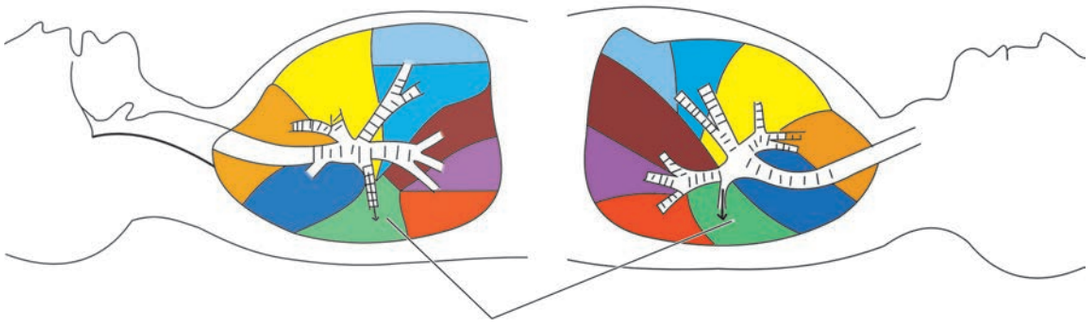


Fig. 41.13: Most dependent bronchopulmonary segments in supine position

- The upper lobe of the right lung is best heard anteriorly in the area extending from the clavicle to the level of 4th costal cartilage, while that of the left lung is best heard in the area up to the level of 6th costal cartilage (Fig. 41.14A and B)
- The middle lobe is heard anteriorly between right 4th and 6th ribs in front of the midaxillary line.
- The apical basal or superior segment of the lower lobe (on both sides) is heard posteriorly in the interval between the medial border of the scapula and the vertebral spines.
- The basal segment of the lower lobe (on both sides) are heard posteriorly in the infrascapular region up to the level of 10th rib.
- When clinicians refer to 'auscultating the base of the lung', they are not usually referring to diaphragmatic surface of lungs, instead posteroinferior part of the lower lobe (i.e. basal segments).

BLOOD SUPPLY TO THE LUNG

Pulmonary Vessels

Each pulmonary artery arises from pulmonary trunk at the level of sternal angle carrying deoxygenated blood to the lungs for oxygenation. The branches of the pulmonary arteries and bronchi are paired in the lung, running in parallel course.

The branches of pulmonary arteries accompanying the bronchiole are thin walled without any muscles in its wall. These arteries end up in forming capillaries, which are placed close to the alveoli of the lung. The venous ends of the capillaries join to form intersegmental veins running in between the bronchopulmonary segment. Finally, two pulmonary veins carrying oxygenated blood emerge from the hilum of the lungs and drain into the left atrium. The right pair of pulmonary veins cross posterior to the base of the heart.

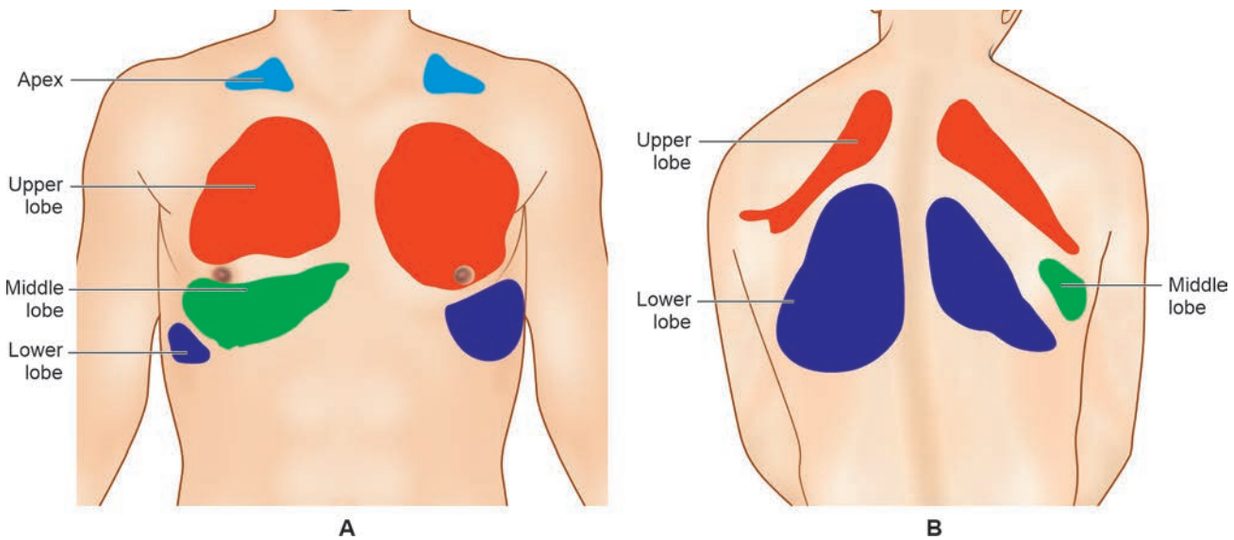


Fig. 41.14: Surface projection of lobes of the lungs for auscultation. **A:** Anterior view; **B:** Posterior view

Clinical Notes

Pulmonary Embolism

An obstruction of a pulmonary artery by a blood clot (embolus) can cause death. The embolus in the pulmonary artery forms when blood clot or fat globule or air bubble travels through veins and reaches the lung after traversing the right atrium and right ventricle. For example, a blood clot arising from a fracture site can dislodge and travel through a person's body to his or her lungs obstructing the pulmonary artery or its branch. The blockage results in a lung or a portion of the lung that is ventilated with air but not perfused with blood. The patient suffers acute respiratory distress because of decrease in oxygenation of the blood. The right side of the heart may become acutely dilated and this results in death within a few minutes. A small embolus can block the artery supplying the bronchopulmonary segment causing a pulmonary infarct, an area of necrotic (dead) lung tissue.

CASE 2

A 65-year-old obese lady with the past history of thrombophlebitis in the leg was admitted to the hospital, for a surgery of hip replacement after traumatic neck fracture of the femur. Her cardiac functions were normal. During postoperative period she was reluctant to undergo routine physical therapy and always preferred to be on the bed. She suddenly developed dyspnea, chest pain, hemoptysis, cyanosis and also deterioration of mental function. A CT angiogram revealed a 'pulmonary embolism' in the left pulmonary artery bifurcation. A catheter introduced into the pulmonary artery has dissolved the clot and the patient was discharged from the hospital after couple of weeks.

1. What is 'pulmonary embolism'?
2. How do you correlate this patient's reluctance to do exercise during postoperative period and development of pulmonary embolism?
3. Trace the venous pathway by which a 'thrombus' travels from calf vein to pulmonary artery.

Bronchial Vessels

The bronchial arteries supply intrapulmonary bronchial tree and connective tissue of lung parenchyma.

1. On right side there is one bronchial artery arising from left bronchial or 3rd right posterior intercostal artery or descending aorta.
2. On the left side there are two bronchial arteries (upper and lower) arising from descending aorta at level of tracheal bifurcation.

The right bronchial vein drains into azygos vein while left bronchial vein opens into either the left superior intercostal vein or the accessory hemiazygos vein.

NERVE SUPPLY OF THE LUNGS

The sympathetic and parasympathetic nerves supplying the lungs are derived from anterior and posterior pulmonary plexus placed in front and behind the root of the lung. These are extensions from cardiac plexus. The effect of sympathetic and parasympathetic stimulation on lungs is summarized in Table 41.3.

LYMPHATIC DRAINAGE OF THE LUNGS

The lymphatic vessels of the lungs can be classified into superficial and deep lymphatic plexus (Fig. 41.15):

- The superficial lymphatic plexus lies deep to the visceral pleura and drains the lung parenchyma and visceral pleura. They run along the borders of the lungs and margins of the fissures to converge at the hilum. These lymphatic vessels drain into **bronchopulmonary lymph nodes** (hilar lymph nodes) at the hilum of the lung.
- The deep lymphatic plexus is located in the submucosa of the bronchi and in the peribronchial connective tissue along the bronchial tree. A lymph vessel from these deep plexus drains initially into **pulmonary lymph nodes**, located along the lobar bronchi within the lungs.
- Lymphatic vessels from these nodes continue to follow the bronchi to the hilum of the lung where they also drain into the bronchopulmonary lymph nodes, hence lymph from both superficial and deep plexuses are drained into **bronchopulmonary lymph nodes** (Fig. 41.16).

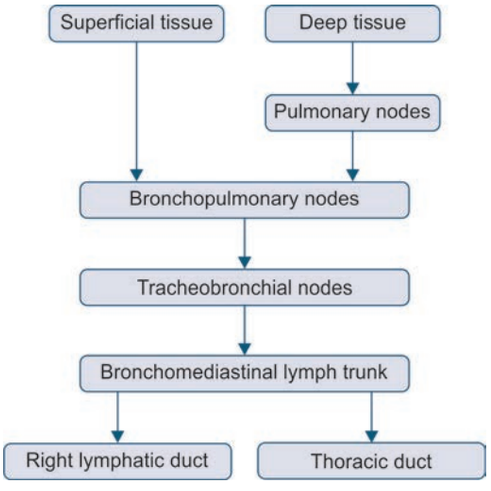


Fig. 41.15: A schematic representation showing lymphatic drainage of the lungs

Table 41.3: Nerve supply of the lungs

Parasympathetic	Sympathetic
• Vagus • Bronchoconstrictors (motor to smooth muscles in the wall of the bronchial tree, the attack of bronchial asthma is due to spasm of smooth muscles of bronchioles). This may be precipitated by (excessive vagal stimulation) exposure to cold air, dust, smoke • Secretomotor to the glands in the mucous membrane of the respiratory tract • Vasodilator (inhibitory to the pulmonary vessels) • Concerned with reflex control of respiratory activity • Parasympathetic fibres are cholinergic	• Upper thoracic segments of spinal cord • Bronchodilators (inhibitor to smooth muscles in the wall of the bronchial tree) • Inhibitor to the glands in the mucous membrane of the respiratory tract • Vasoconstrictor (motor to the pulmonary vessels) • Convey painful stimuli such as chemical irritants, ischemia or excessive stretch • Sympathetic fibres are adrenergic (sympathetic drugs like adrenaline cause bronchodilation)

- In peripheral parts of the lungs, small channels connect superficial and deep lymphatic vessels, and are capable of dilatation to direct lymph from the deep to superficial vessels when outflow from the deep vessels is obstructed by lung diseases.
- Lymph vessels arising from them drain into superior and inferior **tracheobronchial lymph nodes** (placed superior and inferior to the bifurcation of the trachea and main bronchus respectively). These lymph nodes enlarge in carcinoma of the lungs and also in pulmonary tuberculosis. They may compress phrenic nerve (causing paralysis of one half of the diaphragm/hemidiaphragm), recurrent laryngeal nerve on the left side (paralysis of laryngeal muscles on the affected side/hoarseness and even vagus nerve (delayed gastric emptying).
- There is a tendency for vessels from the upper lobes to pass to the superior tracheobronchial nodes and those from lower lobes to the inferior tracheobronchial nodes.
- The right lung drains primarily through the consecutive sets of nodes on right side, and the superior lobe of the left lung drains primarily through the corresponding side of the left side. Many, but not all, of the lymphatics from the lower lobe of the left lung, however, drain into the right superior tracheobronchial lymph nodes; the lymph then continues to follow the right-side pathway.
- The lymph from the tracheobronchial lymph nodes passes to right and left bronchomediastinal lymph trunks. These lymph trunks may end at the junction of internal jugular and subclavian veins of the respective sides, or right bronchomediastinal lymph trunk may join right lymphatic duct and left bronchomediastinal lymph trunk into thoracic duct.

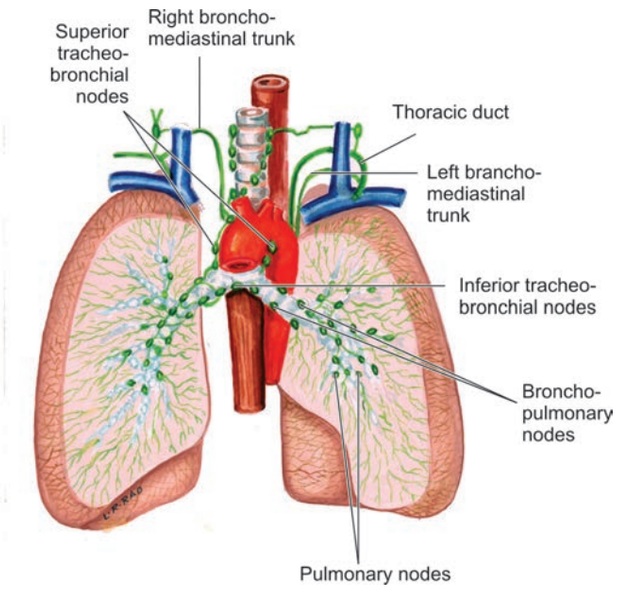


Fig. 41.16: Lymphatic drainage of the lung

CASE 3

A 55-year-old man states that his wife had recently noticed an alteration in his voice. He has lost 16 kg of weight and has a persistent cough with blood-stained sputum. He smokes on an average 15 cigarettes a day. On examination, the left vocal cord is immobile and lies in the adducted position. A posteroanterior chest X-ray reveals a large mass in the upper lobe of the left lung with an increase in width of the mediastinal shadow on the left side.

1. Explain in anatomical basis for the alteration in the voice.
2. Relate the voice change to the other findings.
3. Trace the lymphatic drainage from the lung to the systemic circulation.

Clinical Notes

Radiographic Anatomy of the Lungs

The most common radiographic study of the thorax is the posteroanterior (PA) X-ray. The anterior

aspect of the patients' thorax is placed against the X-ray detector and the shoulders move anteriorly to move the scapula away to expose the superior parts of the lungs (Fig. 41.17). The patient is asked to take a deep breath and hold it. The deep inspiration causes the diaphragmatic dome to descend, moving the inferior margin of lungs into costomediastinal recesses. The inferior margins should appear as sharp, acute angles. Pleural effusions if any do not allow the inferior margin to descend into the recess and the usual radiolucent air density here is replaced with a hazy radiopacity. The PA radiograph of the chest is viewed as if you were facing the patient (an anteroposterior [AP] view). The bony structures like clavicles, ribs, lower cervical and upper thoracic vertebrae are identified and also uncommon cervical ribs, missing ribs, forked ribs and fused ribs should be detected.

Among the soft tissue structures, the trachea is identified in the midline in the superior mediastinum as a translucent air column. The lung fields are translucent (because of low density), but bronchovascular markings are seen as opacities throughout the lungs. In case of pneumonia the affected area appears to be radiodense instead of radiolucent. The hilum is recognized as an opaque area because it contains large blood vessels and lymph nodes. The right and left domes of the diaphragm are visible with a translucent area beneath the left dome of the diaphragm which is due to the gas in the fundus of the stomach.

MICROSCOPIC STRUCTURE

In the given slide of cross section through lungs, you will be able to identify the bronchi, bronchioles, alveoli and capillaries.

Bronchi: They are identified by their cartilage plates and a circular layer of smooth muscles in their wall. The wall of the bronchus presents mucosa, submucosa, pieces of cartilages and adventitia. The mucosa (located towards the lumen) is lined by **pseudostratified ciliated columnar epithelium**. The smooth muscles appear to be discontinuous because of its spiral course. Contraction of these smooth muscles regulates the appropriate diameter of the bronchi.

Bronchioles: Their diameter measures 1 mm or less. The larger bronchioles are branches of segmental bronchi. These ducts branch repeatedly, giving rise to the smaller terminal bronchioles and finally respiratory bronchioles. Large bronchioles are lined by pseudostratified ciliated columnar epithelium. The epithelium gradually transforms into a simple ciliated columnar epithelium as the duct narrows. Goblet cells

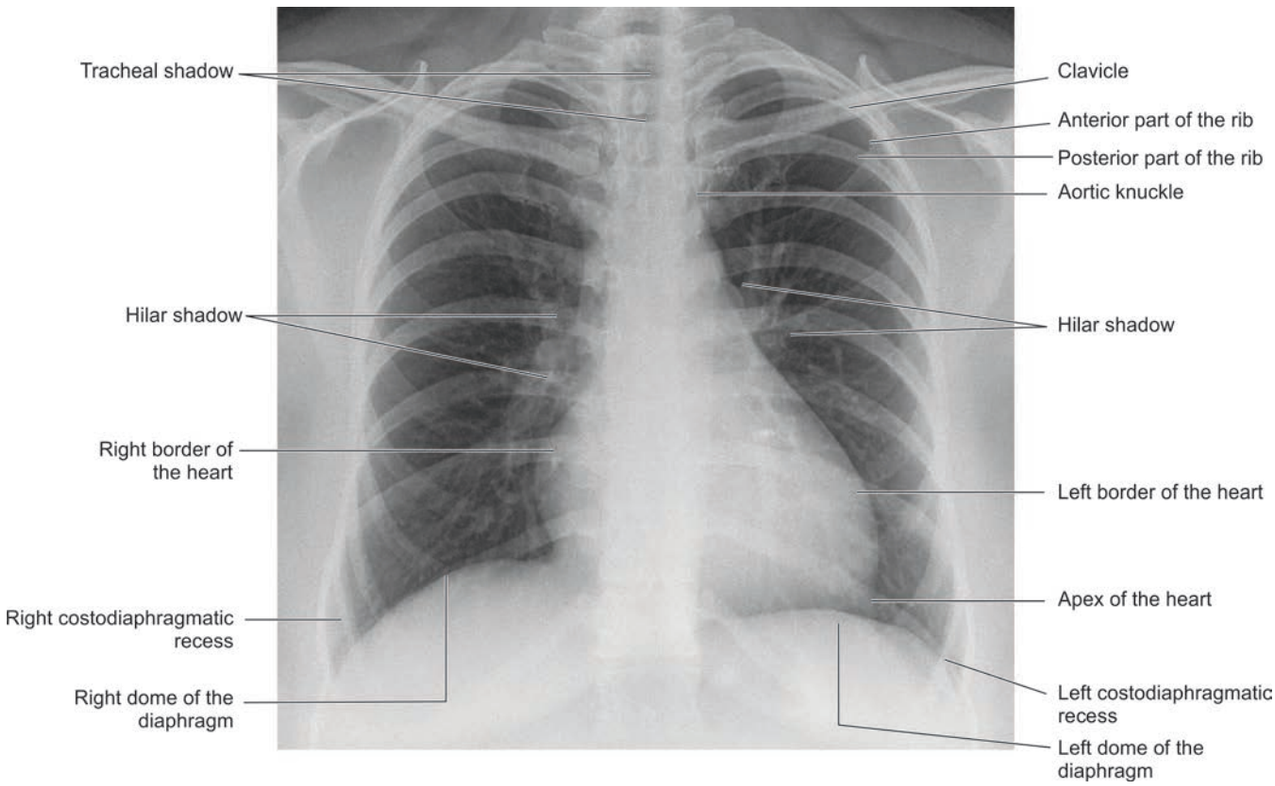


Fig. 41.17: Chest radiograph—PA view

are present in larger bronchioles but absent in terminal bronchioles. Note that the cartilaginous plates are absent in bronchioles, but a relatively thick layer of smooth muscle is present in the wall of all bronchioles.

The terminal bronchioles are lined by **simple cuboidal epithelium** with **Clara cells** in between them. Clara cells are nonciliated cells that have a dome-shaped apical surface projection. They secrete a **surface-active agent**, a lipoprotein that prevents luminal adhesion, particularly during expiration. They also secrete a protein called Clara cell secretory protein (**CC16**). The chronic obstructive pulmonary disease (COPD) and asthma are associated with higher levels of serum CC16. Secretion of CC16 into the bronchial tree decreases during lung injury (because of damage to Clara cells), whereas serum levels of CC16 may increase because of leakage across the air–blood barrier.

Respiratory bronchioles are involved in both air conduction and gas exchange. The respiratory bronchioles are lined by simple cuboidal epithelium. The respiratory bronchioles further give many **alveolar ducts** which are lined by simple cuboidal epithelium. Atria are the distal termination of alveolar ducts. The alveolar ducts and sacs are surrounded by alveoli.

The alveoli are separated from one another by a thin connective tissue layer that contains blood capillaries. The tissue between adjacent alveolar air spaces is called alveolar septum or septal wall.

Alveoli: The alveoli are lined by simple squamous epithelium. These epithelial cells include type I alveolar cells, type II alveolar cells and also few brush cells.

Type I alveolar cells (type I pneumocytes): These simple squamous cells line nearly 95% of the surface of the alveoli. It is connected to the adjacent type I alveolar cells through occluding junctions. They limit pleural effusion-leakage of tissue fluid into the alveolar lumen. Type I alveolar cells form a barrier between the air and blood. The cytoplasmic organelles cluster around the nucleus will facilitate air diffusion. They have many small pinocytotic vesicles that help in the turnover of pulmonary surfactant and removal of small particles from the alveolar surfaces. These cells can be distinguished from the nearby endothelial cells that have rounded nuclei. Type I alveolar cells are not capable of cell division.

Type II alveolar cells (type II pneumocytes): These cells are also called septal cells or secretory cells. These cells may be squamous to cuboidal and bulge into the lumen. They are connected with type I alveolar cells through desmosomes and occluding junctions. The apical portions of the cells present lamellar bodies. These lamellar bodies contain phospholipids, neutral lipids and proteins that are secreted by exocytosis to the surface of the alveolar lining epithelium. This secretion is called **pulmonary surfactants**. The type II alveolar cells are progenitor cells for type I alveolar cells (after lung injury they proliferate). Surfactant decreases the alveolar surface tension and actively participates in the clearance of foreign materials.

Clinical Notes

Inadequate secretion of surfactant results in collapse of alveoli in successive exhalation (expiration). Such collapse in premature infants whose lungs have not developed sufficiently to produce surfactants. This results in **respiratory distress syndrome (RDS)**. In premature infants, the alveoli collapse during exhalation and must be completely reinflated during each inspiration, an effort that requires tremendous expenditure of energy. Prophylactic administration of exogenous surfactant at birth to premature infants reduces the risk of RDS. In addition, administration of cortisol to mothers with threatened premature delivery is in practice.

Brush cells: They are present in the alveolar wall, but they are few in number. They may serve as receptors that monitor air quality in the lung.

Alveolar macrophage cells (dust cells): These are large monocyte-derived representatives of mononuclear phagocyte system. They are located both on the surface of the alveolar septa and interstitium. Macrophages remove debris that escapes the mucus and the cilia in the conducting part of the respiratory tract. They also phagocytose blood cells entering the alveoli because of heart failure and referred as heart failure cells. Macrophage cells also phagocytose infectious organisms such as *Mycobacterium tuberculosis.* The macrophages present in the alveolar septum contribute to the development of emphysema.

The alveoli are set close to the capillaries derived from the pulmonary artery (carrying deoxygenated blood). The structures intervening between air of lung alveoli and blood of pulmonary capillaries constitute air–blood barrier. The structures include (Figs 41.18 and 41.19A and B):

a. Flattened epithelium of the alveoli
b. Its basement membrane
c. Basement membrane of the capillary
d. Endothelial cells lining the capillaries

The average thickness of this barrier is about 0.2 µm. The total surface area of alveoli is about 70–100 sq. meters (both lungs).

Clinical Notes

Bronchoscopy: A bronchoscope is introduced through respiratory passage to examine the internal surface of the main bronchi in the lung. The tube is inserted through the nose or mouth and guided inferiorly through the larynx and trachea. At the bifurcation of the trachea, the **'carina'** is identified. It is the cartilaginous projection. In case of carcinoma, if the tracheobronchial lymph node that is placed between the two main bronchi is enlarged, it can distort the carina. The mucous membrane covering the carina is highly sensitive and is associated with cough reflex. For example, when a foreign body is aspirated, the people choke and cough. In such case, the person is inverted to make use of the gravity to expel the foreign body. Forceps may be attached to the tip of the tube to remove trapped objects, take biopsy samples or retrieve samples of mucus for examination.

Aspiration of foreign body: The right principal bronchus is wider, shorter and more vertical and hence the aspirated foreign bodies or food is more likely to enter it. Infections are more common on the right lung for the same reason. The apical basal (superior) segment of the lower lobe and posterior segment of the upper lobe are common sites of lung abscess caused by aspiration because these segments are most dependent parts of the lung.

Pneumonia: Infection and inflammation of the lungs in which fluid accumulates in the alveoli. This may present as confluent parenchymal opacity or merely patchy opacity **(**Fig. 41.20). **Consolidation** refers to the alveolar air spaces being filled with fluid (exudate/transudate/blood), cells (inflammatory), tissue, or other material. Consolidation must be present to diagnose pneumonia and the signs of lobar pneumonia are characteristic and clinically referred to as consolidation.

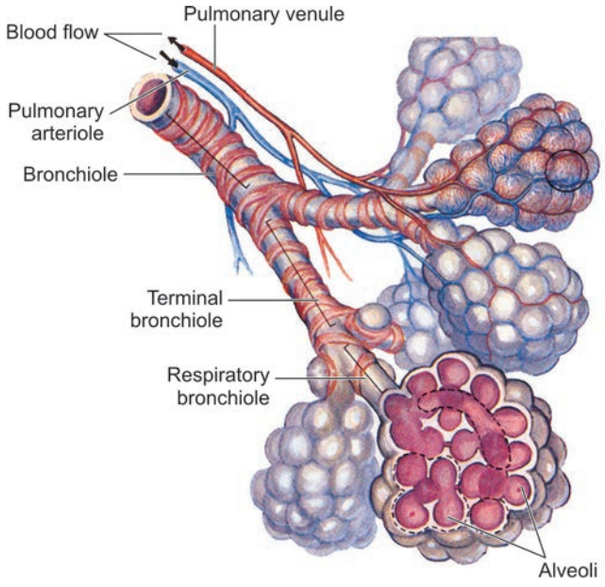


Fig. 41.18: Terminal part of the respiratory tract

Tuberculosis (TB): It is caused by bacterium *Mycobacterium tuberculosis,* which primarily enters the body in inhaled air. The TB typically affects the lungs but can spread through lymph vessels to the other organs. The symptoms of TB are coughing, fever and chest pain. The posterior segment of the right upper lobe is frequently the site of tuberculosis

Pulmonary edema: It is the accumulation of the fluid in the lung alveoli. It occurs in inflammation of the lung tissue. It mainly occurs in pneumonia or left ventricular failure due to myocardial infarction,

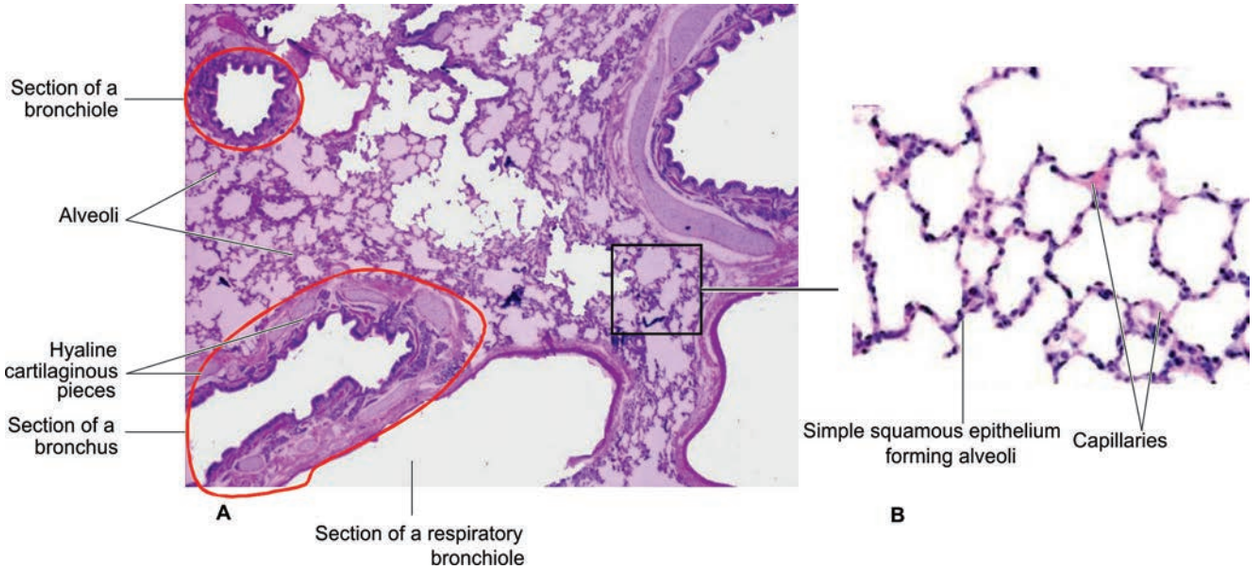


Fig. 41.19: A: Histology of the lung—under 10X magnification (H & E staining); **B:** Alveoli—magnified

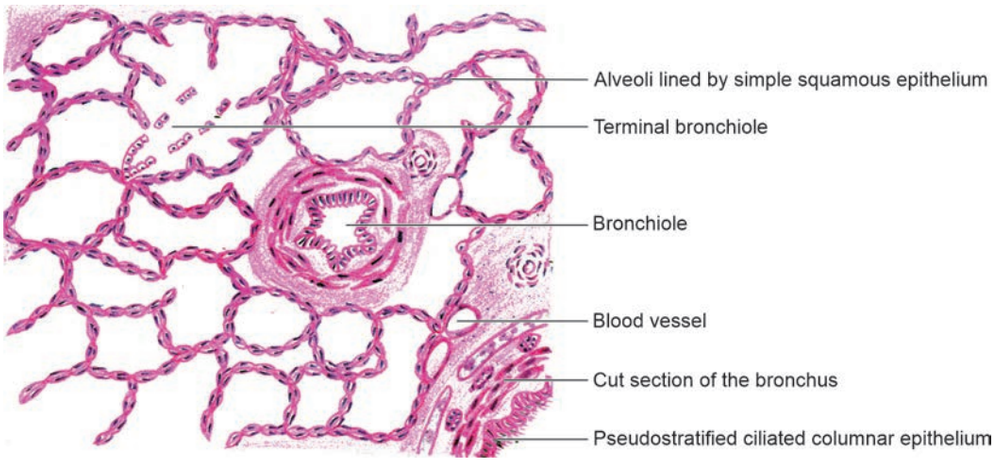


Fig. 41.19C: A schematic illustration shows histology of the lung

mitral stenosis, mitral regurgitation or systemic hypertension. It is characterized by dyspnea, sweating and cyanosis.

Bronchogenic carcinoma: It is the most common cancer in men. Cancer cells spread mostly by the lymphatics. Over 90% of lung cancer patients are smokers. The three most common types of lung cancer are:

- Squamous cell carcinoma (20 to 40% cases)
- Adenocarcinoma (25 to 30%)
- Small cell carcinoma (20%)

The anterior segment of the upper lobe is frequently the site for carcinoma. The lung cancer involving a phrenic nerve may result in paralysis of one half of the diaphragm (hemidiaphragm). Since left recurrent laryngeal nerve is related to medial surface of left lung near its apex, it may cause hoarseness due to paralysis of vocal cord.

Lung resection: For surgical resection of diseased bronchopulmonary segment, a sound knowledge of bronchopulmonary segments and their interpretation in radiographs and other medical images are essential. Tumours or abscesses are often confined to a bronchopulmonary segment and may be surgically resected. In case of carcinoma of the lung, whole lung (pneumonectomy), a lobe (lobectomy), or a bronchopulmonary segment (segmentectomy) may be removed.

Asthma: Asthma is a common chronic inflammatory disease of the respiratory tract characterized by variable and recurring symptoms, airflow obstruction, and bronchospasm (contraction of smooth muscles). It is characterized by wheezing, cough, chest tightness, and shortness of breath.

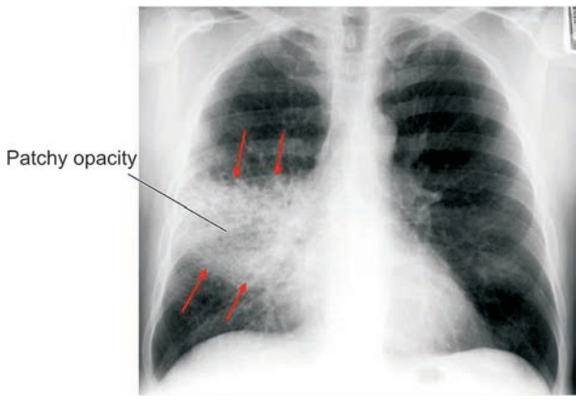


Fig. 41.20: Chest radiograph shows pneumonia

CASE 4

A 54-year-old female patient visits hospital because she has been suffering from a cold for the past few days. When she coughed, she noticed blood in her sputum (hemoptysis). When she coughs you notice that she bends her chest to the right and has a pained expression (it is a really sharp pain). She also tells you that it hurts when she takes a deep breath, and she does with great difficulty (dyspnea). Upon asking to locate the pain, she points to the right side of her chest (The patient abducts the right arm and places the palm of the left hand over the lateral aspect of the right breast and fingers over the medial wall of the right axilla). With the patient seated upright, auscultation reveals the following findings at the second and third intercostal spaces along the right midaxillary line: 1. Fine rales (crepitation or clicking) at the end of deep inspiration. 2. Percussion dullness is found at the same site

1. Which lobe of the lung is affected?
2. Explain the basis for dyspnea in this patient?
3. Use your knowledge of the nerve supply of the thorax to explain the sharp pain experienced when coughing.

4. Examine the chest radiograph and identify all lobes and the structures defining the borders of the cardiovascular shadow.

Solutions to the case studies

Case 1: The bronchopulmonary segments are independent units of the lungs, hence removal of one or other segment may not affect oxygenation process. The spreading of infection/tumor from one segment to the other is prevented to some extent by this connective tissue septum.

Case 2

1. An obstruction or a sudden blockage of a pulmonary artery by a blood clot (embolus) or fat globule, blood clot or air bubble is called pulmonary embolism (a clot that forms in one part of the body and travels in the bloodstream to another part of the body is called an embolus).
2. Immobilization of legs after surgery is a predisposing factor, which can cause deep vein thrombosis (DVT). During postoperative period, there is minimum activity of the legs, which can cause venous stasis and thrombosis. The emboli enter venous circulation to reach the right side of the heart and may cause life-threatening pulmonary embolism.
3. Rarely, pulmonary embolism leads to localized destruction of lung tissue called pulmonary infarction by blocking the arterial blood supply. Infarction is more likely to happen in people with chronic heart or lung disease. Although pulmonary infarction may be so mild as to cause no symptoms, massive embolism (more than 50% blockage of the pulmonary arterial circulation) and infarction can be fatal.
4. Usually, the first symptom is labored breathing, which may be accompanied by chest pain. Other symptoms include a rapid pulse, a productive cough (sputum may be blood-tinged), slight fever, and fluid buildup in the lungs.
5. The embolus from deep veins of the leg enters popliteal vein and then successively through femoral, external iliac, common iliac, inferior vena cava, right atrium, right ventricle, pulmonary trunk and pulmonary artery.

Case 3

1. This patient, a smoker, has an advanced carcinoma of the bronchus in the upper lobe of the left lung that has metastasized (spread) to the tracheobronchial lymph nodes. Enlargement of these nodes has resulted in pressure on the left recurrent laryngeal nerve as it passes under the arch of the aorta.
2. Partial injury of the recurrent laryngeal nerve results in paralysis of the abductor muscles of the vocal cords, leaving the adductor muscles unopposed. The left vocal cord was therefore adducted and immobile.
3. Refer to text

Case 4

1. Consolidation of the upper lobe of the right lung.
2. The patient's dyspnea indicates inadequate ventilation or perfusion of the lungs.
3. The patient's chest pain appears to be somatic pain originating from the parietal pleura of the right pleural space. The movements of the chest wall and diaphragm during inspiration stretch the parietal pleura of the pleural spaces. The increased tension in the parietal pleura elicits a sharp, knife-like pain if the parietal pleura is inflamed. Sharp chest pain produced by the stretching of inflamed parietal pleura is called pleuritic pain.
4. Refer to Fig. 41.17.

MCQs

1. During routine cadaveric dissection, a medical student attempted to pass his index finger posteroinferior to the root of the lung, but he found that the passage was blocked. Which structure would most likely be responsible for this?

A. Costodiaphragmatic recess
B. Inferior vena cava
C. Left pulmonary vein
D. Pulmonary ligament

2. A 50-year-old patient attends the clinic with the complaints of coughing with blood, fever 102°F for seven days. On auscultation of the chest posteriorly the physician could not hear the normal breath sounds above the fifth rib. Which of the following lobe was the physician auscultating?

A. Inferior lobe
B. Superior lobe
C. Lingula
D. Middle lobe

3. During lung resection, the surgeon started operating anterior to the right hilum of the lung. Which of the following structures will be incised (cut) first?

A. Thoracic duct
B. Pulmonary artery
C. Right bronchus
D. Pulmonary vein

4. A 50-year-old male with a chronic history of smoking presented with a hoarse voice and inability to abduct his left vocal cords. The patient also had a mass in the upper lobe of his left lung. Enlargement of which of these lymph nodes has compressed the left recurrent laryngeal nerve?

A. Pulmonary lymph nodes
B. Tracheobronchial lymph nodes
C. Parasternal lymph nodes
D. Bronchopulmonary lymph nodes

5. While examining the chest of a patient, you attempt to identify the oblique fissure. The oblique fissure lies parallel to a line interconnecting the ———

spinous process posteriorly, ——————— rib in the midaxillary line, ——————— costal cartilage anteriorly. Select the correct sequence.

A. T3, 5th, 6th
B. T3, 6th, 7th
C. T4, 5th, 6th
D. T5, 6th, 7th

6. The enlargement of which of the following group of lymph nodes is most likely to compress left recurrent laryngeal nerve?

A. Bronchopulmonary nodes
B. Tracheobronchial nodes
C. Pulmonary nodes
D. Thoracic duct

7. A chest radiograph shows a tumor at the cardiac notch on the upper lobe of the left lung in a 45-year-old woman. The tumor is located in which of the following bronchopulmonary segments?

A. Apical
B. Medial
C. Posterior
D. Superior lingular

8. During dental procedure, it is possible that small fragments may be aspirated into the trachea and can cause aspiration pneumonia. If the patient is sitting upright during the procedure, which of the following is the most common site of aspiration pneumonia?

A. Left lower lobe
B. Left upper lobe
C. Right upper lobe
D. Right lower lobe

9. A 16-year-old boy while lying supine in bed and eating, aspirates a peanut. Which of the following bronchopulmonary segments would this foreign object is most likely to enter?

A. Apical segment of the left upper lobe
B. Apical segment of the right upper lobe
C. Medial segment of the right middle lobe
D. Superior segment of the right lower lobe

10. Which part of the left lung might partially fill the costomediastinal recess in full inspiration?

A. Apex
B. Cupola
C. Hilum
D. Lingula

11. The oblique fissure of the right lung separates which structures?

A. Upper from middle
B. Lower lobe from upper lobe only
C. Lower lobe from both upper and middle lobes
D. Lower lobe from middle lobe only

12. A 35-year-old man was stabbed at the back with a knife that just nicked his left lung halfway between its apex and diaphragmatic surface. Which part of the lung was most likely injured?

A. Hilum
B. Inferior lobe
C. Lingula
D. Middle lobe

13. A 4-year-old girl is brought in with coughing, and you are told by her mother that she had been playing with some beads and had apparently aspirated one (gotten it into her airway). Where would you expect it to most likely be?

A. Left main bronchus
B. Lingular segment of left lung
C. Right main bronchus
D. Terminal bronchiole of right lung, lower lobe

14. A 67-year-old patient, lying supine in bed, aspirates (breathes in) some fluid into her lungs while swallowing. It would most likely end up in which of the following bronchopulmonary segments?

A. Anterior segmental bronchus of right superior lobe
B. Medial segmental bronchus of right middle lobe
C. Superior segmental bronchus of right inferior lobe
D. Medial basal segmental bronchus of left inferior lobe

15. A 10-year-old boy underwent tonsillectomy under general anesthesia. At home he laid supine in bed for two weeks and developed fever and chest pain with cough. He returned to the hospital and was diagnosed as having right lung pneumonia due to aspiration of infectious material during the tonsillectomy. In which bronchopulmonary segment of the lung is fluid (pus) most likely have been accumulated by the simple force of gravity?

A. Anterior basal segment—inferior lobe
B. Anterior segment—superior lobe
C. Lateral segment—middle lobe
D. Superior segment—inferior lobe

16. A 24-year-old man involved in a street fight was brought to the hospital with a deep laceration in the right fourth intercostal space around the midclavicular line. Which lobe is most likely to be damaged?

A. Upper lobe
B. Middle lobe
C. Lower lobe
D. Lingula

17. A patient was brought to the emergency department with a knife wound at the right fifth intercostal space in the midaxillary line. Which of the following structures is likely to have been damaged?

A. Middle lobe of the right lung
B. Right atrium
C. Right pulmonary artery
D. Upper lobe of right lung

18. A 93-year-old lady, who is on a liquid diet was fed in bed. She refused to sit up, so the nurse had to feed her while she was lying on her back. Halfway through the feeding, the patient aspirates the liquid and subsequently develops pneumonia. Which of the following is the most likely site affected by pneumonia?

A. Anterior segment of the right upper lobe
B. Apical segment of the right lower lobe
C. Inferior lingular segment of the left upper lobe
D. Lateral segment of the right middle lobe

19. A thoracic CT scan of a patient reveals that a neoplasm of the right lung has expanded medially into the wall of the pericardium and has compressed nerve fibres that coursed on the surface of the pericardium anterior to the root of the lung. Which of the following signs or symptoms might you expect in this individual?

A. Decreased heart rate and cardiac output
B. Hoarseness
C. Paralysis of right hemidiaphragm
D. Slow gastric emptying

20. A 55-year-old woman is undergoing radiographic evaluation for bronchogenic carcinoma that is discovered incidentally in the lateral segmental bronchus. The tumor is most likely located in which of the following lobes of the lung?

A. Lower lobe of left lung
B. Lower lobe of right lung
C. Middle lobe of right lung
D. Upper lobe of left lung

21. Which of the following components of the respiratory tract will increase in amount from trachea to alveoli?

A. Smooth muscle
B. Goblet cells
C. Cilia
D. Elastic fibres

22. Which of the following structures is located at the transition between conducting and respiratory portions of the respiratory tract?
A. Respiratory bronchioles B. Bronchioles
C. Alveolar ducts D. Tertiary bronchioles

23. Which of the following is true of Clara cells?
A. Are ciliated
B. Are found in primary bronchi
C. Contain secretory granules
D. Have microvilli

24. The pulmonary and bronchial arteries enter the lungs through the hilum separately, but anastomose with each other at which of the following levels?
A. Bronchi B. Alveolar ducts
C. Respiratory bronchioles D. Terminal bronchioles

25. In which of the following parts of the respiratory tract, the cilia are present, but goblet cells are absent?
A. Tertiary bronchioles B. Respiratory bronchioles
C. Bronchi D. Alveolar ducts

26. Which of the following provides immediate relief from the uncontrolled and excessive bronchial smooth muscle contraction suffered by asthmatic patients?
A. Vagal stimulation
B. Glucocorticoid injections
C. Sympathomimetic drugs
D. Local degranulation of mast cells

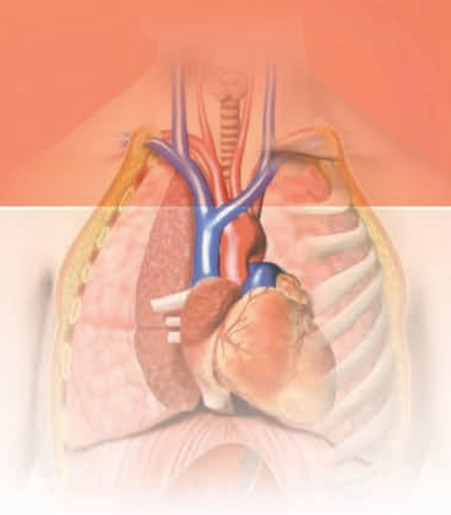
27. The presence of iron deposits in the cytoplasm of which cell type is a diagnostic feature of congestive heart failure?
A. Erythrocytes B. Goblet cells
C. Type I alveolar cells D. Dust cells

ANSWERS TO THE MCQs

1. D	2. B	3. D	4. B	5. A
6. B	7. D	8. D	9. D	10. D
11. C	12. B	13. C	14. C	15. D
16. B	17. D	18. B	19. C	20. C
21. D	22. A	23. C	24. C	25. B
26. C	27. D			

JUST BEFORE THE EXAM

Lung → Each lung presents an apex, base, costal and medial surfaces, anterior, inferior and posterior borders.
Right lung → It has oblique + horizontal fissure and has 3 lobes (upper, middle and lower)
Left lung → It has only oblique fissure, hence only two lobes (upper and lower).
Lingula → Anterior border of the left lung shows cardiac notch and tongue-like portion of the left lung, below the cardiac notch is called lingula.
Hilum of the lung → At the hilum the superior pulmonary vein is the most anterior and the bronchus are identified by the rigid cartilages present in their wall. The arrangement of hilar structure from above downwards on the right side is—eparterial bronchus, pulmonary artery, hyparterial bronchus and inferior pulmonary veins.
On the left side the arrangement from above downwards is—pulmonary artery, left principal bronchus and inferior pulmonary vein.
Phrenic nerve → Descends in front of the root of the lung while vagus nerve → Descends behind the root of the lung. The recurrent laryngeal nerve is related to medial surface of the left lung.
Groove superior to the hilum of the right lung → It is occupied by the arch of the azygos vein.
Groove superior to the hilum of the left lung → It is occupied by the arch of aorta.
Bronchopulmonary segments (BPS) → They are independent units of the lung aerated by tertiary (segmental) bronchus with separate branches of the pulmonary artery. There are 10 bronchopulmonary segments in each lung.
BPS on right lung → They are apical, posterior and anterior (in the upper lobe), medial and lateral (in the middle lobe), superior/apical basal, medial basal, anterior basal, lateral basal, posterior basal (in the lower lobe).
BPS on left lung → They are apical, anterior, posterior, superior lingular, inferior lingular (in the upper lobe) and apical basal, anterior basal, lateral basal, posterior basal and medial basal (in the lower lobe).
Right principal bronchus is wider and straight in line with trachea, hence foreign bodies tend to enter into the right lung. The aspirated contents often enter into superior/apical basal segment of the lower lobe of the right lung.
Bronchial arteries → On left side there are two bronchial arteries which arise from descending thoracic aorta while on right side one bronchial artery which arises from left bronchial or third posterior intercostal artery.
Parasympathetic nerve supply to the lung → It is by vagus nerve. Its stimulation causes bronchoconstriction and secretomotor to the glands in the mucous membrane of the respiratory tract.
Sympathetic nerve supply to the lung → It is derived from upper 5 thoracic segments of the spinal cord. They are bronchodilators and inhibitors to the glands in the mucous membrane in the respiratory tract.
Microscopic structure of the lung → A section of the lung stained with H&E shows cut sections of: (a) Bronchus (with pieces of cartilages) lined by ciliated pseudostratified columnar epithelium, (b) bronchioles lined by ciliated simple columnar epithelium without any cartilage pieces in the wall, (c) respiratory bronchioles lined by simple cuboidal cells. The lung alveoli are lined by simple squamous cells with capillaries placed close to them. The alveoli are lined by type I alveolar cells (for oxygenation) and type II alveolar cells which produce surfactants.



Chapter

42

Development of the Respiratory System

Competency: AN 25.2

Objectives

- To list the source of development of epithelium and musculatures of the respiratory tract
- To know the normal state of differentiation of the lung parenchyma and pulmonary vasculature at the sixth month of gestation, and at birth, and changes that occurs postnatally
- To explain the state of surfactant production in the premature neonate with the full-term neonate, and state of foetal age at which alveolar type II cells begin to produce surfactants
- To explain the embryological basis and consequences of tracheoesophageal fistula

DEVELOPMENT OF THE RESPIRATORY SYSTEM

Development of the respiratory system begins during 4th week of development. During this period, the lung buds (respiratory diverticulum) grows from the ventral wall of the foregut (endoderm). Increase in the retinoic acid from the adjacent mesoderm upregulates the transcription factor TBX4, which further differentiates lung buds. Further growth and differentiation of this respiratory diverticulum forms the lining epithelium of the entire respiratory tract. Hence, lining epithelium of the larynx, trachea, bronchi, bronchiole and alveoli of the lung are endodermal in origin. However, the cartilages, musculature and connective tissues present in the wall of the respiratory tract are derived from splanchnopleuric mesoderm surrounding the foregut.

- When the lung bud/respiratory diverticulum grows downwards it communicates with foregut. Now right and left tracheoesophageal ridges appear separating it from the foregut (Fig. 42.1).

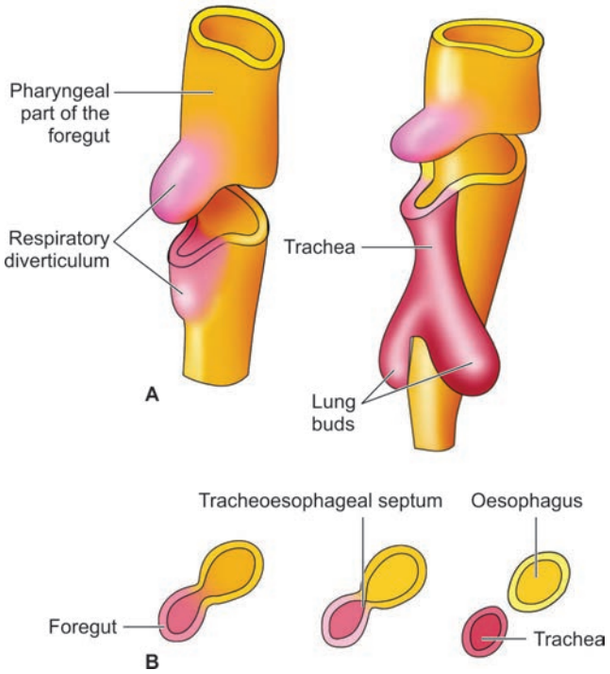


Fig. 42.1: Upper part of the foregut shows respiratory diverticulum; **A**: Anterolateral view; **B**: Cross-sectional view

- Gradually, these ridges fuse to form tracheoesophageal septum, thus that part of the foregut is divided into dorsal part forming oesophagus and ventral part trachea and lung buds.

Larynx and Trachea

The lining epithelium of the larynx is endodermal in origin from proximal part of the respiratory diverticulum. This diverticulum where it communicates

with foregut forms laryngeal orifice/inlet. The cartilages and muscles are derived from 4th and 6th pharyngeal arches (thyroid cartilage and cricothyroid muscle from 4th arch, cricoid, arytenoid cartilage and remaining intrinsic muscles of the larynx develop from 6th arch). The laryngeal epithelium proliferates to such an extent that it temporarily occludes the lumen of the developing larynx. Later canalization produces right and left saccules which are bounded by folds of tissues that differentiate into false and true vocal cords.

The lower end of the respiratory diverticulum forms the lining epithelium of the trachea. The cartilages, muscles and connective tissues in the wall of the trachea develops from splanchnic mesoderm.

- The distal end of the respiratory diverticulum becomes bifid and are called bronchial buds (Fig. 42.2).

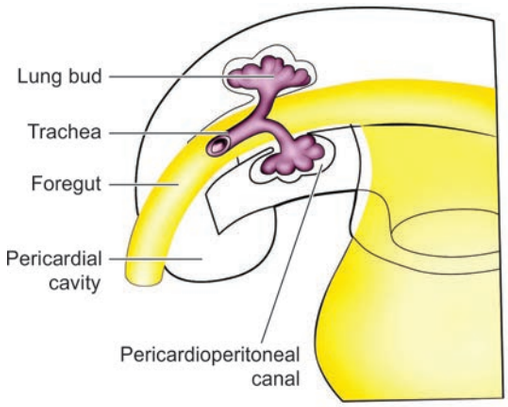


Fig. 42.2: Development of lung buds into the pericardio-peritoneal canal

- At the beginning of the 5th week each bronchial bud enlarges to form right and left main bronchi.
- This growing lung bud invaginates into pericardio-peritoneal canals (part of intraembryonic coelom) on each side.

After head fold formation, the septum transversum (unsplit intraembryonic mesoderm at the cranial end of the embryo) positions between thoracic and abdominal cavities with two large openings on each side. They are called **pericardioperitoneal canals.** They are located on either side of the foregut.

The thoracic cavity is divided into pericardial cavity and two pleural cavities. The pleural and pericardial cavities communicate with abdominal cavity through pericardioperitoneal canals, which is closed by pleuroperitoneal folds. The pleuroperitoneal folds separate pericardioperitoneal canal from the peritoneal cavities.The pleuropericardial folds separate pericardioperitoneal canal from the pericardial cavities.

With this the pericardial and peritoneal cavities are separated by pleuropericardial and pleuroperitoneal folds.

The lung buds grow to pericardioperitoneal canal behind the pleuropericardial folds (arises from lateral aspect on each side with phrenic nerve within it) (Fig. 42.3).

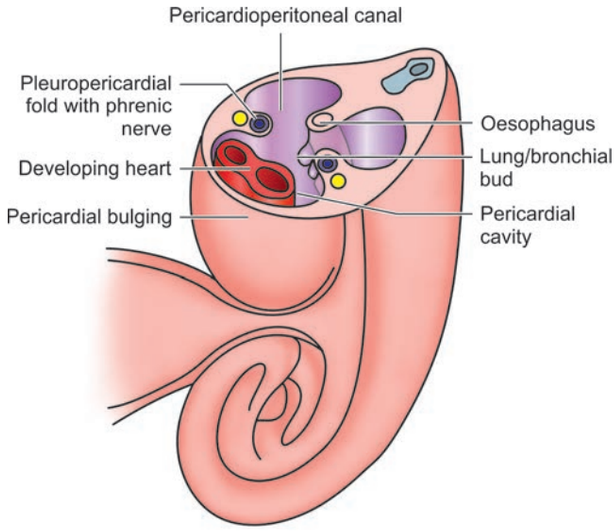


Fig. 42.3: Pericardioperitoneal canal and lung bud development (schematic)

The splanchnopleuric layer of mesoderm of the coelomic cavity forms visceral pleura outside the lung, while somatopleuric layer forms parietal pleura (lining the body wall).

Clinical Notes

Tracheoesophageal Fistula

- The abnormal partition of the oesophagus and trachea can cause oesophageal atresia with or without tracheoesophageal fistulas (TEF).
- The complication of tracheoesophageal fistula is polyhydramnios (excess of amniotic fluid). The amniotic fluid will not enter the stomach. The amniotic fluid and gastric contents can enter the trachea through fistula and cause pneumonia after birth.
- The infants born with tracheoesophageal fistula will choke with first feed.
- In 90% of the tracheoesophageal fistula, the upper portion of the oesophagus ends in a blind pouch and lower portion forms a fistula with the trachea (Fig. 42.4A).
- 'H' type of tracheoesophageal fistula: In this case the oesophagus communicates with trachea without obliteration of its lumen (Fig. 42.4B).

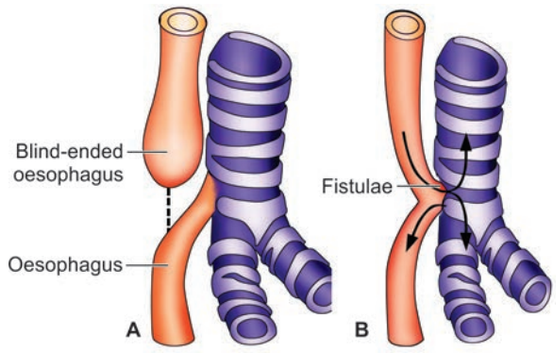


Fig. 42.4: Tracheoesophageal fistula. **A:** Upper portion of the oesophagus ends in a blind pouch; **B:** Oesophagus communicates with trachea

- Isolated cases where the upper portion of the oesophagus communicates with trachea while lower portion is a blind segment.

Lungs

At the beginning of the fifth week, the bronchial buds enlarge to form right and left main bronchi. The right bronchus forms three secondary bronchi and the left bronchus forms two secondary bronchi. These secondary bronchi divide repeatedly in a dichotomous manner forming 10 tertiary bronchi. By the end of the six months, approximately 17 generations of subdivisions had formed. Additional six divisions occur during postnatal life. Because of these repeated divisions the lungs reach a more caudal position.

Maturation of the Lungs

The maturation of the lungs is divided into four periods (Fig. 42.5):

1. **Pseudoglandular period (between 5th and 16th week of development):** By 16th week, all the major elements of the lung have formed, except those involved with gas exchange. Hence foetuses born during this period are unable to survive. The lung buds branch repeatedly up to terminal bronchiole.
2. **Canalicular period (between 16th week and 26th week of development):** The lumen of the bronchi and terminal bronchiole become larger, and the lung tissue becomes highly vascular. During this period, the terminal bronchiole divides into respiratory bronchioles, which further divides into alveolar ducts. Towards the end of the canalicular stage, few thin-walled terminal sacs in the form of primordial alveoli develop. Hence, foetus born during 24 to 26 weeks may survive, if given intensive care.
3. **Terminal sac period (between 26th week to birth):** From the alveolar ducts, primitive alveoli are formed, and they establish close contact with

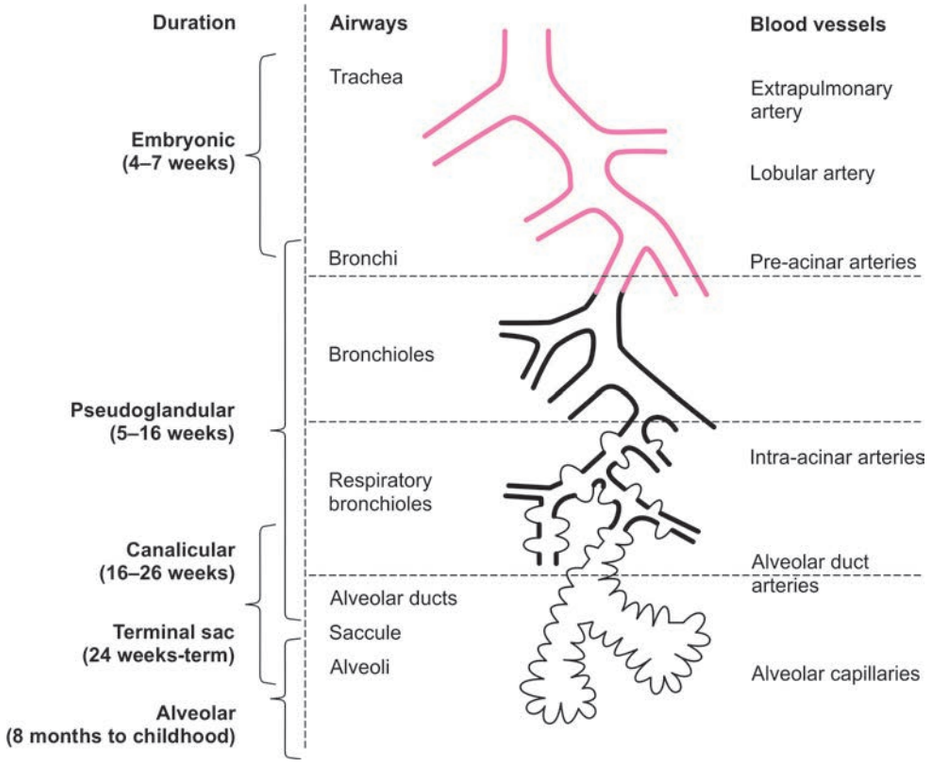


Fig. 42.5: A schematic representation of stages of lung maturation

capillaries. During the 7th month, enough capillaries are present to ensure adequate gas exchange, hence the premature infant will be able to survive by 26 weeks. The terminal sacs are lined mainly by squamous epithelial cells (type I alveolar cells). The lymphatic capillaries also develop. The surfactant producing type II alveolar cells also develops (under the influence of fibroblast-pneumocyte factor/FPF, produced by the lung fibroblasts). The maturation of alveolar type II cells and the production of surfactant vary in foetuses. **Surfactant production begins by 20 to 22 weeks, but surfactant is present in only a small amount in premature infants**. It does not reach adequate levels until the late foetal period.

4. **Alveolar period (8 months to childhood):** The alveoli mature and are in contact with endothelium of the capillaries. During the last two months of prenatal period and also for several years after birth, the cells lining the alveoli become thinner (type I alveolar epithelial cells) and surrounding capillaries invaginate into these alveolar sacs. Mature alveoli are not present before birth. Approximately 95% of mature alveoli develop in the postnatal period. The amount of surfactant in the fluid increases, particularly during the last two weeks before birth. After birth, the primordial alveoli enlarge as the lungs expand; however, most of the increase in the size of the lungs results from a continued increase in the number of respiratory bronchioles. Alveolar development is largely complete by 3 years of age, but new alveoli may be added until approximately 8 years of age.

There are three factors that are essential for normal lung development. They are:

1. Adequate thoracic space for lung growth
2. Adequate amniotic fluid volume
3. Foetal breathing movements

Clinical Notes

The foetal breathing movements cause aspiration of amniotic fluid into the lungs, which is necessary for lung development and to condition the respiratory muscles. The urine liberated from the foetal kidney maintains the volume of amniotic fluid, which is required for development of lung. Hence, renal agenesis affects branching of bronchial tree in lung causing pulmonary hypoplasia (Potter's syndrome).

When the respiration begins at birth, most of the fluid inside the lung is absorbed by blood and lymph capillaries except surfactant which remains deposited over the alveolar cell membrane. When the air enters the alveoli during first breath, the surfactant layer prevents collapsing of the alveoli during expiration.

In premature infants, the inadequate surfactant can cause collapse of lung during expiration. This is called respiratory distress syndrome (RDS or hyaline membrane disease). This is the common cause of death in the premature infant. Now there are artificial surfactants and also treatment of premature babies with glucocorticoids to stimulate surfactant production to tackle these problems.

The foetal adrenal gland consists of an inner active foetal zone and an outer dormant adult zone. The foetal zone produces mainly androgens in concert with the placenta. The outer zone is dormant during early foetal life and produces only small amounts of cortisol. Late in gestation, the production of cortisol gradually increases, and is thought to be responsible for foetal lung maturation (stimulates surfactant production). The secretion of cortisol from the adult zone of the adrenal cortex is controlled by ACTH and CRH from both the foetal pituitary and the placenta. Interestingly, CRH secretion from the placenta is upregulated by cortisol. Therefore, in late gestation, cortisol secretion from the adult zone of the foetal adrenal cortex is augmented by high placental CRH secretion. In summary, both maternal and foetal cortisol help to accelerate foetal lung maturation by stimulating surfactant production. The lecithin–sphingomyelin ratio is a marker of foetal lung maturity. Values above 1.9 are indicative of mature foetal lungs.

Lecithin–sphingomyelin ratio in amniotic fluid: Phospholipids including dipalmitoyl phosphatidylcholine, are a major component of pulmonary surfactant. The level of phosphatidylcholine (also called lecithin) is measured in amniotic fluid to gauge fetal lung maturity. This test measures the amount of two substances, lecithin and sphingomyelin, that are found in the amniotic fluid during pregnancy. The two substances are surfactants.

- A value of less than 1.5:1 means that baby's lungs are immature. If born now, the baby may have breathing problems.
- A value between 1.5:1 and 1.9:1 means that the baby may be at risk for immature lungs and breathing problems.
- A value of greater than 2:1 means that the baby has mature lungs and is ready for life outside the womb.

Other Anomalies of Lungs

1. **Lobe of the azygos vein:** The apex of the right lung may be a separate lobe, divided by a pleural fold with azygos vein. The medial part

of the divided apex is called lobe of the azygos vein (Fig.42.6).

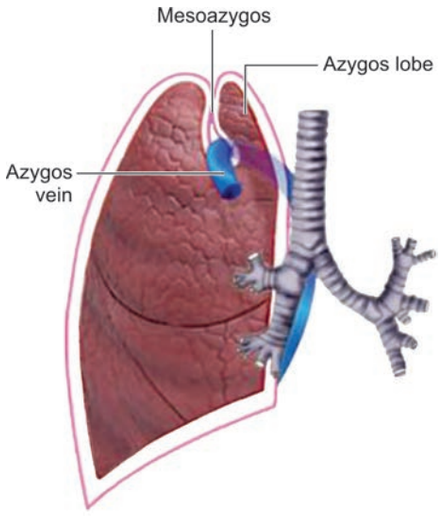


Fig. 42.6: Azygos lobe of the lung

2. **Congenital cysts of lung:** These are formed by dilation of terminal or larger bronchi. These cysts give a 'honeycomb' appearance on radiographs.
3. **Primary ciliary dyskinesia (PCD):** This is an autosomal recessive disorder affecting the movements of the cilia. Ciliary dysfunction prevents the clearance of mucous from the lungs, paranasal sinuses and middle ears. Bacteria and other irritants in the mucous lead to frequent respiratory infections. Kartagener syndrome is a type of PCD associated with a mirror-image orientation of the heart and other internal organs (situs inversus). The common features of the disease (begin shortly after birth) include coughing, gagging, choking and lung atelectasis (neonatal respiratory distress). Affected individuals often experience chronic sinus, middle ear and lung infections as well as chronic coughing, excess mucus and hearing loss. The recurring respiratory infections can lead to an irreversible scarring and dilation in the bronchi (bronchiectasis) and severe lung damage. People with PCD may become infertile because of dysmotility of sperm.

CASE 1

Ultrasound examination *in utero* reveals bilateral absence of the kidneys in a foetus at 34 weeks of gestation. The baby is born alive with club feet and various deformities of face at term but dies 12 hours after birth. What is the syndrome called?

Solutions to the case study

Case 1: The infant dies due to Potter's syndrome. The patient described in the question stem suffers bilateral renal agenesis, which invariably leads to oligohydramnios or anhydramnios (decreased or absent amniotic fluid) and results in Potter's syndrome. The signs of Potter's syndrome can result from any cause of persistent oligohydramnios. These signs include clubfeet, classic facies consisting of nasal, ocular, ear, and jaw deformities, and pulmonary hypoplasia. By definition, true Potter's syndrome results from bilateral renal aplasia and is a very rare condition: A similar presentation caused by other etiologies is called the Potter's sequence.

The amniotic fluid volume is maintained primarily by the fetus. The fetus swallows amniotic fluid, which is then absorbed by the fetal gastrointestinal tract and released by the fetal urinary system back into the amniotic fluid space. Swallowed amniotic fluid also contributes to the development and maturation of the fetal lungs. Infants with prolonged oligohydramnios often suffer from respiratory distress due to pulmonary hypoplasia. Respiratory failure and renal failure cause death within hours of birth in 100% of infants born with bilateral renal agenesis.

MCQs

1. **A newborn 3 hours ago is having difficulty in breathing. The baby was born prematurely at 28 weeks gestation. He is tachypneic and is using his accessory muscles to breathe with nasal flaring and grunting. The baby's heart rate is 120/min; blood pressure is 100/60 mm Hg, and respiratory rate is 55/min. Analysis of amniotic fluid reveals a lecithin: sphingomyelin ratio of 0.9:1. What is this baby's lung lacking?**
   A. Elastase
   B. Angiotensin-converting enzyme
   C. Dipalmitoyl phosphatidylcholine
   D. Collagen
2. **A 3-day-old girl is brought to the pediatric clinic because of breathing difficulties and poor feeding. She coughs, chokes, and spits up milk very soon after beginning to suckle. Physical examination and radiographs reveal the presence of the most common type of tracheoesophageal fistula. Which of the following is responsible for this defect?**
   A. Failure of the buccopharyngeal membrane to rupture
   B. Failure of the tracheoesophageal ridges to fuse
   C. Incomplete recanalization of the larynx
   D. Patent thyroglossal duct
3. **During ultrasound investigation of a pregnant woman, it is revealed that she has oligohydramnios. Which of the following congenital defects of the foetuses would be most likely associated with this abnormality?**
   A. Tracheoesophageal fistula
   B. Anencephaly

C. Congenital pyloric stenosis
D. Pulmonary hypoplasia

4. A pediatrician is called in to evaluate an infant who has not been able to swallow at all since birth. His mother reports that every time she tries to breastfeed him, the infant chokes and coughs. She says that her pregnancy and delivery were uneventful, but remembers the obstetrician being concerned about excess amniotic fluid seen on her ultrasound. Which of the following is most likely to be seen on the infant's X-ray of the chest?

A. Air in the stomach
B. Herniation of the stomach, spleen and intestines
C. Lung hypoplasia
D. Pleural effusion

ANSWER TO THE MCQs

1. C 2. B 3. D 4. A

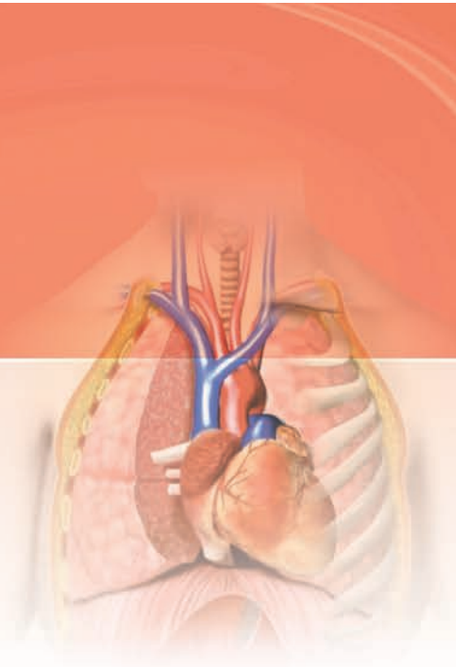
JUST BEFORE THE EXAMS

Development of the respiratory tract → Lining epithelium develops from endoderm while muscles, connective tissue and cartilages present in the wall of the respiratory tract develop from splanchnic mesoderm.

Maturation of the lungs → It is divided into 4 periods—pseudoglandular phase, canalicular phase, terminal sac phase and alveolar phase.

Surfactant production → Begins by 20 to 22 weeks, but surfactant is present in only small amount in premature infants. Foetuses born at the end of six months are viable to survive.

Amniotic fluid is necessary for lung maturation and oligohydramnios in pregnant women may indicate under development of the lungs.



Chapter

43

Pericardium and Heart

Competencies: AN 22.1 to 22.7, 25.7, 25.9

Objectives

- To list different subdivisions of the pericardium, their nerve supply and its clinical relevance
- To describe the pericardial sinuses and their clinical relevance
- To describe the anatomy of the pericardiocentesis
- To describe the external features of the heart
- To surface mark the borders of the heart on a cadaver or in a simulated patient
- To describe the internal features of each chamber of the heart including the features of the valves
- To locate the auscultation areas of the cardiac valves in a cadaver or in a simulated patient
- To identify the normal cardiac features observed in a PA view of chest X-ray

PERICARDIUM

Heart is covered by a fibroserous membrane called pericardium. Pericardium consists of outer fibrous layer and inner serous layer. The pericardium keeps the heart in position and prevents its over-distension.

Parts of the Pericardium

- The inner serous pericardium has an outer parietal layer, which blends with fibrous pericardium.
- The visceral layer (epicardium) of the serous pericardium is closely applied to the heart.
- The space between the two layers of serous pericardium is called pericardial cavity, which contains a thin layer of fluid (which allows the free movement of the heart within the fibrous pericardium).

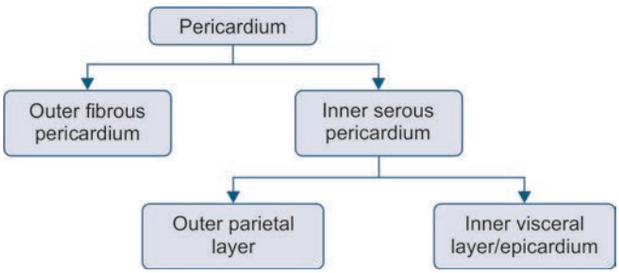


Fig. 43.1: Subdivision of the pericardium

Fibrous Pericardium

- It is a tough non-elastic external layer of the pericardium.
- Superiorly it continues with the tunica adventitia of great vessels entering or emerging from the heart and with a pretracheal layer of the deep cervical fascia.
- Anteriorly it is attached to the posterior surface of the body of the sternum by superior and inferior sternopericardial ligaments.
- Posteriorly it is separated from the posterior mediastinum by loose connective tissue.
- Inferiorly it is attached to the central tendon of the diaphragm by pericardiophrenic ligament.
- The central tendon of the diaphragm and the fibrous pericardium is developmentally from the same source, the septum transversum.
- The fibrous pericardium protects the heart against sudden overfilling because it is so unyielding.
- The ascending aorta carries the pericardium superiorly beyond the heart to the level of sternal angle (Fig. 43.2).

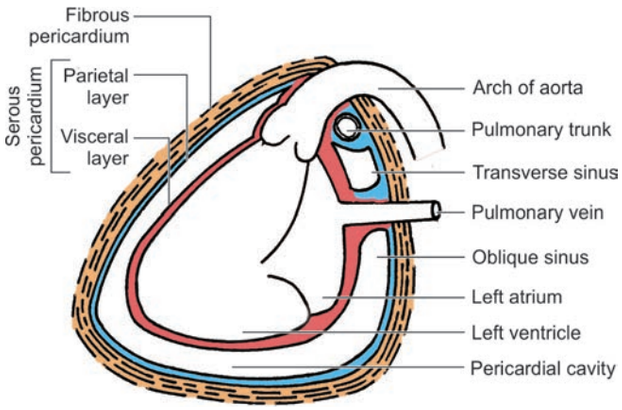


Fig. 43.2: Pericardium and its sinuses

Serous Pericardium

- It is a thin glistening membrane having an outer parietal layer and inner visceral layer. It is made up of a single layer of mesothelial cells resting on the basement membrane facing the pericardial cavity.
- Its parietal layer lines the inner surface of the fibrous pericardium and inner visceral layer (epicardium) covers the external surface of the heart.
- The visceral layer becomes continuous with parietal layer where aorta and pulmonary trunk leave the heart and superior vena cava (SVC), inferior vena cava (IVC) and pulmonary veins enter the heart.

Pericardial Sinuses

These are parts of the pericardial cavity formed around the sites of reflection between parietal and visceral pericardium. The pericardial sinuses are formed during the development of the heart, as a consequence of the folding of the developing heart tube.

Transverse sinus: It is a transverse gap behind the pulmonary trunk and ascending aorta and in front of the superior vena cava (Figs 43.2 and 43.3).

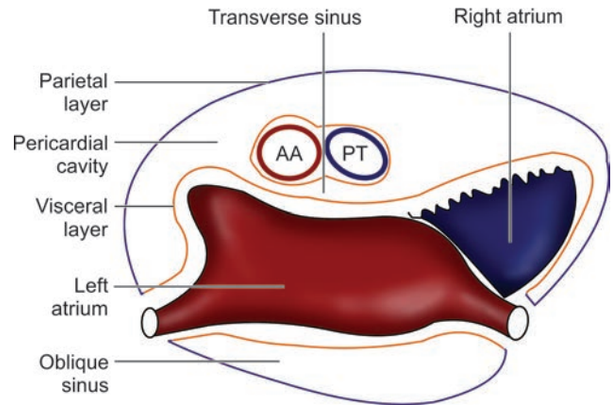


Fig. 43.3: Pericardial sinuses: Transverse section; AA:Ascending aorta, PT: Pulmonary trunk

Boundaries

Anteriorly: Visceral pericardium covering ascending aorta and pulmonary trunk.

Posteriorly: Visceral pericardium covering anterior surface of the left atrium.

On each side it opens into pericardial cavity.

Oblique sinus: It is part of the pericardial cavity behind the left atrium (Figs 43.2 and 43.3).

Boundaries

Anteriorly: Visceral pericardium covering posterior surface of the left atrium.

Posteriorly: Parietal pericardium and fibrous pericardium further outside.

On right side: It is bound by pericardial reflection from inferior vena cava to right pulmonary veins on left side.

On left side: The pericardial reflection from left pulmonary veins.

The oblique sinus opens inferiorly into the pericardial cavity. Fingers can be passed just behind the apex of the heart and traced upwards through this inferior opening of the oblique sinus.

Arterial Supply

- The fibrous and parietal layers are supplied by branches of internal thoracic artery and descending thoracic aorta. It is also supplied by pericardiophrenic artery.
- The visceral layer is supplied by coronary arteries.

Nerve Supply

- The fibrous and parietal layers are supplied by phrenic nerve (C3–5).
- The visceral layer is supplied by vagus and sympathetic nerves.
- The pain sensation from the fibrous pericardium is carried by phrenic nerve and is referred to the skin above the clavicle (which is supplied by supraclavicular nerves sharing root value—C3,4).

Clinical Notes

Surgical significance of transverse pericardial sinus: During cardiac surgeries, after opening of the pericardial cavity, a finger can be passed through the transverse pericardial sinus that lies posterior to the ascending aorta and pulmonary trunk. By passing a surgical clamp or a ligature around these large vessels, inserting the tubes of the coronary bypass machine, the surgeons can stop or divert the circulation of blood in these arteries while performing cardiac surgery.

Pericarditis, pericardial rub and pericardial effusion: The inflammation of pericardium in several diseases is called pericarditis. It causes chest pain. The serous pericardium becomes rough. The smooth opposing layers of serous

pericardium normally make no detectable sound during auscultation. In case of pericarditis, friction between the two layers of the serous pericardium sounds like the **rustle of silk** when listening with a stethoscope. This is called **pericardial friction rub**. A chronic inflammation of the pericardium adversely affects the functioning of the heart. The accumulation of the fluid in the pericardial cavity is called **pericardial effusion**, which occurs in certain inflammatory diseases. In pericardial effusion, the heart will not be able to expand fully.

Cardiac tamponade: The compression of the heart due to excessive pericardial effusion is called cardiac tamponade. If extensive pericardial effusion exists, the pericardial sac does not allow full expansion of the heart due to tough, nonelastic nature of the fibrous pericardium. It causes a decrease in cardiac output. The accumulation of the blood in the pericardial cavity is called **hemopericardium**, it can also produce cardiac tamponade. In chest radiograph it appears as a **globular shadow**. One of the etiologies of cardiac tamponade is a collection of transudative fluid in a patient with renal failure.

Pericardiocentesis: In case of cardiac tamponade, it is necessary to drain excess fluid from the pericardial cavity. The procedure by which the excessive fluid of the pericardial cavity is removed is called pericardiocentesis. There are two approaches for this procedure:

a. **Parasternal route:** A needle may be inserted through the left 5th or 6th intercostal space near the lateral border of the sternum. This approach is possible through the cardiac notch in the left lung and shallower notch in the left pleural cavity. This is the area where heart and the pericardium is not overlapped by lung and pleura (area of superficial cardiac dullness).

b. **Subcostal route:** The needle is introduced at the left costoxiphoid angle in an upward, backward direction to enter the pericardial cavity (through the aponeurosis of external and internal oblique muscles of the abdominal wall, rectus sheath and central tendon of the diaphragm). The needle is inserted at an angle of 45° towards the left scapula. In this approach, the needle will not enter into pleural cavity, because both anterior border of left lung (cardiac notch) and costomediastinal reflection of pleura deviates laterally below the level of left 4th costal cartilage. However, care must be taken not to puncture the internal thoracic artery or its terminal branches (Fig. 43.4) In acute cardiac tamponade an emergency thoracotomy may be performed.

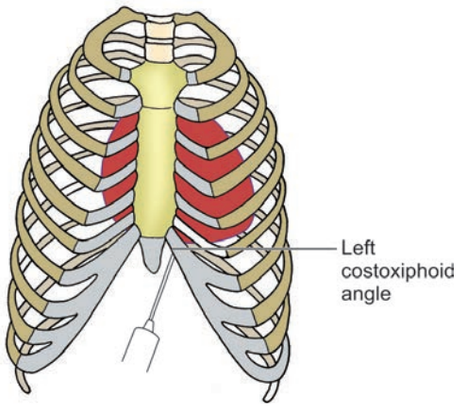


Fig. 43.4: Pericardiocentesis—schematic

CASE 1

A 26-year-old male is brought into the emergency room after having been kicked on the chest by his opponent teammate while playing football. After examination, it is concluded that the most likely immediate complication of this condition is cardiac tamponade (bleeding into the pericardial cavity). The physician decides to draw off some amount of the blood from the cavity to relieve the pressure on the heart.

1. What is cardiac tamponade?
2. How does the pericardial tamponade appear in a chest radiograph?
3. What are the two approaches for pericardiocentesis?

HEART

Human heart is a hollow muscular organ, which pumps blood to various parts of the body to meet the nutritive requirement. It is slightly larger than one's own clenched fist.

Situation

The heart is placed obliquely in the thoracic cavity (middle mediastinum) between the two lungs and behind the sternum (Fig. 43.5).

Measurement

The normal adult heart measures about 12 cm vertically and about 6 cm anteroposteriorly. The average weight of the male heart is 300 g and female heart is 250 g.

The heart consists of four chambers. The right and left atria, right and left ventricles. The auricles are the extensions (appendages) of atria.

Circulation of Blood

The right atrium receives deoxygenated blood from the whole body through the superior and inferior

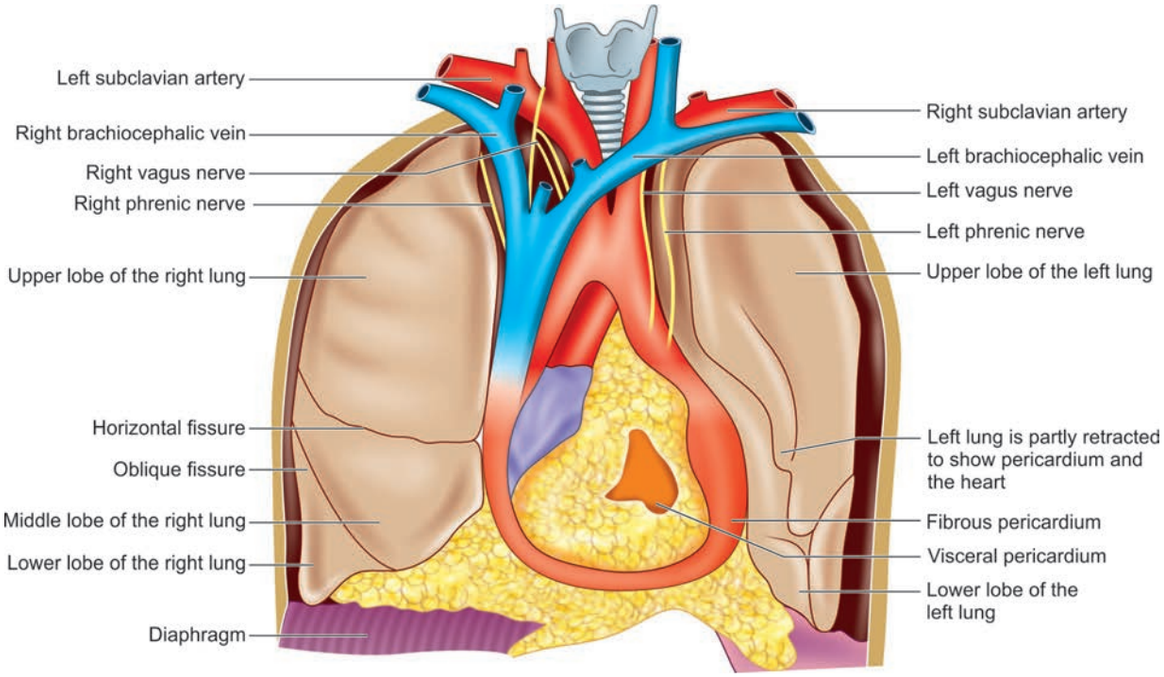


Fig. 43.5: Anterior view of the thoracic cavity with heart and pericardium

vena cavae and coronary sinus. When it contracts, the blood passes to the right ventricle through the right atrioventricular orifice. When the right ventricle contracts, blood passes to the lungs through the pulmonary trunk and pulmonary arteries. In the lungs the blood gets oxygenated, returns to the left atrium through the pulmonary veins and reaches the left ventricle through the left atrioventricular orifice. When the left ventricle contracts, the blood passes to the aorta and through its branches to the different parts of the body.

External Features of the Heart

Heart consists of an apex, a base, four surfaces and four borders (Fig. 43.6A and B).

Apex of the Heart

- It is conical and is formed by the left ventricle.
- It is situated in the left 5th intercostal space, about 9 cm from the median plane (little medial to the left midclavicular line). It remains motionless throughout the cardiac cycle. The sounds of mitral valve closure are best heard during auscultation at this place (apex beat).

Base or Posterior Surface

- It is the fixed part of the heart during cardiac motion.
- It is formed by two atria (2/3 by posterior surface of left atrium and 1/3 by right atrium).
- Posteriorly it is related to the bodies of the vertebrae T6–T9 and is separated from them by right pair of

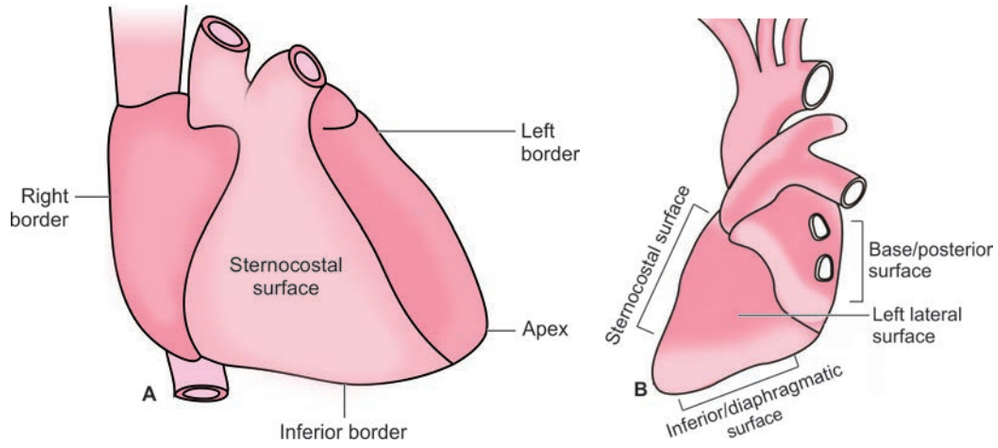


Fig. 43.6: Borders and surfaces of the heart. **A:** Anterior view; **B:** Left lateral view

pulmonary veins, oesophagus, descending thoracic aorta.
- Enlargement of left atrium in mitral stenosis may compress oesophagus and produce difficulty in swallowing.

Sternocostal Surface
- It is formed mainly by right ventricle and also right atrium with its auricle, and part of the left ventricle.
- This surface is related to posterior aspect of the sternum and adjoining costal cartilages (3rd to 6th costal cartilage) but separated by pericardium, anterior margins of lung with pleura.
- Due to the cardiac notch of left lung, lung and pleura do not cover a portion of right ventricle on this surface. This area is called area of superficial cardiac dullness.
- The sternocostal surface presents anterior part of the coronary sulcus and anterior interventricular sulcus (Fig. 43.7A).

Diaphragmatic (Inferior) Surface
- It rests on the central portion of the diaphragm and separates the heart from liver and fundus of stomach.
- The diaphragmatic surface is formed by two ventricles, 2/3rd by left ventricle and 1/3rd by right ventricle.
- This surface is traversed by posterior interventricular sulcus (Fig. 43.7B).

Left Pulmonary Surface
- It is formed by left ventricle and partly by left atrium and its auricle.
- A major part of this surface is related to medial surface of the left lung.

Right Pulmonary Surface
- It is formed by the right atrium.
- It is rounded convex surface related to medial surface of the right lung.

Right Border
- It is vertical and formed by right atrium only.
- It extends from the right side of the superior vena caval orifice to inferior vena caval orifice.
- A shallow sulcus 'sulcus terminalis' runs along the right border.
- The right border separates sternocostal surface from the base of the heart. This border is closely related to right pericardiophrenic vessels.

Inferior Acute Border
- It is horizontal formed mainly by right ventricle and partly by left ventricle.
- This border extends from inferior vena caval orifice to apex of the heart.
- Inferior border separates diaphragmatic surface from the sternocostal surface.

Left obtuse border
- It is ill defined and extends from apex of the heart to the left auricle.
- It is formed by left ventricle and partly by left auricle.
- Left border separates sternocostal surface from left surface.

Upper Border
It is formed mainly by left atrium.

Coronary Sulcus
- The atria are separated from ventricles externally by atrioventricular groove or coronary sulcus.
- The right anterior coronary sulcus extends downwards and is occupied by right coronary artery.

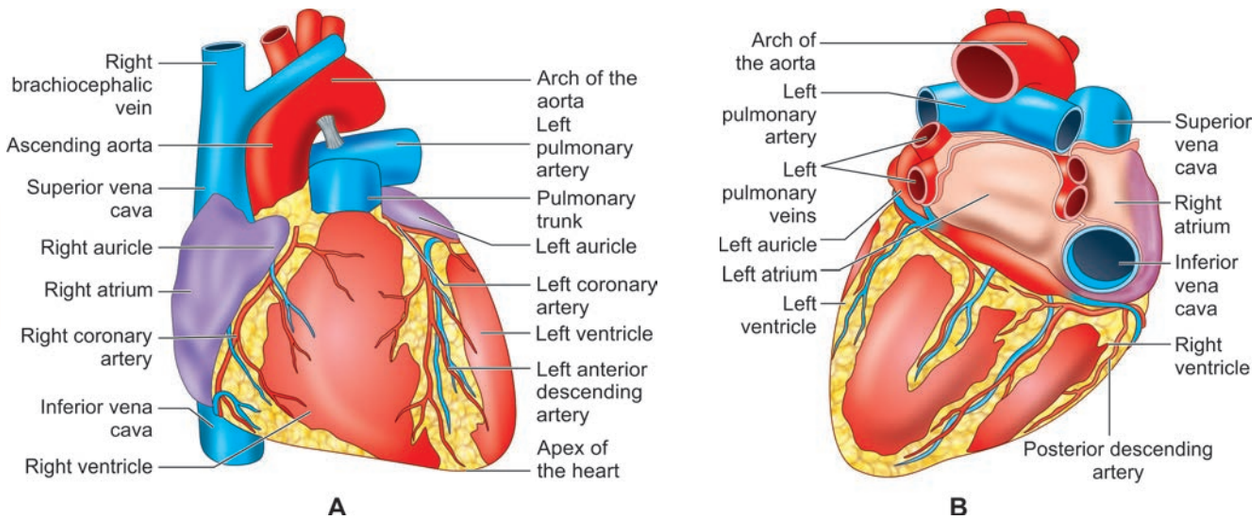


Fig. 43.7: External features of the heart (schematic). **A:** Sternocostal surface; **B:** Base and diaphragmatic surface

- The left anterior coronary sulcus intervenes between left auricle and left ventricle and is occupied by circumflex branch of left coronary artery and great cardiac vein.
- The posterior part of the coronary sulcus intervenes between base of the heart and its diaphragmatic surface. On the left side, it is occupied by coronary sinus and circumflex artery and on right side by right coronary artery and small cardiac vein.
- The right and left ventricles are separated externally by anterior interventricular sulcus (on sternocostal surface) and posterior interventricular sulcus (on diaphragmatic surface). They are occupied by anterior and posterior interventricular arteries respectively.

Crux of the Heart

It is the meeting point of posterior interventricular, atrioventricular and interatrial grooves.

Surface Marking of the Heart

The outline of the heart can be marked by connecting the following points (Fig. 43.8):

Apex: A point 9 cm away from midline in the left 5th intercostal space.

Right margin: A point at the lower part of right 2nd intercostal space close to sternum to a point at right 6th costal cartilage, 1–2 cm from sternal margin.

Inferior margin: A point from right 6th costal cartilage to apex of the heart.

Left margin: A point from the apex of the heart to a point on the left 2nd intercostal space 1–2 cm lateral to the sternal margin.

Superior margin: It is marked by connecting the upper part of right and left margins.

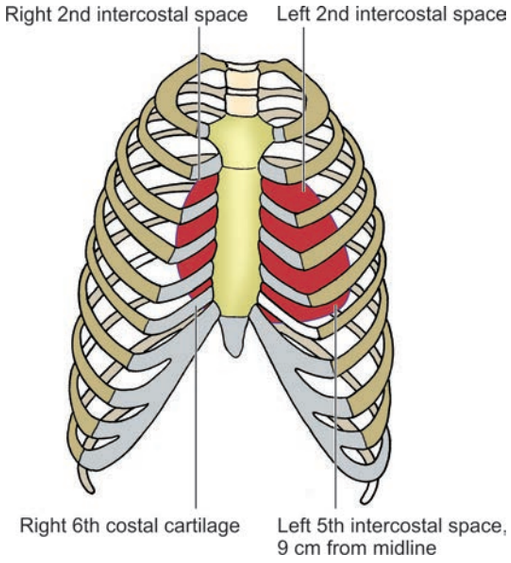


Fig. 43.8: Surface marking of the heart

Chambers of the Heart

The human heart consists of four chambers—two atria and two ventricles. The two atria are thin-walled chambers that receive blood from the veins. The two ventricles are thick-walled chambers that forcefully pump blood out of the heart. The atria are placed superior to the ventricles, and they are little posterior to the ventricle when viewed from above. The ventricles are placed inferior to the atria, and they are bit anterior to the atria when viewed from above. The right atrium and right ventricle are placed to the right side of the left atrium and left ventricle respectively and also little anterior to them.

RIGHT ATRIUM

External Features

- It forms the part of sternocostal surface, entire right border and right 1/3rd of the base.
- Right auricle is the conical projection of right atrium towards ascending aorta.
- Sulcus terminalis is a shallow groove, which extends from superior vena caval orifice to inferior vena caval orifice. It corresponds to a ridge inside the right atrium called crista terminalis.

Interior of the Right Atrium

The cavity of the right atrium presents three walls (anterior, posterior and septal).

1. Anterior rough wall

- **Crista terminalis** is a smooth muscular ridge, which extends from the upper part of the inter-atrial septum. It passes in front of the superior vena caval orifice and then descends along the right border of the heart (Fig. 43.9). Below it ends by joining with right horn of Eustachian valve (valve guarding IVC orifice). Externally it corresponds to sulcus terminalis.
- Crista terminalis separates anterior rough wall from the posterior smooth wall. Upper part of the crista terminalis lodges sinuatrial node (SA node).
- **Musculi pectinati** (pectinate muscles) are parallelly placed muscular ridges extending from crista terminalis and are directed towards the right atrioventricular orifice (Fig. 43.9).

2. Posterior smooth wall

- It is also called sinus venarum. It presents the following openings for major veins, which bring deoxygenated blood from the body and the heart itself.
- Opening of the superior vena cava—in the upper part.
- Opening of the inferior vena cava—in the lower part. This opening is guarded by a semilunar

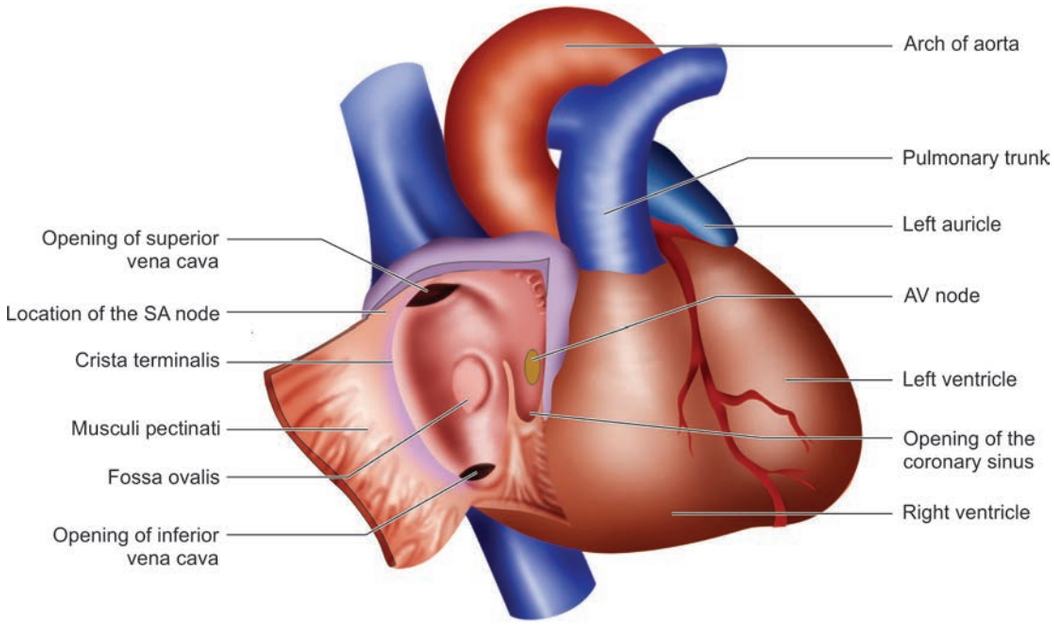


Fig. 43.9: Interior of the right atrium

valve called Eustachian valve which presents right and left horns (Fig. 43.9).

- Opening of coronary sinus: The venous blood from musculature of the heart is drained into coronary sinus which opens into the right atrium between inferior vena caval orifice and right atrio-ventricular orifice.

3. Septal wall

- It separates the right atrium from left atrium, which is placed posteriorly and to the left. It presents the following features when seen from the right atrium (Fig. 43.9).
- **Fossa ovalis**: It is an oval depression. In the foetal life the right and left atria are communicated through a foramen called foramen ovale. This opening is closed immediately after the birth. The depression below this opening forms fossa ovalis.
- **Limbus fossa ovalis**: It is the sharp margin surrounding the fossa ovalis in its upper, anterior and posterior margins.
- **Triangle of Koch**: It is a triangular area behind the septal leaflet of the tricuspid valve and the opening of coronary sinus. The atrioventricular node (AV node) is lodged in this area.
- **Torus aorticus**: It is a bulging produced by the right posterior aortic sinus of the ascending aorta in the septal wall.

Development of the Right Atrium

1. The anterior rough wall is developed from the right half of the primitive atrium.
2. The posterior smooth wall is developed from absorption of body and right horn of the sinus venosus.
3. The fossa ovalis of the septal wall is developed from septum primum and remaining part of the septal wall (including limbus fossa ovalis) is developed from septum secundum.
4. The crista terminalis, valve of IVC and valve of coronary sinus are developed from right venous valve.

Right Atrioventricular Orifice

It is an oval opening communicating right atrium with right ventricle. The blood flows in posteroanterior direction since the plane of the orifice is vertical. This orifice is guarded by a tricuspid valve.

Right Atrioventricular/Tricuspid Valve

- It guards the right atrioventricular orifice (Figs 43.10 and 43.11A).

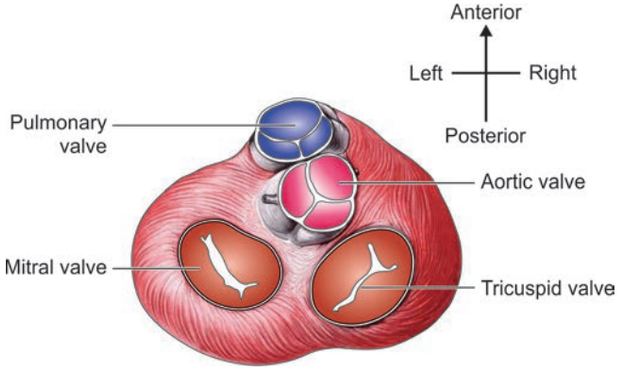


Fig. 43.10: Valves of the heart—superior view

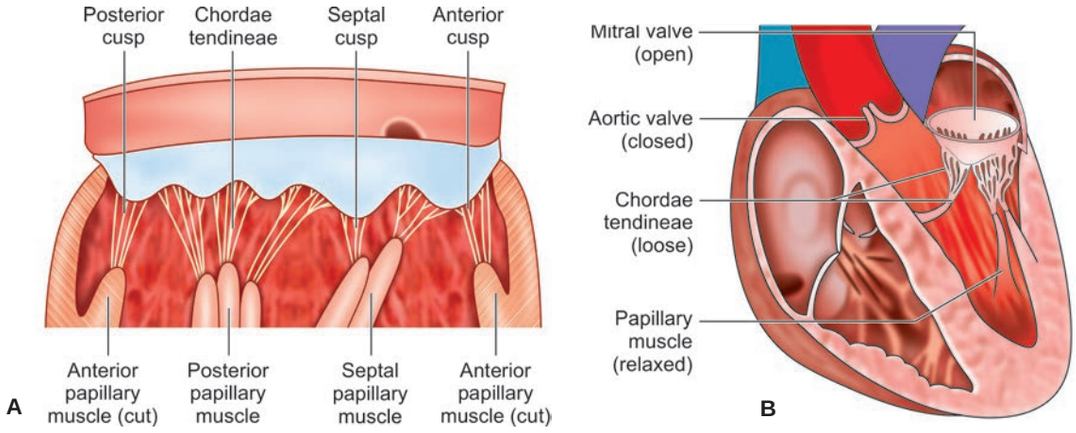


Fig. 43.11A and B: Tricuspid valve viewed after opening the right ventricle and stretching it

- It consists of three cusps or leaflets. They are named anterior, posterior and septal. They are attached to the corresponding sides of the orifice. The other end (free margin) of each cusp extends into the cavity of right ventricle.
- This free margin provides attachments to the chordae tendineae (tendinous cords).
- The chordae tendineae arise from the apical part of the papillary muscles present in the rough part of the right ventricle.
- The papillary muscles contract when rest of the ventricle contracts (during ventricular systole), and they pull on the chordae tendineae to prevent the AV valve from everting. The regurgitation of blood from the right ventricle back into the right atrium is blocked during ventricular systole by the valve cusps (Fig. 43.11B). When the ventricles begin to contract, pressure within the ventricles rises and blood flows toward the area of lowest pressure, which is initially in the atria. This backflow causes the cusps of the tricuspid and mitral (bicuspid) valves to close. During the relaxation phase of the cardiac cycle, the papillary muscles are also relaxed and the tension on the chordae tendineae is less.

RIGHT VENTRICLE

Right ventricle forms sternocostal surface, diaphragmatic surface and inferior border of the heart.

Internal Features

The interior of the right ventricle is semilunar on cross section due to bulging of interventricular septum towards the right ventricular cavity (Fig. 43.12). The interior of the right ventricle consists of two parts:

- Rough inflowing part (ventricle proper)
- Smooth out flowing part (infundibulum)

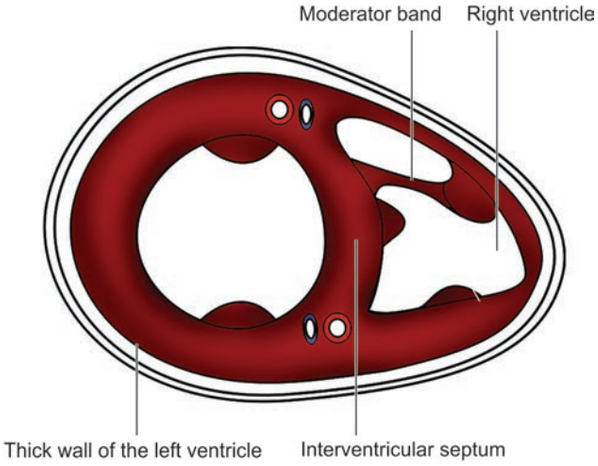


Fig. 43.12: Cross section through ventricles

Rough Inflowing Part

It receives blood from the right atrium. Roughness of this part is due to the presence of muscular ridges called **trabeculae carneae**. Trabeculae carneae are of three types (Figs 43.13 and 43.15).

1. **Ridges:** These are muscular elevations, e.g. supraventricular crest which separates the smooth part from the rough part of the right ventricle.
2. **Bridges:** The two ends are connected to the wall of the ventricle with central free portion, e.g. **septo-marginal trabecula (moderator band)** which extends from the interventricular septum to the base of the anterior papillary muscle. It conveys right branch of the atrioventricular (AV) bundle.
3. **Papillary muscles:** These are conical muscular projections usually three in number (anterior, posterior and septal). The **anterior papillary muscle** is the largest and most prominent. It arises from the anterior wall of the right ventricle and its chordae tendineae are attached to anterior and posterior cusps of the tricuspid valve. The **posterior**

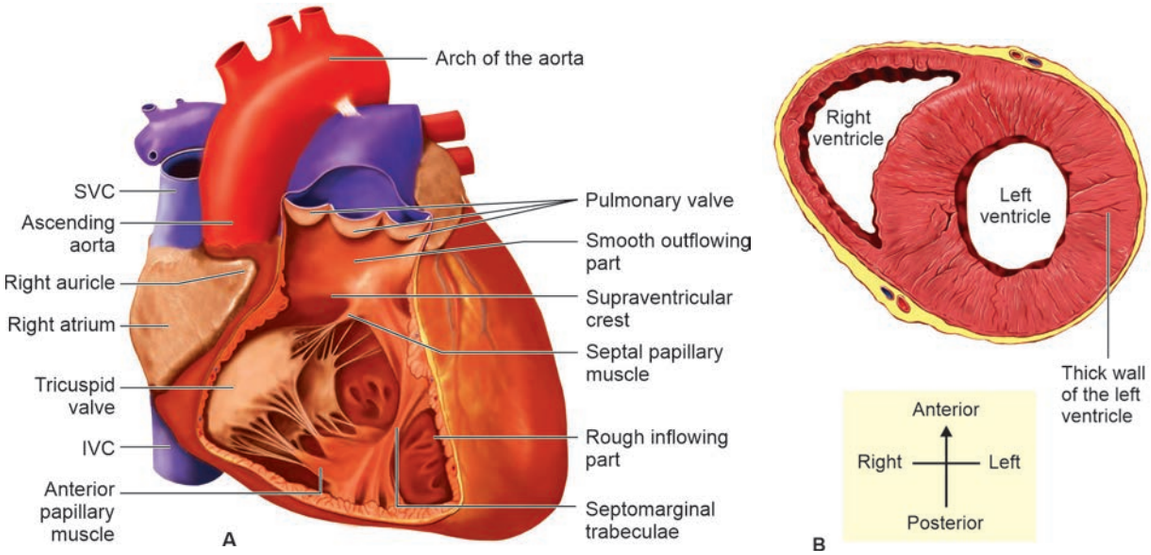


Fig. 43.13: A: Interior of the right ventricle (anterior view); **B:** Cross section through the ventricle

papillary muscle arises from the inferior wall of the right ventricle and its chordae tendineae are attached to posterior and septal cusps. The **septal papillary muscle** arises from interventricular septum and their chordae tendineae are attached to the anterior and septal cusps. The septal papillary muscles are usually divided into several small ridges.

Smooth Outflowing Part (Infundibulum)

The apex of the infundibulum presents pulmonary orifice, which is guarded by three semilunar cusps. The free margins of the cusps are directed into the pulmonary trunk.

The right atrium contracts when the right ventricle is empty and relaxed. The blood that enters the right ventricle takes a U-shaped path to enter the pulmonary trunk. This change in direction is due to the presence of supraventricular crest (which separates smooth and rough part of the right ventricle).

Development of the Left Ventricle

1. The rough inflowing part is developed from right half of the primitive ventricle.
2. The smooth outflowing part is developed from absorption of bulbus cordis.

Pulmonary Valve

It is the most superficial (anterior) and uppermost valve (Fig. 43.10). It has three semilunar cusps (leaflets) which are **left, right and anterior**. There is a thickening in the middle part of the free margins of each cusp called 'nodule'. The margin on either side of the nodule is called 'lunule'. The pulmonary trunk shows a little dilatation above the valve called pulmonary sinus.

Interventricular Septum

- It is a strong obliquely placed partition between right and left ventricles (Fig. 43.12).
- It has muscular (rough) and membranous (smooth) parts. The muscular part is rough due to trabeculae carneae.
- Posterosuperiorly the partition between the two ventricles is formed by a thin membrane called pars membranacea septi (membranous part).
- The septal leaflet of the tricuspid valve is attached to the middle of the membranous part on its right surface dividing them into superior and inferior parts.
- The inferior part is 'interventricular' separating right and left ventricles.
- The superior part is 'atrioventricular' separating right atrium from the left ventricle.
- The anterior 2/3rds of the septum is supplied by anterior interventricular artery (branch of left coronary artery) and posterior 1/3rd by posterior interventricular artery (branch of right coronary artery).
- The membranous part presents an AV bundle, and the muscular part has right and left terminal branch of the AV bundle.
- The muscular part is developed from primitive interventricular septum. The membranous part is developed from proliferation of AV cushion (the posterior atrioventricular part) and proximal bulbar septum (the anterior interventricular part).

LEFT ATRIUM

It is situated posteriorly and to the left of right atrium. It forms the base and part of left surface and left border

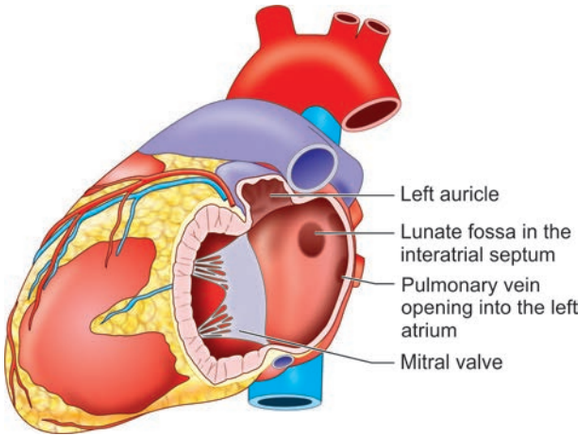


Fig. 43.14: Interior of the left atrium (lateral view)

of the heart. Left auricle is the projection of left atrium towards the root of pulmonary trunk.

Interior of the Left Atrium

- The wall of the left atrium is slightly thicker than that of the right atrium.
- A major part of the interior is smooth except at the auricle, which presents musculi pectinati. The posterior wall of the left atrium receives the openings of four valveless pulmonary veins (Fig. 43.14).
- Anteriorly, it communicates with left ventricle through left atrioventricular orifice, which is guarded by mitral valve.
- The septal wall separating it from the right atrium presents a lunate fossa corresponding to the fossa ovalis (of the right atrium).

LEFT VENTRICLE

It forms the sternocostal, diaphragmatic and left surfaces and left border of the heart. The apex of the heart is formed by left ventricle. The wall of the left ventricle is three times thicker than that of right ventricle to pump the oxygenated blood to all parts of the body.

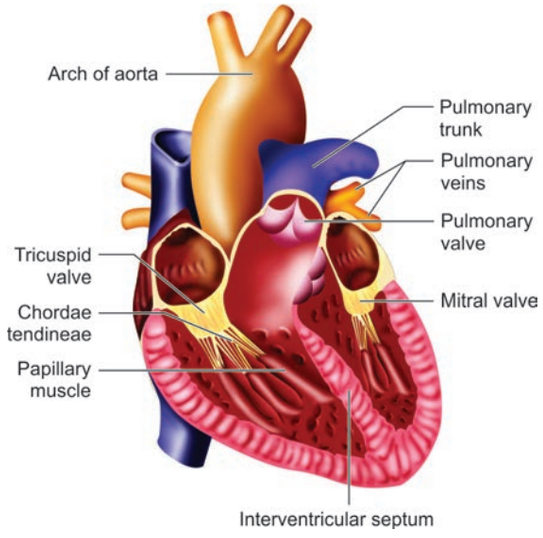


Fig. 43.15: Coronal section through the heart

Interior of the Left Ventricle

- The interior is circular in cross section due to bulging of the interventricular septum towards the cavity of right ventricle (Fig. 43.13B).
- The interior of the left ventricle also presents an inflowing rough part and a smooth outflowing part.
- The rough inflowing part presents left atrioventricular orifice with mitral valve and trabeculae carneae.
- The trabeculae carneae are finer and more numerous than those of the right ventricle. It presents anterior and posterior papillary muscles (Fig. 43.15).
- The outflowing part of the left ventricle is called **aortic vestibule**, leading to aortic orifice.
- The summit of the vestibule presents three semilunar cusps (aortic valve). Above the cusps the wall of the ascending aorta presents three dilatations called aortic sinuses.

Left Atrioventricular/Bicuspid/Mitral Valve

- It consists of two cusps anterior and posterior.
- These cusps are attached to the margin of left atrioventricular orifice. Their free ends provide attachment to the chordae tendineae. These chordae tendineae arise from papillary muscles present in the left ventricle.
- The cords become taut just before and during systole, preventing the cusps from being forced into the left atrium.
- The mitral valve is most strained because it must resist the powerful contraction of left ventricle. Therefore, it is often involved in valve disorders.

Aortic Valve

The aortic valve also presents three semilunar cusps (leaflets) which are named as **left, right and posterior** (Fig. 43.16). The aortic valve is stronger than pulmonary valve. It also presents 'nodule' and 'lunule' on their free surface. At the level of the cusps, the aorta shows dilatation called aortic sinuses and they are also named according to their position, anterior, right posterior and left posterior. The anterior aortic sinus gives origin to right coronary artery and left posterior aortic sinus gives origin to left coronary artery. The right posterior aortic sinus will not give origin to any coronary artery and is called **noncoronary** which produces a bulge in the right atrium called **torus aorticus**.

When the two atria contract, the tricuspid and mitral valves open, which both allow blood to move to the

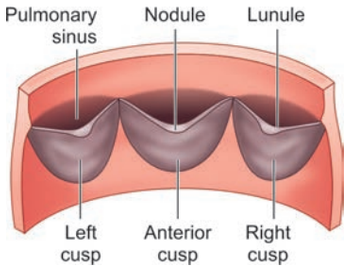


Fig. 43.16: Aortic valve viewed after opening the ascending aorta and stretching it

ventricles. When the two ventricles contract, they force the tricuspid and mitral valves to close as the pulmonary and aortic valves open.

The cardiac cycle begins with atrial systole, the sequential activation and contraction of the two atria. The atrial systole is followed by the delayed ventricular contraction (termed ventricular systole). During ventricular contraction, the atria relax (atrial diastole) and receive venous return from both the body and the lungs. Then, in ventricular diastole, the ventricles relax, allowing initial passive filling of the thick-walled ventricles and emptying of the atria. Later, during the terminal period of ventricular relaxation, the atria contract. This atrial systole augments ventricular filling just before the onset of the next ventricular contraction.

Surface Markings of the Valves/Orifice

Pulmonary orifice: Draw 2.5 cm transverse line partly behind the left 3rd costal cartilage and partly behind the adjacent left half of sternum.

Aortic orifice: Draw oblique line, 2.5 cm long behind the left half of the body of sternum at the level of 3rd intercostal space.

Mitral orifice: Draw 3 cm long oblique line behind the left half of the sternum opposite the left 4th costal cartilage.

Tricuspid orifice: Draw 4 cm long line vertically behind the right half of the sternum opposite the 4th intercostal space.

Areas of Auscultation of Cardiac Valves

1. **Pulmonary valve:** Second intercostal space to the left of the sternum.
2. **Aortic valve:** Second intercostal space to the right of the sternum.
3. **Tricuspid valve:** Left 4th intercostal space.
4. **Mitral valve:** Left 5th intercostal space 9 cm away from midline/little medial to the right midclavicular line (apex of the heart) (Fig. 43.17).

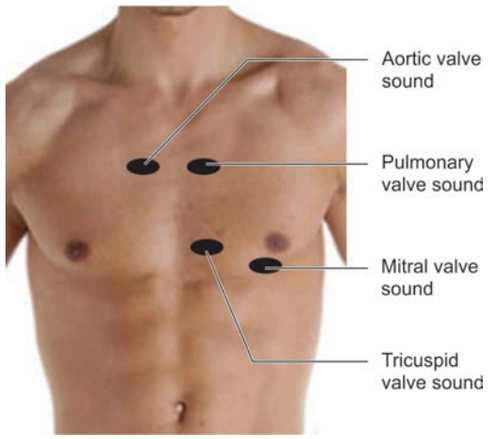


Fig. 43.17: Auscultation area of cardiac valves

Clinical Notes

Movements of cardiac valves during cardiac cycle

Cardiac cycle includes cyclical events of contraction and relaxation of atria and ventricles in the form of systole and diastole respectively.

Atrial systole: Blood flows from atria to ventricle by atrial contraction, but ventricular filling is primarily passive (because during atrial systole, the ventricle is in the phase of diastole with reduced intraventricular pressure).

Atrial diastole: It appears after systole.

Ventricular systole: It starts after atrial contraction. The papillary muscle contracts first by tightening the chordae tendineae and drawing the cusps of AV valve together in order to close the mitral and tricuspid valves (first heart sound) where ventricular pressure exceeds atrial pressure. This is followed by contraction of the rest of the ventricular muscles, which causes the semilunar valves to open (when ventricular pressure exceeds diastole pressure in pulmonary trunk and ascending aorta). The later part of the ventricular systole is called ejection period.

Ventricular diastole: It begins after ventricular systole when the ventricle pressure begins to fall sharply but the semilunar valves are still open. This allows the backflow of blood from aorta and pulmonary trunk to close the semilunar valves by elastic recoil of the vessels. This produces the second heart sound and records the diastolic pressure.

Radiological Anatomy of the Heart (PA View)

In a PA chest X-ray, following features of the heart need to be identified (Fig. 43.18):

- Cardiac shadow of a normal sized heart is equal to half the diameter of the chest. When it exceeds this ratio (1:2), it is suggestive of cardiac enlargement.
- Right margin of cardiac shadow is formed by SVC, right atrium and, IVC.

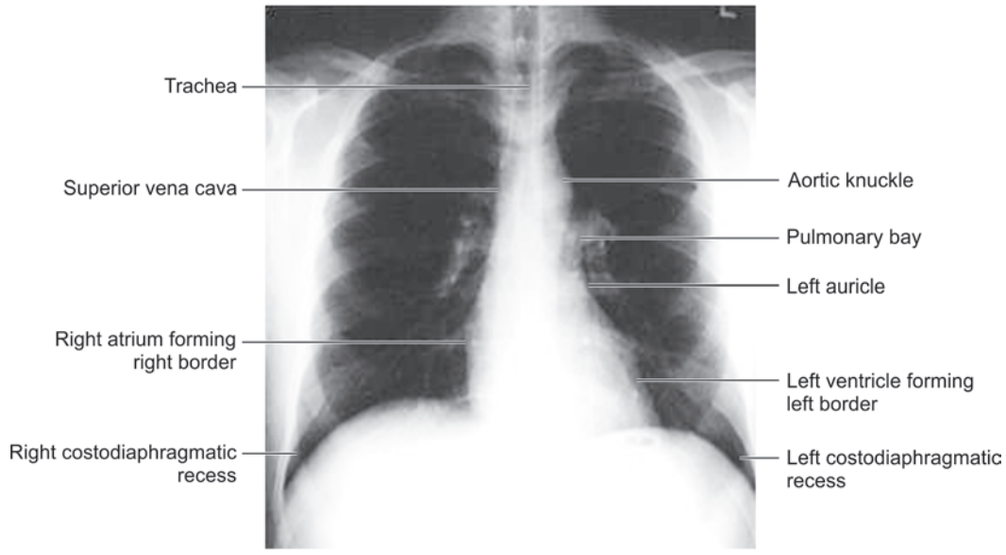


Fig. 43.18: Chest radiograph (PA view)

- Left margin of cardiac shadow is formed by aortic knuckle (produced by arch of aorta), pulmonary bay, left auricle and left ventricle.
- **Aortic knuckle:** Aortic knuckle or knob is formed by the posterior part of the arch of the aorta protruding from the mediastinum in radiograph of the chest. It may be indistinct in young people and very prominent in older people. Below the aortic knuckle is the air space called aortopulmonary window. Failure to identify this clear space indicates the pathology.
- The aortic window is a normally radiolucent region below the aortic arch. It is formed by the bifurcation of the trachea and traversed by the left pulmonary artery. It is visible in the left anterior oblique radiograph of the heart and great vessels.

Echocardiography (ECHO) is a method by which the position and motion of the heart is recorded. Pericardial effusion can be detected by this technique. Doppler echocardiography is a technique that demonstrates and records the flow of blood through the heart. This is very useful in diagnosis and analysis of problems with blood flow through the heart, such as septal defects, valvular stenosis and regurgitation. However, it is not possible to properly visualize the structures at the base of the heart in ECHO, this drawback is overcome by the transoesophageal echography.

Valvular heart diseases: The defect and dysfunctions of the valves will interfere with pumping efficiency of the heart. The valvular heart disease produces either stenosis (narrowing) or insufficiency.

a. Stenosis is a failure of a valve to **open fully**, slowing the blood flow from a chamber.
b. Insufficiency (or regurgitation) is failure of valve to **close completely**. It occurs due to structural changes in the valve (nodule formation on the edges of the cusps). It leads to regurgitation of the blood back into the chambers from which it was just ejected.

Both stenosis and regurgitation result in increased workload for the heart and produce turbulence in blood flow. This turbulence results in vibrations which are audible as murmurs.

Clinically the valvular dysfunction may be insignificant in some cases, but in others it may be severe and fatal. The valvular diseases may be congenital or acquired. The diseases of the valves of the heart usually arise from the history of rheumatic fever in childhood. Damaged or defective cardiac valves can be repaired or replaced by artificial valves (made up of synthetic material).

Mitral valve insufficiency (regurgitation/ incompetence): The mitral valve fails to close during systole and the blood regurgitates into the left atrium. So, during diastole there is an overfilling left ventricle. Eventually it leads to enlargement of the left ventricle and left ventricular failure.

It is caused by various mechanisms related to structural or functional abnormalities of the mitral valve, adjacent myocardium, or both. Significant mitral valve regurgitation occurs in about 2% of the population with a similar prevalence in males and females.

Patients with chronic, severe mitral regurgitation may remain asymptomatic for years because the regurgitant volume load is well tolerated because of compensatory ventricular and atrial dilation.

When symptoms do develop, the most common are dyspnea, fatigue, paroxysmal nocturnal dyspnea, and palpitations caused by atrial fibrillation. The chest radiograph demonstrates left atrial enlargement and cardiomegaly.

Patients with mitral stenosis may present with exertional dyspnea, fatigue, atrial arrhythmias, angina-like chest pain, hemoptysis, or even right-sided heart failure.

On chest radiography, the characteristic findings of mitral stenosis are pulmonary congestion, enlargement of the main pulmonary arteries, and enlargement of the left atrium without cardiomegaly.

Mitral valve stenosis: Mitral valve stenosis refers to narrowing of the mitral valve orifice, resulting in impedance of filling of the left ventricle in diastole. It is usually caused by rheumatic heart disease during childhood.

Patients with mitral valve stenosis typically present it more than 20 years after an episode of rheumatic fever.

Patients with mitral stenosis may present with exertional dyspnea, fatigue, atrial arrhythmias, angina-like chest pain, hemoptysis, or even right-sided heart failure.

On chest radiography, the characteristic findings of mitral stenosis are pulmonary congestion, enlargement of the main pulmonary arteries, and enlargement of the left atrium without cardiomegaly.

An electrocardiogram (ECG) may reveal evidence of left atrial enlargement, atrial fibrillation or, in advanced disease, right ventricular hypertrophy consistent with pulmonary hypertension.

The enlarged left atrium may compress oesophagus causing dysphagia and on left recurrent laryngeal nerve (hoarseness of voice).

The embolic event of mitral stenosis: The stasis of the blood in the left auricle encourages clot formation. The detached clots form emboli, enter the left ventricle, ascending aorta then into circulation and cause various types of problems depending on sites blocked. It can cause gangrene of lower limb (due to occlusion of femoral artery) or myocardial infarction (due to occlusion of coronary artery) or stroke (occlusion of cerebral artery) or renal infarct (due to occlusion of segmental branch of renal artery).

Aortic valve insufficiency (regurgitation/ incompetence): Aortic regurgitation is incompetence or insufficiency of aortic valve that allows the blood to flow back into the left ventricle. The cusps are unable to close properly due to structural changes. The left ventricle has to repump the blood with every heartbeat, leading to an increased workload and **enlargement of left ventricle.**

Aortic valve stenosis: The aortic stenosis is abnormal narrowing of the aortic valve. It is the most common valve abnormality. It usually arises from the history of rheumatic fever in childhood. Aortic stenosis causes extra work for the heart and causes **enlargement of the left ventricle**. The signs and symptoms include angina (chest pain), fainting (syncope) and shortness of breath (associated with exertion or excitement).

Pulmonary valve insufficiency (regurgitation/ incompetence): The structural changes in the pulmonary valves (becoming thick) or damage by disease, cause incomplete closure of this valve. It results in backward flow of blood into the right ventricle **during diastole.** Mild cases usually do not cause any symptoms, but severe regurgitation may contribute to **right ventricular hypertrophy,** and in later stages, right heart failure.

Pulmonary valve stenosis: Pulmonary stenosis is narrowing of the pulmonary outflow tract causing obstruction of blood flow from the right ventricle to the pulmonary artery **during systole.** Most cases are congenital; many remain asymptomatic until adulthood. When symptoms develop, they resemble those of aortic stenosis (syncope, angina, dyspnea) and can cause variable degree of right **ventricular hypertrophy.**

Structure of the Heart

Heart consists of three coats from outside to inside—epicardium, myocardium and endocardium.

1. **Epicardium:** It is a thin outer covering (mesothelium) derived from the visceral layer of serous pericardium.
2. **Myocardium:** It is made up of cardiac muscles, which present striations with centrally placed nucleus. The muscle fibres branch and anastomose with adjacent fibres. Intercalated discs connect the adjacent muscle cells (myocytes). Some of the cardiac muscle fibres are specialized to form **Purkinje fibres**, which constitute the conducting system of the heart (for further detail *refer* to histology of cardiac muscle in Chapter 10).
   The wall of the ventricle is thicker than that of the atria. The cardiac muscle fibres are anchored to the **fibrous skeleton of the heart.**
3. **Endocardium:** It is the lining endothelial cells of the chambers.

Fibrous Skeleton of the Heart

The fibrous skeleton of the heart provides attachment of atrial and ventricular musculature and supports the valves of the heart (keep them competent). The continuity between atrial and ventricular musculature is disturbed by the fibrous skeleton, hence propagation of impulses from atria to ventricle (SA node to AV

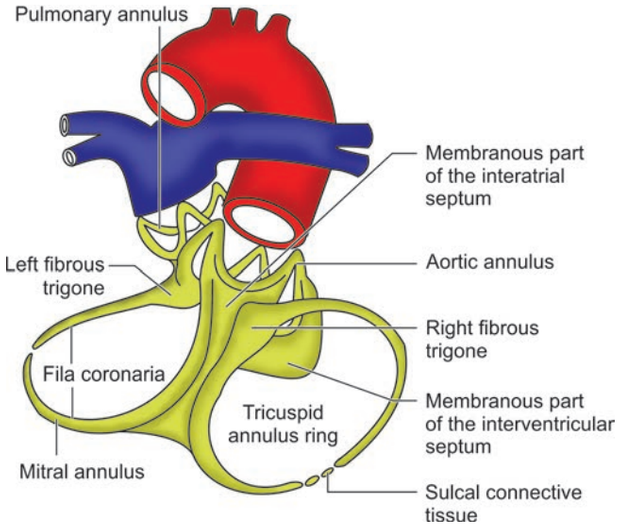


Fig. 43.19: Skeleton of the heart

node) is by specialized conducting system of the heart (Fig. 43.19).

The skeleton consists of four fibrous rings (or annulus) at right and left atrioventricular orifices, pulmonary and aortic orifices.

- The pulmonary annulus is the anterior most, while aortic annulus is placed behind and little to the right of the pulmonary annulus.
- These two annuli are connected by a fibrous structure called tendon of infundibulum.
- The right (tricuspid) and left (mitral) atrioventricular annuli are placed further behind the aortic annulus. The right and left atrioventricular annuli are connected by a fibrous structure called trigonum fibrosum dextrum. The left margin of the trigonum connects mitral annulus with aortic annulus called trigonum fibrosum sinistrum.
- The left bottom of the aortic annulus forms a left fibrous trigone, which gives attachment to the anterior filum coronarium of the mitral annulus. The right bottom of the aortic annulus forms right fibrous trigone, which provides attachment to posterior filum coronarium of the mitral annulus. Thus, the mitral annulus is formed by anterior and posterior fila coronaria and the gap between their ends is connected by sulcal connective tissue.
- The tricuspid annulus is also made up of anterior and posterior fila coronaria and sulcal connective tissue. These fila coronaria are connected to right fibrous trigone (central fibrous body).

CASE 2

A 40-year-old woman visits hospital with complaints of shortness of breath and fatigue. Her history is unremarkable except for a vague history of fever and joint pain as a child. On examination, her heart rate is 120 beats/min, and the rhythm has no discernible pattern (irregularly irregular). Auscultation of the heart indicates a systolic murmur (during left ventricular ejection of blood) that is harsh in character. It is diagnosed as atrial fibrillation due to left atrial enlargement. It was due to mitral stenosis due to rheumatic heart disease.

1. Name the cardiac valves and give their surface markings.
2. Give the surface markings of auscultation area of each cardiac valve.
3. Give an account of structure and functions of valves of the heart.

Answers to the clinical case studies

Case 1

1. Refer the clinical anatomy section
2. Globular shadow
3. The safest site at which to insert the needle of the syringe in order to miss the pleura would be just to the left of the xiphisternal junction.

Case 2

1), 2) and 3). Refer to text.

MCQs

1. Which of these structures is located at the junction of the superior vena cava and right atrium?
A. SA node B. AV node
C. AV bundle D. Right bundle branch

2. In which of the following locations the AV bundle is located?
A. Right atrium
B. Left atrium
C. Interatrial septum
D. Membranous interventricular septum

3. Which chamber of the heart mainly contributes to its sternocostal surface?
A. Left atrium B. Left ventricle
C. Right atrium D. Right ventricle

4. A patient involved in an automobile accident presents with a sharp object penetrating the middle of the sternum at about the level of the 4th or 5th costal cartilage. If the object also penetrated pericardium and wall of the heart, which heart chamber would most likely be damaged?
A. Left atrium B. Left ventricle
C. Right ventricle D. Right atrium

5. A 23-year-old male injured in an industrial explosion was found to have multiple small metal fragments in his thoracic cavity. Since the pericardium was torn, the surgeon began to explore for fragments in the pericardial cavity. Moving his hand under the apex of the heart, he slid his fingers upward and to the right within the sac until they were stopped by the cul-de-sac formed by the pericardial reflection near the base of the heart. His fingertips were in which of these locations?
A. Coronary sinus B. Oblique sinus
C. Coronary sulcus D. Costomediastinal recess

6. During cardiac surgery, it is sometimes necessary to clamp off all arterial flow out of the heart. This could be done within the pericardial sac by inserting the index finger immediately behind the two great arteries and compressing them with the thumb of the same hand. The index finger would have to be inserted into which space?
A. Cardiac notch
B. Coronary sinus
C. Oblique pericardial sinus
D. Transverse pericardial sinus

7. During a heart transplant procedure, the surgeon inserted his left index finger through the transverse pericardial sinus, and then pulled forward on the two large vessels lying ventral to his finger. Which vessels were these?
A. Pulmonary trunk and brachiocephalic trunk
B. Pulmonary trunk and ascending aorta
C. Pulmonary trunk and superior vena cava
D. Superior vena cava and aorta

8. A stethoscope placed over the left second intercostal space just lateral to the sternum would be best positioned to detect sounds associated with which heart valve?
A. Aortic
B. Pulmonary
C. Mitral
D. Tricuspid

9. A 3rd-year medical student was doing her first physical exam. In order to properly place her stethoscope to listen to heart sounds, she palpated bony landmarks. She began at the jugular notch, then slid her fingers down to the sternal angle. At which rib (costal cartilage) levels were her fingers?
A. 1
B. 3
C. 2
D. 4

10. In which of these locations, the heart sound associated with the mitral valve is best heard?
A. In the jugular notch
B. In the second left intercostal space
C. In the second right intercostal space
D. In the left fifth intercostal space

11. Which heart valve has leaflets described as "anterior, left and right"?
A. Aortic
B. Pulmonary
C. Left atrioventricular
D. Right atrioventricular

12. In preparation for thoracic surgery, a median sternal splitting procedure was carried out. But an improper depth setting on the saw blade resulted in a slight nick on the underlying sternocostal surface of the heart. Which heart chamber would most likely have been opened had the blade completely penetrated this wall?
A. Left atrium
B. Left ventricle
C. Right atrium
D. Right ventricle

13. The sound associated with tricuspid stenosis (narrowing) would be best heard at which location on the anterior chest wall?
A. Below the left nipple
B. In the right 2nd intercostal space near the sternum
C. Over the apex of the heart
D. Left 4th intercostal space

14. Which of the following structures does NOT lie in the coronary sulcus?
A. Circumflex artery
B. Coronary sinus
C. Right coronary artery
D. Right marginal artery

15. Which of the following posterior mediastinal structures is most closely related to the posterior surface of the pericardial sac?
A. Aorta
B. Azygos vein
C. Oesophagus
D. Thoracic duct

16. While listening to a patient's heart sounds with a stethoscope, you identify a high-pitched sound in the second right intercostal space, just lateral to the edge of the sternum. Your correct conclusion is that you have detected stenosis of which heart valve?
A. Aortic
B. Mitral
C. Pulmonary
D. Tricuspid

17. Which of these structures is least likely to be penetrated by a needle while performing a pericardiocentesis?
A. Endothoracic fascia
B. The aponeuroses of the external and internal oblique muscles
C. The left parietal and visceral layers of pleura
D. The rectus abdominis muscle

18. A patient is brought to the emergency room after having been stabbed. He has suffered a penetrating wound in the left fourth intercostal space immediately lateral to the sternal border. Which of the following thoracic structures is most likely to have been injured?
A. Left atrium
B. Left ventricle
C. Right atrium
D. Right ventricle

19. A 35-year-old woman suffers severe chest trauma. She is unconscious and her blood pressure is substantially decreased. She has sustained a tear in one of the pulmonary veins at the point at which the vein enters the heart. Into which of the following spaces is the patient bleeding?
A. Between the epicardium and the parietal pericardium
B. Between the fibrous pericardium and the parietal pleura
C. Between the myocardium and the epicardium
D. Between the parietal pericardium and the fibrous pericardium

20. In reviewing a lateral projection of a barium swallow of a patient, a physician notes that the anterior wall of the oesophagus is compressed by an enlarged structure immediately anterior to it. Which of these structures is most likely compressing the oesophagus?
A. Right ventricle
B. Left ventricle
C. Right auricular appendage
D. Left atrium

21. A patient has been admitted to the hospital after suffering from a knife wound of the chest just to the left of the sternum. He is slightly cyanotic, and there is a distension of veins of the neck during inspiration. You suspect that the patient has a cardiac tamponade and order a pericardiocentesis. What is the last tissue layer that the needle must traverse in order to reach the accumulating blood?
A. Epicardium
B. Fibrous pericardium
C. Mediastinal pleura
D. Parietal layer of serous pericardium

ANSWERS TO MCQs

1. A	2. D	3. D	4. C	5. B
6. D	7. B	8. B	9. C	10. D
11. A	12. D	13. D	14. D	15. C
16. A	17. C	18. D	19. A	20. D
21. D				

JUST BEFORE THE EXAM

Pericardium → Outer fibrous pericardium and inner serous pericardium. Serous pericardium → Outer parietal layer + Inner visceral layer with pericardial cavity in between them.

Sinuses of the pericardium → **Transverse sinus** → Posterior to the ascending aorta and pulmonary trunk and anterior to the left atrium. **Oblique sinus** → Part of the pericardial cavity behind the left atrium.

Nerve supply to the pericardium → Fibrous and parietal layer of the serous pericardium is supplied by phrenic nerve and is sensitive to the pain while visceral pericardium is supplied by autonomic nerves.

Heart external features → The heart consists of base (left atrium and partly right atrium) on the posterior aspect, apex (left ventricle) on the anteroinferior aspect.

Sternocostal surface → By right ventricle and partly by right atrium and left ventricle; **Left surface** → By left ventricle; **Diaphragmatic surface** → By left ventricle and partly right ventricle on the inferior aspect which rests on the diaphragm.

Right border → It is vertical, exclusively formed by right atrium. It extends from superior vena caval orifice to inferior vena caval orifice and marked by sulcus terminalis. **Inferior border** → It is almost horizontal, formed by right ventricle and left ventricle. It extends from inferior vena caval orifice to apex of the heart. **Left border** → is formed by the left ventricle, and it separates sternocostal surface from left surface.

Coronary sulcus → Atria are separated from the ventricles by coronar sulcus which are occupied by coronary vessels.

Interior of the right atrium → It presents 3 walls (anterior, posterior and septal); **a. Anterior wall** → Rough because of pectinate muscles which arise from the crista terminalis. The crista terminalis extends from upper part of the inter atrial septum, crosses in front of the superior vena caval orifice and then descends on the right side up to the inferior vena caval orifice. It corresponds to sulcus terminalis present externally. The SA node is located in the upper part of the crista terminalis. **b. Posterior wall** → Smooth and is referred as sinus venarum. It presents 3 openings—openings of superior vena cava, inferior vena cava with a valve and opening of the coronary sinus with a valve. **c. Septal wall** → It separates the right atrium from the left atrium. It presents an oval depression called fossa ovalis. The margin of the fossa ovalis is called limbus fossa ovalis. The lower part of the interatrial septum presents an area called triangle of Koch in which the AV node is located.

Right atrioventricular orifice → Right atrium opens into the right ventricle through right atrioventricular orifice which is guarded by tricuspid valve.

Interior of the right ventricle → Rough inflowing part, which is because of presence of ridges, bridges (moderator band/septomarginal trabecula) and three papillary muscles (anterior, posterior and septal). The apical part of the papillary muscles presents chordae tendineae which are attached to the cusps of the tricuspid valve. Smooth outflowing part of the right ventricle is called infundibulum. It continues with pulmonary trunk. The apex of the infundibulum presents pulmonary orifice which is guarded by three semilunar cusps of the pulmonary valve.

Left atrium → Interior of the left atrium is smooth except left auricle which presents pectinate muscles. The left atrium receives 4 pulmonary veins. Posteriorly the left atrium is related to oblique sinus of the pericardium and the oesophagus.

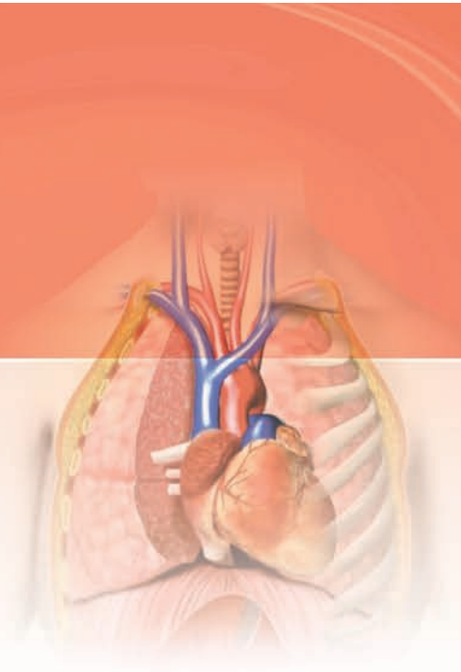
Left atrioventricular orifice → The left atrium opens into the left ventricle through left atrioventricular orifice, which is guarded by bicuspid/mitral valve.

The wall of the left ventricle is 3 times thicker than that of the right ventricle, because it has to pump blood to all parts of the body. The interventricular septum bulges towards the cavity of the right ventricle, hence its cavity of the left ventricle is circular in shape in cross section image.

Interior of the left ventricle → Rough inflowing parts (ridges, bridges and 2 papillary muscles) and a smooth outflowing part called aortic vestibule. The aortic vestibule continues as ascending aorta. The vestibule presents aortic orifice at its apex which is guarded by semilunar aortic valve.

Membranous part of the interventricular septum → The upper part of the interventricular septum is called membranous part which lodges the AV bundle.

Auscultation area of cardiac valves → Pulmonary valve sound is heard at left second intercostal space close to the sternum. **Aortic valve** sound is heard at the right second intercostal space to the right of the sternum. **Tricuspid valve** sound is heard at left 4th intercostal space and **mitral valve** sound is heard at left 5th intercostal space about 9 cm away from the anterior midline (apex of the heart).



Chapter

44

Blood and Nerve Supply to the Heart

Competencies: AN 22.3, 22.4, 22.5, 22.7

Objectives

- To describe the origin, course, branches and distribution of right and left coronary arteries and their clinical relevance
- To describe the arterial supply to the different parts of the conducting system of the heart and its clinical relevance
- To describe the venous drainage of the heart
- To describe the source of sympathetic and parasympathetic nerve supply to the heart and to list the effect of their stimulation on heart function
- To trace the pain pathway from the heart to the spinal cord and to explain the anatomical basis of referred pain
- To know the clinical methods employed in identifying the coronary obstruction and methods to restore the coronary circulation

BLOOD SUPPLY TO THE HEART

Arterial Supply

The blood within the chambers of the heart will only supply the endocardium and subendocardial tissue. The thick musculature of the heart needs an additional source of arterial supply. Heart is supplied by right and left coronary arteries (Figs 44.1 and 44.2).

1. Right Coronary Artery

Origin

It arises from anterior aortic sinus of the ascending aorta.

Course

a. The artery appears between right auricle and pulmonary trunk and passes into right anterior coronary sulcus.

b. It descends obliquely downwards towards lower part of the right border and curves around this border to enter the right posterior coronary sulcus. The course of the artery up to this point is referred as first segment.

c. It reaches the crux and ends a little to the left of the crux by anastomosing with a circumflex branch of the left coronary artery. This part of the artery (in the right posterior coronary sulcus) is referred as second segment.

Branches

1. **Right conus artery**
   It forms an arterial circle around the pulmonary trunk by anastomosing with a similar branch from the left coronary artery. This arterial circle is called **annulus of Vieussens**.
2. **Atrial branches**
   They are classified into anterior, lateral and posterior groups. One of the anterior atrial branches is called **artery to the sinuatrial node**. This nodal branch forms a loop at the base of the superior vena cava and gives a prominent branch called ramus cristae terminalis, which traverses and supplies the SA node.
3. **Ventricular branches**
   These arteries are classified into anterior and posterior groups. The anterior group traverses the sternocostal surface and posterior group traverses the diaphragmatic surface.
4. **Right marginal artery**
   This branch arises when right coronary artery crosses the right border of the heart. This marginal

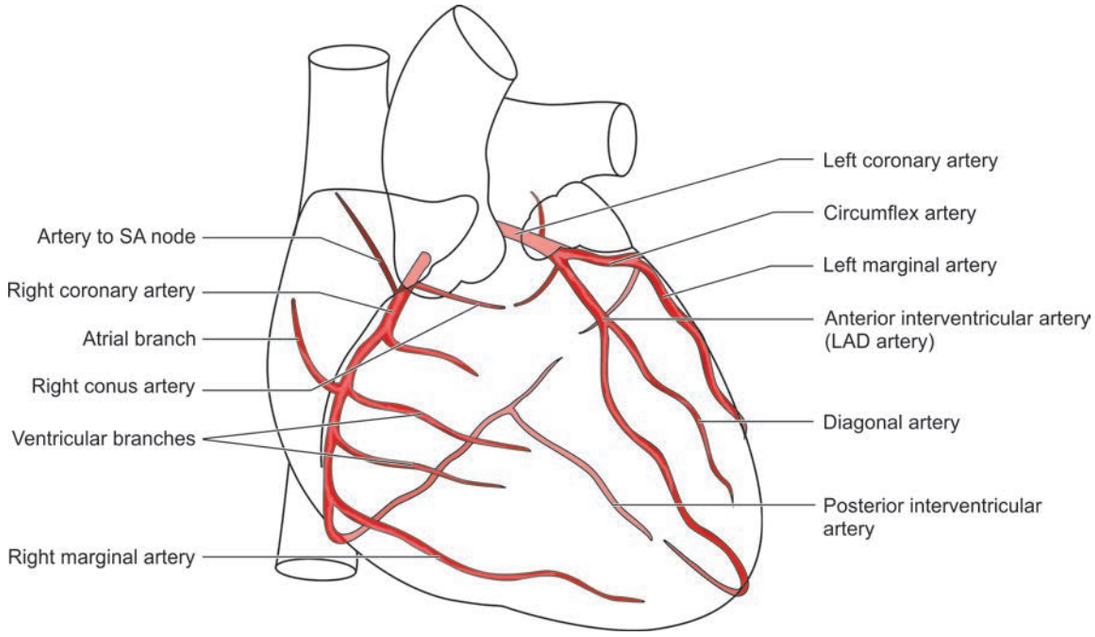


Fig. 44.1: Anterior view of the heart showing coronary arteries

branch passes along the inferior border of the heart up to the apex. It anastomoses with left marginal artery.

5. **Posterior interventricular artery (clinically referred as posterior descending artery/PDA)** This branch arises close to the crux and proceeds in posterior interventricular groove. This artery is accompanied by middle cardiac vein. The posterior interventricular artery gives many septal branches and one of the upper septal branches supplies AV node. The terminal part of the artery anastomoses with terminal part of the anterior interventricular artery.

Areas of Distribution of Right Coronary Artery

a. Right atrium.
b. Greater part of the right ventricle except a part at the anterior interventricular groove.
c. A small portion of left ventricle adjoining posterior interventricular groove.
d. The entire conducting system of the heart except the left branch of the AV bundle. (AV bundle can be supplied by left coronary artery).
e. Posterior 1/3rd of the interventricular septum.

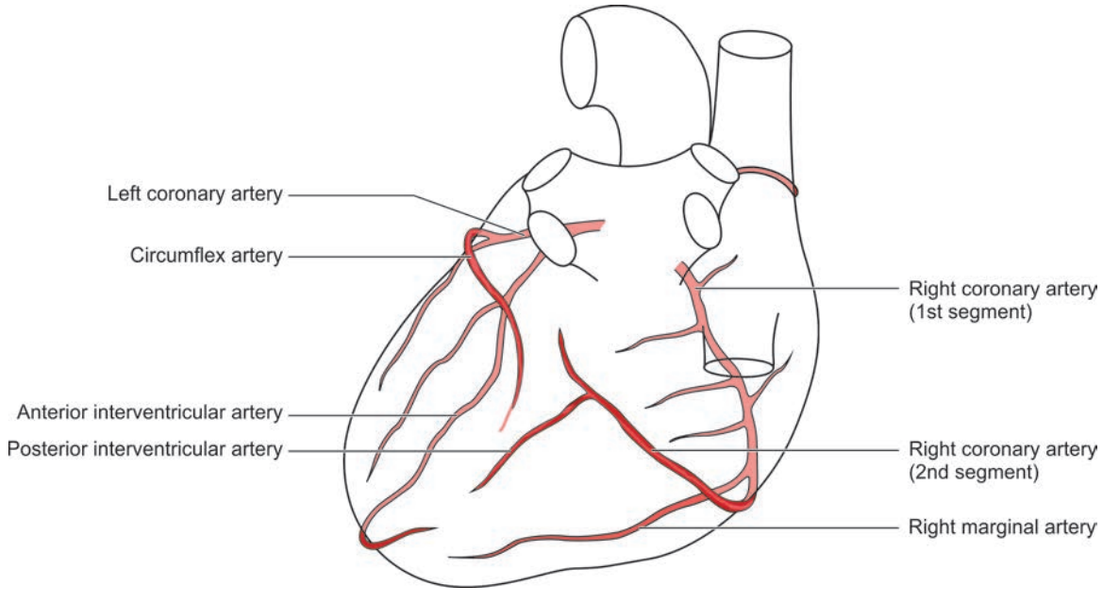


Fig. 44.2: Posterior view of the heart shows coronary arteries

2. Left Coronary Artery

Origin

It arises from the left posterior aortic sinus of the ascending aorta.

Course

The artery passes between pulmonary trunk and left auricle and enters left anterior coronary sulcus. Soon it divides into two (or three) branches.

Branches

1. **The anterior interventricular artery (clinically referred as left anterior descending artery (LAD)**
   It descends in the anterior interventricular groove. It is accompanied by great cardiac vein. It anastomoses with terminal branches of posterior interventricular artery. The anterior interventricular artery gives following branches:
   a. **Right anterior ventricular branches:** They arise from its right side on sternocostal surface.
   b. **Left anterior ventricular branches:** They arise from its left side. One of these branches is large and is called **left diagonal artery**.
   c. **Left conus artery:** It forms an arterial ring around the pulmonary trunk along with right conus artery.
   d. **Septal branches:** They supply anterior 2/3rds of the interventricular septum.
2. **Circumflex artery**
   This artery traverses the left anterior coronary sulcus and then curves around the left border of the heart. It partly runs in the left posterior coronary sulcus. It terminates (little to the left of the crux) with terminal branches of the right coronary artery. It is accompanied by great cardiac vein. Circumflex artery gives following branches:
   a. **Left marginal artery:** It descends along the left border up to the apex of the heart. It anastomoses with right marginal artery.
   b. **Anterior and posterior ventricular branches:** The anterior ventricular branches mainly traverse left surface while posterior ventricular branches traverse diaphragmatic surface.
   c. **Atrial branches** are classified into anterior, posterior and lateral groups supplying left atrium.
   d. **Kugel's anastomotic artery** traverses the anterior interatrial sulcus to establish direct or indirect anastomosis with right coronary artery.

Areas of Distribution of Left Coronary Artery

a. Left atrium.
b. Greater part of the left ventricle except at the posterior interventricular groove.
c. A small part of the right ventricle at the anterior interventricular groove.
d. A part of the left branch of the AV bundle.

Dominant Coronary Circulation

About 70% of individuals have a **right dominant** coronary circulation. This means the right coronary artery gives rise to the posterior interventricular artery. When this branch arises from the left coronary's circumflex branch, then the heart is considered '**left dominant**'. If both right and left coronary arteries contribute to this branch, then the circulation is considered 'balanced'.
In case of left dominance, the AV node and AV bundle are supplied by left coronary artery (Figs 44.3 and 44.4).

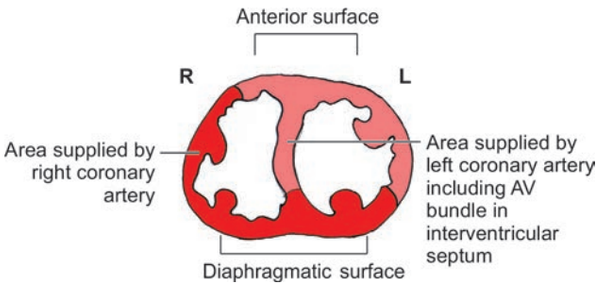


Fig. 44.3: Arterial supply to the interventricular septum (inferior view of the cross section)

In most cases the SA node and AV node with AV bundle are supplied by right coronary artery, however it is possible that these structures may be supplied by circumflex branch of the left coronary artery.

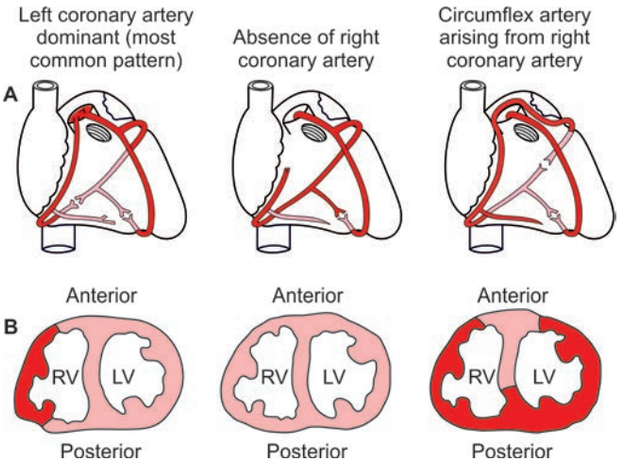


Fig. 44.4: Major variations in the arterial supply to the heart. **A:** Anterior views; **B:** Inferior views of the cross section through the ventricles (RV: Right ventricle; LV: Left ventricle)

Special Features of the Coronary Arteries

- The diameter of the coronary artery varies from 1.5 to 5.5 mm.
- Left coronary artery is larger in caliber, supplying greater volume of the myocardium.

- Coronary arteries are the only vessels where blood flows in diastole.
- Posterior interventricular artery normally arises from right coronary artery and is referred as 'right dominance'.
- The branches of the coronary arteries are generally considered as functional end arteries.
- Sympathetic stimulation constricts the epicardial arteries and dilates the intramuscular arteries.

Coronary artery anastomoses: They have been established that anastomoses do occur particularly between subpericardial branches, and they may increase during individual life by mechanisms of angiogenesis and arteriogenesis. Clinical studies suggest that anastomoses cannot rapidly provide collateral routes sufficient to compensate for sudden coronary obstruction. Following collateral anastomoses have been documented:

a. The annulus of Vieussens connects right conus artery with left conus artery a branch of anterior interventricular artery.
b. The artery to the SA node provides communications between the proximal part of the coronary arteries.
c. The apical collateral artery connects anterior and posterior interventricular arteries.
d. The first septal branch of the anterior interventricular artery and Kugel's anastomotic artery anastomoses with the distal part of the right coronary artery.

Venous Drainage of the Heart

The venous blood from the musculature of the heart is drained into the right atrium through:

a. Coronary sinus
b. Anterior cardiac veins
c. Venae cordis minimae (Thebesian veins)

Coronary Sinus

It is a venous sac about 2 to 3 cm long, situated in the left posterior coronary sulcus. It opens into the right atrium by an orifice, which is guarded by a valve. Following are the tributaries of the coronary sinus (Figs 44.5 and 44.6).

1. Great cardiac vein
It begins near the apex, ascends in the anterior interventricular groove and then traverses the coronary sulcus. It receives left marginal vein. The great cardiac vein opens into the left end of the coronary sinus.

2. Small cardiac vein
It passes along the right posterior coronary sulcus and opens into the right end of the coronary sinus.

3. Middle cardiac vein
It begins near the apex and traverses the posterior interventricular groove. It opens into the lower part of the coronary sinus.

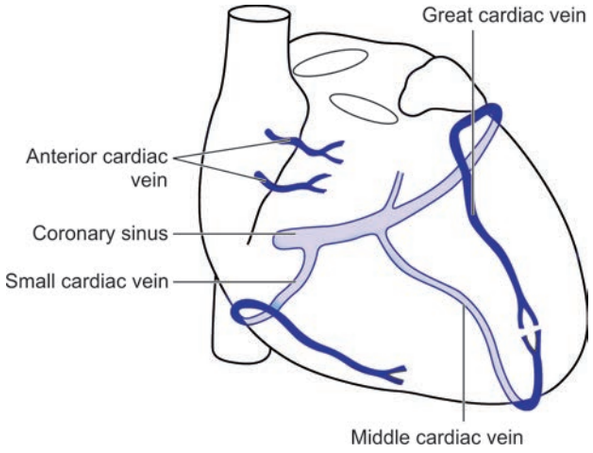


Fig. 44.5: Venous drainage of the heart—anterior view

4. Posterior vein of the left ventricle
It is present on the diaphragmatic surface of the left ventricle.

5. Oblique vein of the left atrium (of Marshall)
It descends obliquely on the back of the left atrium to join the coronary sinus.

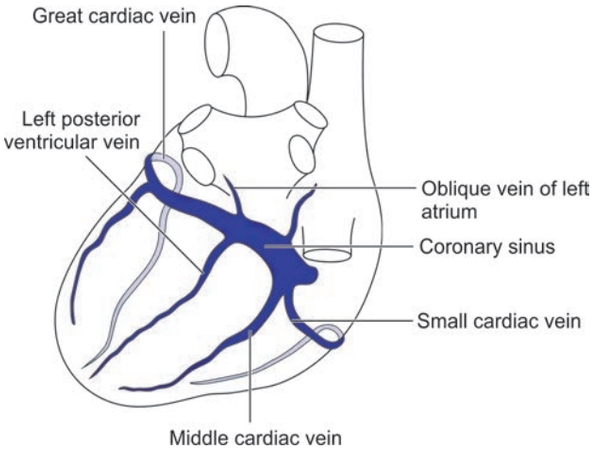


Fig. 44.6: Venous drainage of the heart—posterior view

Anterior Cardiac Veins

They drain anterior part of the right ventricle and are usually two or three in number. They ascend to open directly into right atrium, crossing first segments of right coronary artery.

Venae Cordis Minimae

They are numerous in the right atrium and ventricle. They open into all the chambers of the heart.

NERVE SUPPLY TO THE HEART

Though the cardiac muscle contracts rhythmically and automatically, the nerves supplying the heart alter the cardiac rate.

The sympathetic and parasympathetic fibres supplying the heart form two cardiac plexuses—superficial and deep. The fibres arising from these plexuses follow the coronary arteries and to the components of conducting system, particularly the SA node (finally the sympathetic and parasympathetic nerve fibres end in SA node).

Sympathetic Source

The preganglionic fibres arise from upper 5 thoracic segment (T1–T6) of the spinal cord (lateral horn/intermediate horn) to reach upper 5 thoracic sympathetic ganglia where the preganglionic sympathetic fibres synapse. Some of the preganglionic sympathetic fibres ascend to the cervical part of the sympathetic chain. The postganglionic fibres from upper 5 thoracic sympathetic ganglia and all the three cervical sympathetic ganglia reach cardiac plexus.

Parasympathetic Source

It is derived from right and left **vagus nerves**. The vagus nerve gives cardiac branches in the neck (cervical cardiac branch) and also few in the thorax. These are preganglionic parasympathetic (or presynaptic) fibres, which make synapses with small ganglia close to the myocardium.

a. Superficial cardiac plexus

It is situated below the arch of aorta and in front of the right pulmonary artery. Fibres from the superficial cardiac plexus pass into deep cardiac plexus and pulmonary plexus for lungs (Figs 44.7 and 44.8).

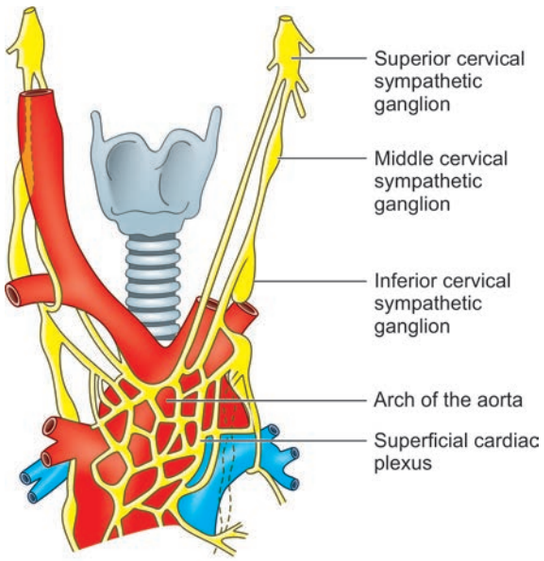


Fig. 44.7: Cardiac plexus—schematic

Formation

1. A branch from the left superior cervical sympathetic ganglion.
2. Lower cervical cardiac branch of the left vagus nerve.

b. Deep cardiac plexus

It is situated in front of the bifurcation of the trachea.

Formation

1. Cardiac branches of both (right and left) cervical sympathetic ganglia (except from left superior).

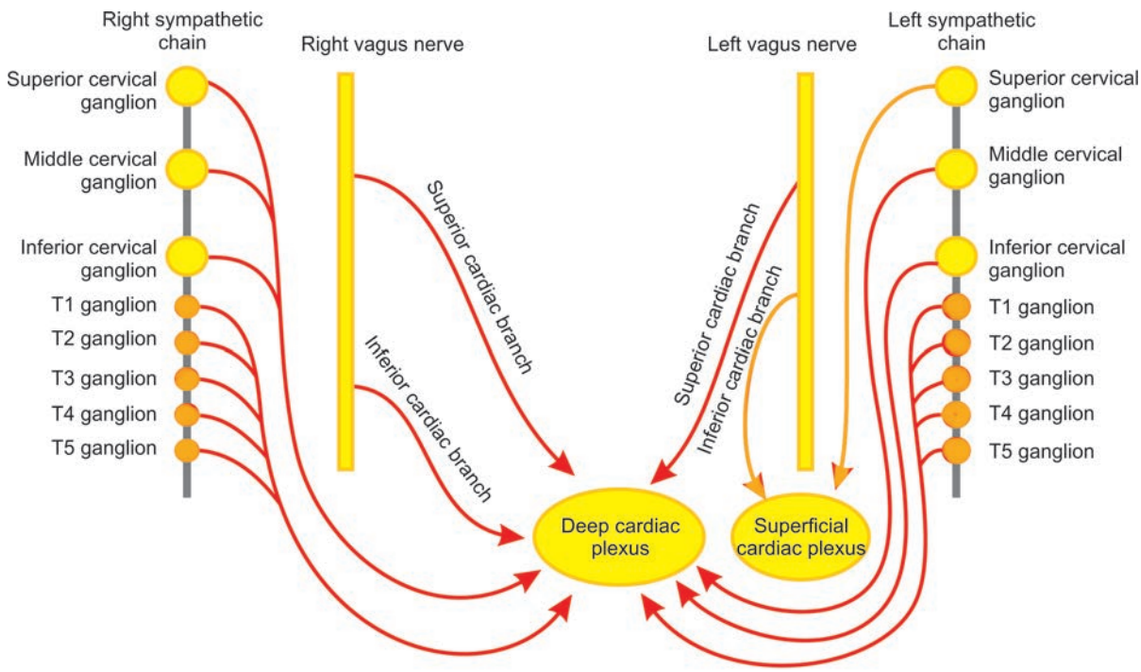


Fig. 44.8: Formation of cardiac plexus (schematic)

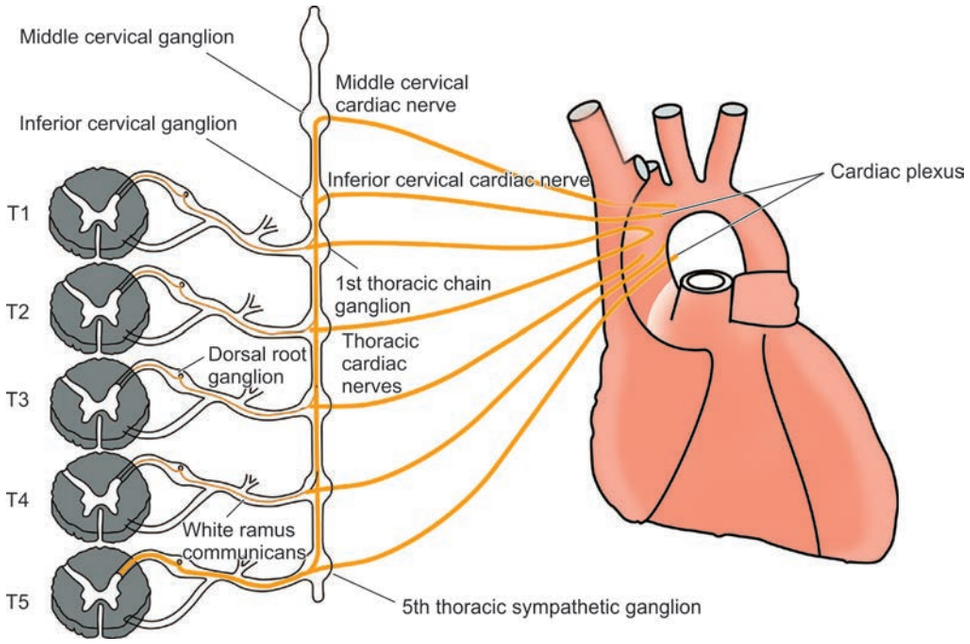


Fig. 44.9: Cardiac pain pathway

2. Cardiac branches from the upper four or five thoracic sympathetic ganglia.
3. Cardiac branches of both vagus (except lower cervical cardiac branch of left vagus).

Functions

- Sympathetic fibres increase the heart rate, impulse conduction, force of contraction (increases cardiac output) and increased blood flow through coronary vessels to support the increased activity (most adrenergic receptors/β_2 on coronary blood vessels, when activated cause relaxation of smooth muscles in the wall of the coronary arteries, therefore dilation of the arteries occur, this supplies more oxygen and nutrients to the myocardium).
- Sympathetic fibres also carry pain sensation (due to ischemia of the heart) from the heart. These afferent fibres reach the sympathetic ganglia and then through **white ramus communicans** joins the spinal nerve. Then through the dorsal root of the spinal nerve it enters the spinal cord (Fig. 44.9).
- Parasympathetic stimulation slows the heart rate, reduces the force of contraction and constricts the coronary arteries (post-synaptic parasympathetic fibres release acetylcholine).

CONDUCTING SYSTEM OF THE HEART

The conducting system consists of specialized cardiac muscle fibres. It includes pacemaker and Purkinje muscle fibres. These structures are capable of initiating and conducting the cardiac impulses, which produce the coordinated contraction of atrium and ventricles (Fig. 44.10).

1. Sinuatrial node (SA node)

It is known as the **pacemaker** of the heart. It is situated in the **upper part of the crista terminalis**. The SA node initiates and regulates the impulses for the contraction of the heart. The sympathetic fibres stimulate the SA node while parasympathetic inhibit it. The impulses from the SA node reach atrioventricular node through the walls of the right atrium (in the interatrial septum and crista terminalis).

2. Atrioventricular node (AV node)

It is located in the **triangle of Koch,** which is placed in the lower part of the interatrial septum. The

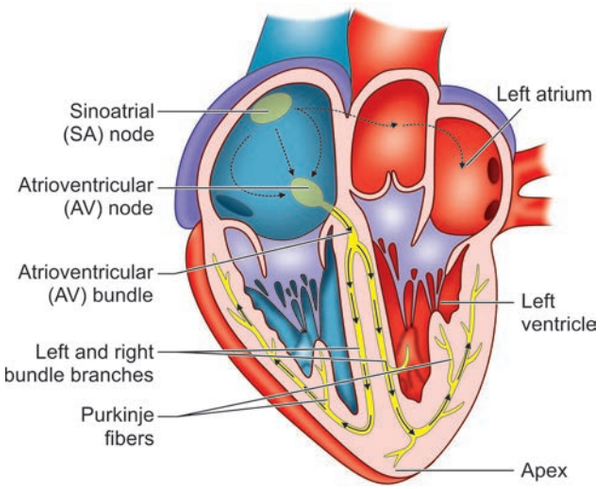


Fig. 44.10: Conducting system of heart

impulses are then conveyed to the ventricle through AV bundle.

3. Atrioventricular bundle (AV bundle or bundle of His)

It begins from the AV node, traverses the **membranous part of the interventricular septum**. The AV bundle is the only bridge between the atrial and ventricular myocardium. At the junction of membranous and muscular part of the interventricular septum, the AV bundle divides into right and left branches.

a. **The right branch** passes to the right side of the interventricular septum. Majority of the fibres enter septomarginal trabecula (moderator band) to reach the base of the anterior papillary muscle. The remaining fibres ramify on the musculature of the right ventricle forming subendocardial plexus.

b. **The left branch** is distributed in the wall of the left ventricle and also anterior and posterior papillary muscles of the mitral valve.

4. Purkinje fibers (subendocardial branches)

They are located just beneath the endocardium of the ventricles. These fibers are specialized myocardial fibres. The Purkinje fibers are specialized to rapidly conduct impulses (numerous sodium ion channels and mitochondria, fewer myofibrils than the surrounding muscle tissue). Purkinje fibres take up stain differently than the surrounding muscle cells, and, on a slide, they often appear lighter and larger than their neighbors. They are binucleated.

Blood Supply to Conducting System

- Usually, SA node is supplied by right coronary artery, but in 35% individuals, can be supplied by branch of left coronary artery.
- Usually, AV node and AV bundle are supplied by right coronary artery, but in 20% the circumflex branch of left coronary artery supplies it. The AV bundle may be supplied by LAD artery.
- The right bundle branch receives blood from both right and left coronary arteries.
- The left bundle branch from the LAD branch of the left coronary artery.
- In left coronary dominance, entire interventricular septum receives branches from left coronary artery.

Lymphatic Drainage of the Heart

Lymphatic vessels arising from the musculature of the heart forms subepicardial lymphatic plexus. Lymphatic vessels arising from these plexuses follow the coronary artery and finally a single lymphatic vessel is formed which ascends between pulmonary trunk and left atrium to end in inferior tracheobronchial lymph nodes, usually on the right side.

Clinical Notes

Angina pectoris: Angina pectoris is the term referring to pain originating from heart. It is a severe constricting pain as tightness in the thorax, deep to the sternum. The pain is the result of **ischemia of the myocardium.** This ischemia causes cellular necrosis (infarction) in myocardium, because of which the myocardium will not be able to pump the blood.

The common cause for angina is narrowing of the coronary artery. This results in reduced blood flow, reduced oxygen supply to the cardiac muscle cells. This limited anaerobic metabolism (using carbohydrates in absence of oxygen) of the myocytes, causes **lactic acid** accumulation and **reduced pH**. The pain receptors are stimulated by lactic acid.

Strenuous exercise, sudden exposure to cold and stress are the added factors in a patient with narrowed coronary vessels that cause angina, because all these require increased activity of the heart. After a heavy meal more blood flows into the digestive tract, for which some blood may be diverted from heart also. This can also cause angina in patients with narrowed coronary vessels followed by a heavy meal.

The angina is relieved by rest which reduces the workload on the heart. **Sublingual nitroglycerin** is placed under the tongue for rapid absorption, which dilates the coronary arteries. Such angina warns the patient about occlusion or narrowed coronary arteries indicating health care intervention.

The pain resulting from myocardial infarction is more severe than angina pectoris and the pain does not subside after 1–2 minute of rest.

The stable angina is characterized by chest discomfort and pain precipitated by some activity (running, walking, etc.) with minimal or non-existent symptoms at rest. In **unstable angina**, the chest discomfort and pain occur even at rest, and it is severe and of new onset (i.e. within 4–6 weeks). The pathophysiology of unstable angina is the reduction of coronary flow due to transient **platelet aggregation** on apparently normal endothelium, coronary artery spasms or coronary thrombosis.

Cardiac referred pain: The pain sensation from the heart is derived from ischemia of the myocardium. The ischemia causes accumulation of certain metabolic products which are stimulus to pain receptors. (Heart is insensitive to touch, cold, heat or cutting.) The sympathetic fibres carry pain sensation from the heart. These afferent fibres reach the sympathetic ganglia (upper five thoracic, middle and inferior cervical) and then through

white ramus communicans joins the spinal nerve. Then through the dorsal root of the spinal nerve (especially on the left side, hence pain is referred in left arm) it enters the spinal cord at the level of T1 to T5 segment (Fig. 44.9).
The cardiac referred pain (angina pectoris) is felt as radiates from the substernal and left pectoral regions to the left shoulder and the medial aspect of the left upper limb (Fig. 44.11).

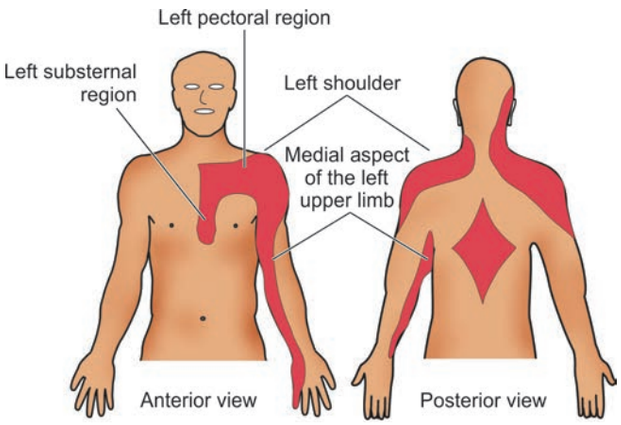


Fig. 44.11: Cardiac referred pain areas

The referred pain at the substernal area and pectoral region is due to common innervation (T2–T5) to that part of the body wall (somatic nerve/intercostal) and heart (visceral) by T2 to T5 segment of the spinal cord.
The referred pain at the shoulder and medial aspect of the upper limb is because T1 and T2 segment of the spinal cord also supply upper limb through brachial plexus. Skin of the floor of the axilla or medial side of the arm is supplied by T2 (intercostobrachial nerve).
The cardiac pain is usually referred to the left side because cardiac lesions mostly occur in the left half of the heart, but if the lesion is in right half of the heart, the pain will be referred to the right side.
Coronary angiography: This is a radiographic technique in which the coronary arteries are visualized. A catheter is introduced into the femoral artery or radial artery then guided into ascending aorta with the help of a monitor. Under the fluoroscopic control, the tip of the catheter is placed just inside the coronary artery. A radiopaque contrast material is injected, and radiographs are taken. The radiograph shows the lumen of the coronary arteries and its branches and also stenotic area if any (Fig. 44.12A and B).

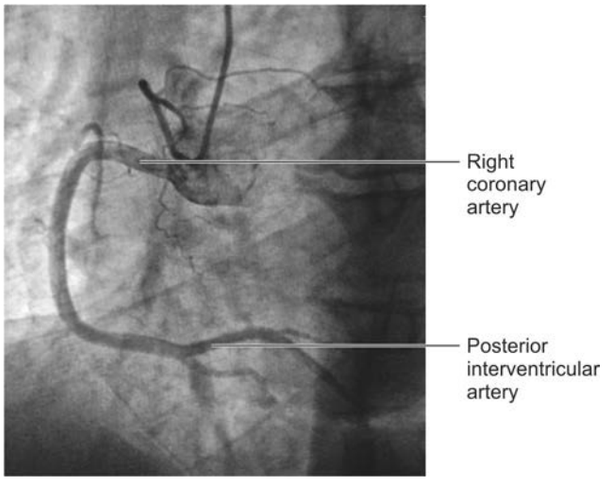


Fig. 44.12A: Coronary angiography of right coronary artery

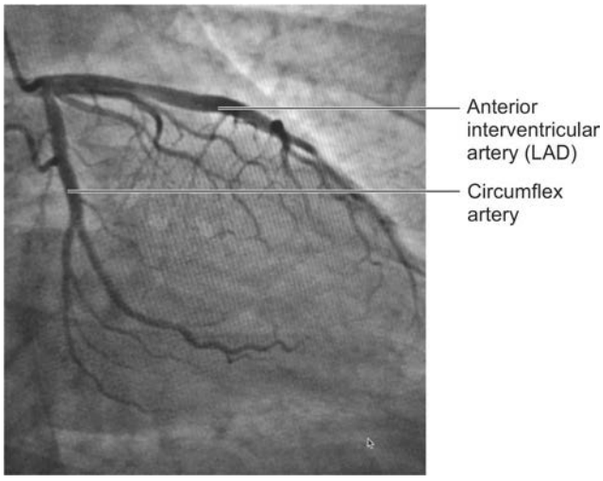


Fig. 44.12B: Coronary angiography of left coronary artery

CASE 1
A 48-year-old male software engineer while doing his regular exercise, noticed a diffuse substernal pain that radiated across his chest to the left shoulder and medial side of the left arm. Having been a sports person almost all his life, he continued his regular exercise as well as swimming. The spells of pain became recurrent with strenuous exercise and subsided during rest. Thinking the pain would go away, he did not seek medical assistance. During one particularly long and strenuous session of swimming, he experienced a crushing pain in the chest, and fell to the floor. He was taken to the nearest hospital and placed immediately in the intensive care unit. Tests revealed, among other things, an elevated serum cholesterol level and an abnormal ECG. The patient was placed on anticoagulant and vasodilatory drug therapy and prescribed

total bed rest for 10 days, followed by a long period of rehabilitation that included modified diet, rest, moderate exercise, and reduction of stress. His condition improved steadily without any recurrences. The underlying cause usually is a narrowing of the diameter of one or more of the major arteries of the heart as a result of atherosclerotic plaque formation on the internal walls of these vessels. The patient's elevated cholesterol level combined with the pain upon exertion would tend to support a diagnosis of reduced coronary artery blood flow. When the patient was at rest, the arteries apparently were capable of carrying an adequate blood supply, but with increased demand, as occurs in exercise, the heart became deprived of its required oxygen level, resulting in ischemia and pain.

1. What is the term for the recurring pain experienced by the patient upon exertion?
2. Describe the sensory nerve supply to the heart.
3. Explain the referred pain experienced with this condition.
4. Trace the pain pathway from the heart to spinal cord.

CASE 2

A 58-year-old man was brought to the emergency room of the hospital with pain in his left shoulder that radiates to the scapula. While taking the patient's history it was noted that the patient had many episodes of such attacks in the past two years, with lengthy intervals between them. The patient also said that such attacks of pain were always associated with physical exertion and disappeared after rest. However, the attacks had occurred every day for the past one week. The physical examination revealed:

- shoulder joint within normal limits, range of motion free,
- heart slightly enlarged, otherwise within normal limits, and
- no elevation of cardiac enzymes.

Administration of sublingual nitroglycerin resulted in pain relief. He was diagnosed with angina pectoris and discharged until further tests could be performed.

1. What is the anatomical basis of angina pectoris?
2. Describe the blood supply to the heart, listing the major arteries and branches.
3. Why is pain related to myocardial ischemia often "referred"?
4. What is the difference between angina pectoris and myocardial infarction?

Clinical Notes

Myocardial infarction (heart attack): A sudden occlusion of the coronary artery or its major branch by an embolus causes infarction of the myocardium (and followed by its necrosis) in the area of the heart supplied by it. This is called 'myocardial infarction'. An area of the myocardium that has undergone necrosis constitutes a myocardial infarction.

The most common cause for such sudden occlusion of the coronary artery is due to atherosclerotic changes in the coronary artery. Apart from severe chest pain (tightness in the chest), the victims of heart attack may also have dyspnea, nausea, vomiting, sweating, pain in the left armpit and medial side of the arm. Abnormalities in the electrical activity usually occur with heart attacks and ECG can identify the areas of heart muscle that are deprived of oxygen and/or areas of muscle that have died. Apart from ECG, estimation of cardiac enzymes will also help in diagnosing the myocardial infarction. Cardiac enzymes are proteins that are released into the blood by dying heart muscles.

These cardiac enzymes are **creatine phosphokinase** (CPK), special sub-fractions of CPK, and **troponin**, and their levels can be measured in blood. These cardiac enzymes typically are elevated in the blood several hours after the onset of a heart attack.

The three most common sites of coronary artery occlusion are:

1. Left anterior descending (LAD)/anterior interventricular artery branch of left coronary artery (40–50%).
2. Right coronary artery (30–40%).
3. Circumflex branch of the left coronary artery (15–20%).

Coronary atherosclerosis: It is characterized by deposition of cholesterol, calcium and cellular waste. As this atherosclerotic plaque buildup in the tunica intima of the coronary arteries, a stenosis (narrowing) of the lumen develops slowly. As coronary atherosclerosis progresses, the collateral channels are established which may initially permit adequate perfusion of the heart. But when heart needs to perform increased amounts of work (for example strenuous exercise), these collateral channels are not sufficient and which results in angina or myocardial infarction if there is total obstruction (Fig. 44.13).

Coronary angioplasty: In certain people with coronary obstruction, the cardiologists use percutaneous transluminal coronary angioplasty. A catheter with inflatable balloon attached to its tip is introduced to the lumen of coronary artery at the site of obstruction. Then the balloon is inflated,

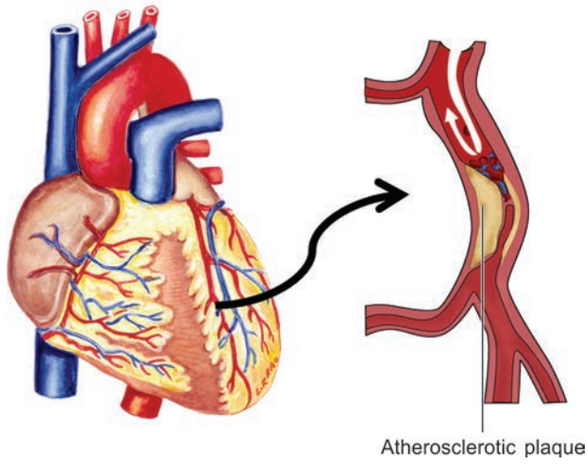


Fig. 44.13: Coronary atherosclerosis

flattening the atherosclerotic plaque against the arterial wall. The artery is stretched to increase the size of the lumen, thus improving the blood flow. Sometime **thrombokinase/streptokinase** an enzyme dissolves the blood clot is injected through the catheter. It is also possible to introduce **intravascular stent** to maintain the dilation. These intravascular stents are rigid or semirigid tubular meshes (Fig. 44.14).

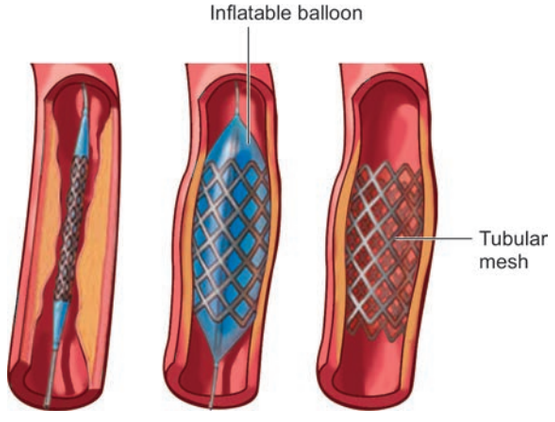


Fig. 44.14: Coronary angioplasty

Coronary artery bypass graft (CABG): It is also called "**the cabbage procedure**", which is indicated in patients with coronary obstruction and severe angina. A segment of the vein or an artery from elsewhere in the patient's body is grafted into the coronary artery to improve the circulation. The one end of the arterial graft is connected to aorta or coronary artery proximal to the block and another end to the coronary artery distal to the site of the block.

A portion of the great saphenous vein is commonly used for coronary graft because its diameter is equal or greater than coronary arteries and can be easily dissected from the lower limb. The portion of the great saphenous vein is grafted in reverse direction due to the presence of valves. Other alternatives include usage of radial artery and internal thoracic artery (Fig. 44.15).

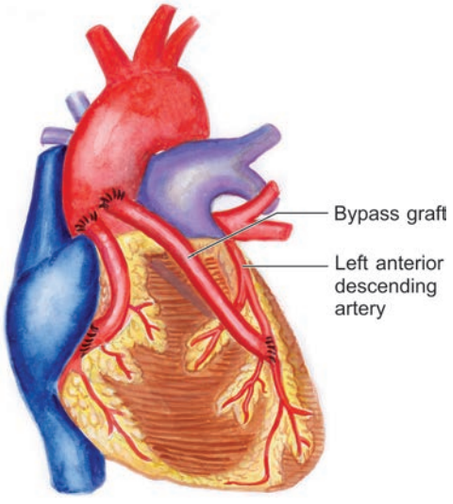


Fig. 44.15: Coronary bypass surgery

Electrocardiography (ECG or EKG): It is a noninvasive recording procedure for interpretation of the electrical activity of the heart. The ECG works mostly by detecting and amplifying the tiny electrical changes (depolarization) that is triggered by the cells in the sinuatrial node, spreads out through the atrium, passes through "intrinsic conduction pathways" and then spreads all over the ventricles. This is detected as tiny rises and falls in the voltage between two electrodes placed on either side of the heart which is displayed as a wavy line either on a screen or on paper. This display indicates the overall rhythm of the heart and weaknesses in different parts of the heart muscle.

The heart function is also tested by exercise tolerance test (treadmill stress test).

Artificial cardiac pacemaker: The AV node is damaged by various forms of heart diseases. The only route for impulse transmission from the atria to the ventricles is through the AV node. Therefore, damage to this node is called **'heart block'.** It interferes with the ability of the ventricles to receive the impulses. Without these signals, the ventricles beat at an intrinsic rate that is slower than that of the atria and too slow to maintain adequate

circulation. In such cases an **artificial pacemaker** set to discharge impulses at the appropriate rate is usually implanted.

The pacemaker consists of a battery pack, a wire and an electrode. An electrode connected to a catheter is inserted to a vein and then guided towards superior vena cava, right atrium, right ventricle with a fluoroscope. Here the electrode is firmly fixed to the trabeculae carneae of the ventricle. The opposite end of the electrode lead is connected to the pacemaker generator. The pacemaker produces electrical impulses that are spread into the musculature of the ventricles for its contraction at predetermined rate. Modern pacemakers are externally programmable and allow the cardiologist to select the optimum pacing models for individual patients.

Fibrillation and Defibrillation of Heart

Atrial fibrillation: It is the most common cardiac arrhythmia (abnormal heart rhythm) and involves the two atria of the heart. Instead of a coordinated contraction, the atria present rapid, irregular and uncoordinated contraction of atrial wall. It can often be identified by taking a pulse and observing that the heartbeats do not occur at regular intervals. However, a stronger indicator of atrial fibrillation is the absence of P waves on an electrocardiogram (ECG). Atrial fibrillation is often asymptomatic and is not in itself generally life-threatening, but it may result in palpitations, fainting, chest pain or congestive heart failure. People with AF usually have a significantly increased risk of stroke.

Ventricular fibrillation: It is a condition in which there is uncoordinated contraction of the ventricles of the heart. Ventricular fibrillation is a medical emergency. Ventricular fibrillation is a cause of cardiac arrest and sudden death.

Defibrillation of heart: An electric shock may be given to the heart through the thoracic wall via large electrodes. This shock causes cessation of all cardiac movements and few seconds later the heart may begin to beat more normally.

Restarting heart (cardiopulmonary resuscitation/CPR): It is an emergency procedure for people with cardiac arrest or, in some circumstances like respiratory arrest. CPR is performed both in hospitals and in pre-hospital settings (by first-aid workers). CPR involves physical intervention to create artificial circulation through rhythmic pressing on the patient's chest to manually pump blood through the heart, called chest compressions, and usually involves the rescuer exhaling into the patient (or using a device to simulate this) to ventilate the lungs and pass oxygen into the blood, called artificial respiration. Some protocols now downplay the importance of the artificial respirations and focus on the chest compressions only. Despite its name, CPR is unlikely to restart the heart; its main purpose is to maintain a flow of oxygenated blood to the brain and the heart, which are both the most essential organs to human life and are most vulnerable to damage from lack of oxygen (hypoxia).

The CPR procedure involves three steps: (1) Compression, (2) airway, (3) breathing (use mnemonic CAB).

Compressions: This step is to restore the blood flow. The performer will use your hands to push down hard and fast in a specific way on the person's chest. Compressions are the most important step in CPR. Put the victim/patient on his or her back on a firm surface (supine position). The performer kneels next to the patients neck and shoulders and places his proximal palm over the center of the patient's chest. Then the other hand on top of the first hand. The performer pushes straight down on (compresses) the chest at least 2 inches (5 centimeters) but no more than 2.4 inches (6 centimeters). The performer shall use his or her entire body weight (not just arms) when doing compressions. The performer pushes hard at a rate of 100 to 120 compressions a minute and allows the chest to spring back (recoil) after each push. If the performer is not trained in CPR, he or she shall continue chest compressions until there are signs of movement or until emergency medical personnel take over.

Airway: If the performer is trained in CPR, he or she can move into the next step of opening the airway and rescue breathing. After performing 30 chest compressions, the performer opens the patient's airway using the head-tilt, chin-lift maneuver.

Breathing: Rescue breathing can be mouth-to-mouth breathing or mouth-to-nose breathing if the mouth is seriously injured or cannot be opened. After opening the airway, the performer gives mouth-to-mouth breathing. After first rescue breath he or she will watch to see if the chest rises. If the chest rises, the performer gives a second breath. Thirty chest compressions followed by two rescue breaths is considered one cycle. Be careful not to provide too many breaths or to breathe with too much force. The performer will continue CPR until there are signs of movement or emergency medical personnel take over (Fig. 44.16).

Fig. 44.16: Cardiopulmonary resuscitation (CPR)

CASE 3

A 65-year-old man complains of tight chest pain and shortness of breath after lifting several boxes in his garage. He says he believes his heart is skipping beats. His medical history is significant for hypertension and cigarette smoking. On examination, his heart rate was 55 beats/min and regular, and his lungs are clear on auscultation. An electrocardiogram shows bradycardia with an increased PR interval and ST-segment elevation in multiple leads including the anterior leads, V1 and V2. Further estimation of cardiac enzymes after several hours, showed an increase in cardiac enzyme levels. The cardiologist decided to perform a coronary bypass surgery. After the surgery the patient recovered well and got discharged from the hospital.

1. What anatomical structures are most likely to be affected?
2. Describe the course and areas of the heart supplied by the right and left coronary arteries, respectively.
3. Describe the venous drainage of the heart.
4. Name three blood vessels of the body that can be used for coronary artery graft.
5. To perform coronary angiography the cardiologist chooses the right femoral artery. Trace the path of catheter from the femoral artery to the coronary ostia.

CASE 4

A 17-year male athlete visited the hospital with complaints of breathlessness, dizziness, weakness, fainting and fatigue. A detailed medical history of the patient was taken and followed by series of tests, which included portable ECG, which recorded heart's electric activity for 48 hours. The ECG is characterized by intermittently nonconducted P waves, not preceded by PR prolongation and not followed by PR shortening. The patient was diagnosed to have Mobitz type II heart block. The cardiologist decided to place an artificial pacemaker to maintain the heart rate.

1. Name the anatomical components of conducting system of heart and their specific locations in the heart.
2. What is 'Heart block' and how does it interfere with heart's function?
3. How is the electrical activity of the heart recorded?
4. Describe the arterial supply to the different parts of the conducting system of the heart.
5. How does an artificial 'pacemaker' help in case of heart block?

Solutions to the clinical case studies

Case 1

1. This patient was suffering from angina pectoris
2. The heart is supplied by the autonomic nervous system through parasympathetic (vagus nerve) and sympathetic (upper 4 segments of the thoracic portion of the spinal cord/T1–T4). The two autonomic subdivisions are antagonistic in their action on the heart, the sympathetic causing the heart rate to increase, whereas the parasympathetic is responsible for reducing the rate. The fibres from both subdivisions intermingle and ramify around the aorta as the cardiac plexuses of nerves. In addition, sensory fibres travel from the heart and enter the dorsal roots of the upper four or five thoracic spinal nerves.
3. These same nerves receive afferent fibres from the shoulder and arm (mainly T1 and T2) and from the thoracic wall. Although the mechanism of referred pain is still poorly understood, somehow pain impulses from the heart become intermingled with afferent fibres from the periphery of the body in such a way that somatic pain is also felt (in this case from the left shoulder and arm).
4. Refer to text.

Case 2

1. Angina pectoris, "chest pain," is due to myocardial ischemia. The pain is frequently precipitated by exercise, stress, or eating. During periods of increased oxygen demand, narrowed arteries may not be able to deliver adequate blood supply. Angina is combined with exertion, and relieved by 1-2 minutes of rest.
2. Refer to text.
3. Cardiac pain is often referred to areas of the body surface which send sensory impulses to the same levels of the spinal cord that receive cardiac sensation. This is true especially on the left side. The sensory nerve fibres from the heart and blood vessel walls travel through the cardiac plexus, sympathetic chain, and up to the dorsal roots and ganglia of spinal nerves T1–T4. Make sure you look up the dermatomes of T1–T4 to see the cutaneous distribution of this part of the spinal cord, as this is the common site of referred pain. The common sites of referred pain include the neck, jaws, shoulders, arms, and epigastric area.
4. Angina pectoris is the chest pain located in the retrosternal area, that may or may not be caused by exercise, and can or cannot subside with rest (that depends if the angina is stable or unstable). The angina can be caused by myocardial infarction, or just by ischemia of the muscle. The myocardial infarction is the death of the heart cells by necrosis, and the pain will not be relieved by rest and immediate medical intervention is a must.

Case 3

1. Right coronary artery and left anterior descending artery
2. Refer to text
3. Refer to text
4. Internal thoracic artery, radial artery and tributary or a segment of great saphenous vein.
5. Right femoral artery, right external iliac artery, right common iliac artery, abdominal aorta, thoracic aorta, arch of the aorta and ascending aorta.

Case 4

1. SA node—in the upper part of the crista terminalis, AV node—in the interatrial septum (triangle of Koch), AV bundle—in the membranous part of the interventricular septum, right branch of AV bundle—in rough part of interventricular septum and septomarginal trabaculae, left branch of AV bundle—in rough part of interventricular septum
2. Refer to text
3. Refer to text
4. Refer to text.
5. The pacemaker produces electrical impulses that spread into the musculature of the ventricles for its contraction at predetermined rate. Modern pacemakers are externally programmable and allow the cardiologist to select the optimum pacing modes for individual patients.

MCQs

1. A 55-year-old man is awakened from sleep by crushing substernal chest pain that radiates to his jaw. Upon arrival at the hospital, he is hypotensive and bradycardic. The electrocardiogram demonstrates third degree heart block. Which of these arteries usually supplies the atrioventricular node?

A. Circumflex artery B. Left coronary artery
C. Left marginal artery D. Right coronary artery

2. A 67-year-old man is brought to the hospital by ambulance after a cardiac arrest. After defibrillation, an electrocardiogram demonstrates ST segment elevation in leads V2, V3, V4, V5 and V6 consistent with an anterior wall myocardial infarction. Which of the following arteries is least likely to supply the anterior wall of the left ventricle?

A. Right coronary artery
B. Left marginal artery
C. Diagonal branch of the left anterior descending artery
D. Circumflex artery

3. A 60-year-old man develops a myocardial infarction and is noted to have a heart rate of 40 beats/min. The cardiologist diagnoses an occlusion of the right coronary artery. Which of the following structures is most likely to be affected?

A. AV node
B. AV bundle
C. Left branch of the AV bundle
D. Mitral valve

4. Which of these arteries usually gives a branch that supplies SA node?

A. Right coronary artery
B. Right marginal artery
C. Posterior interventricular artery
D. Anterior interventricular artery

5. Which artery mainly supplies interventricular septum in normal coronary artery pattern?

A. Right coronary artery
B. Posterior interventricular artery
C. Anterior interventricular artery
D. Circumflex artery

6. Which artery usually supplies the AV node?

A. Right coronary artery—first segment
B. Right marginal artery
C. Posterior interventricular artery
D. Anterior interventricular artery

7. An elderly lady suffers a coronary artery occlusion and subsequently it is noted that there is a heart block (left bundle of the conduction system have been damaged). Which of these arteries is most likely involved?

A. Circumflex branch
B. Anterior interventricular
C. Posterior interventricular
D. Right marginal

8. Blockage of blood flow in the proximal part of the anterior interventricular artery could deprive a large area of heart tissue of blood supply, unless a substantial retrograde flow into this artery develops via an important anastomosis with which of these arteries?
A. Circumflex B. Left marginal
C. Posterior interventricular D. Right coronary

9. While attempting to suture the distal end of a coronary bypass onto the anterior interventricular artery, the surgeon accidentally passed the needle through the adjacent vein. Which vein was damaged?
A. Anterior cardiac vein B. Coronary sinus
C. Great cardiac vein D. Middle cardiac vein

10. Normal cardiac conduction depends upon electrical communication between cardiac muscle cells occurring at gap junctions found in which of the following regions?
A. Atrioventricular bundle (of His)
B. Atrioventricular node
C. Cardiac skeleton
D. Intercalated disks

11. Pain from the heart typically is conducted by fibres of which of the following nerves?
A. Cervical cardiac branches of sympathetic trunk
B. Cervical cardiac branches of vagus nerves
C. Thoracic splanchnic nerves
D. Ventral rami of spinal nerves T1–T4

12. A 66-year-old man presents to the emergency department with sweating and crushing chest pain that radiates down his left arm. An ECG is performed and shows ST elevation and inverted T waves. His troponin level is high. He is taken to the cardiac catheterization unit, where he is diagnosed with an obstructive myocardial infarction due to a blockage in his left anterior descending artery (LAD). Which of the following best describes the area of myocardium supplied by the LAD?
A. Anterior wall and interventricular septum
B. Atrioventricular node and posterior septum
C. Left atrium and left ventricle
D. Right atrium and posterior wall

13. A 48-year-old man with a history of stable angina presents to the hospital with an episode of chest pain that is not relieved by rest or nitroglycerin. After stabilization in the hospital for 2 days, he undergoes angiography test. The results showed reduced perfusion of the lateral wall of the left ventricle. Which artery is most likely to be occluded?
A. Left anterior descending B. Circumflex
C. Left main coronary D. Right coronary

14. A 55-year-old male lawyer is brought to the hospital by his wife. The wife states that her husband complained of a sharp, squeezing chest pain behind the sternum after a meal and has had repeated episodes of chest pain after exertion over the past several months. A diagnosis is made of an acute myocardial infarction (MI) of the AV bundle. What was the most likely site of an occlusion?
A. Posterior interventricular artery
B. Circumflex artery
C. Marginal artery
D. Left marginal artery

15. Which of the following is a neural structure that carries visceral pain fibers from the heart that results in referred pain over the TI–5 dermatomes?
A. Ventral roots of the TI–5 spinal nerves
B. Dorsal roots of the TI–5 spinal nerves
C. Greater splanchnic nerves
D. Gray rami communicantes of the TI-5 spinal nerves

16. A 43-year-old woman is diagnosed with a heart block in which contraction of the ventricles is dissociated from that of the atria. The suspected cause is ischemia of the atrioventricular node resulting from coronary artery blockage. In most individuals, the atrioventricular nodal artery is the branch from which of the following vessels?
A. Anterior interventricular artery
B. Circumflex branch of left coronary artery
C. Left marginal artery
D. Posterior interventricular artery

17. Myocardial infarction caused by occlusion of the circumflex branch of the left coronary artery is most likely to occur in which of the following locations?
A. Apex
B. Left atrium and left ventricle
C. Right and left ventricles
D. Right atrium and right ventricle

18. A 72-year-old woman arrives at the emergency department and states that her left arm is numb, and she is sweaty. Laboratory studies show an elevated troponin I level. An echocardiogram indicates an abnormality of the anterior interventricular septum. Stenosis of which of the following arteries would most likely cause this condition?
A. Acute marginal artery
B. Circumflex artery
C. Left anterior descending artery
D. Posterior descending artery

ANSWERS TO MCQs

1. D	2. A	3. A	4. A	5. C
6. C	7. B	8. C	9. C	10. D
11. A	12. A	13. B	14. A	15. B
16. D	17. B	18. C		

JUST BEFORE THE EXAM

Right coronary artery → Originates from the anterior aortic sinus of the ascending aorta. It gives atrial, ventricular, right marginal and posterior interventricular branches (supplies posterior 1/3rd of the interventricular septum). One of the anterior atrial branches supplies SA node and septal branch

from the posterior interventricular artery supplies AV node and part of the AV bundle.

Left coronary artery → Originates from left posterior aortic sinus of the ascending aorta. It gives anterior interventricular (LAD) and circumflex arteries. The LAD artery accompanies great cardiac vein. It gives septal branches (supplying anterior 2/3rds of the interventricular septum), left diagonal artery (one of the ventricular branches). The circumflex artery gives atrial and ventricular branches (major part of the thick wall of the left ventricle.

Coronary sinus → A venous sac located in the left posterior coronary sulcus. It receives venous blood from the heart. It receives small cardiac vein on its right end, great cardiac vein on its left end. The middle cardiac vein (accompanies posterior interventricular artery) opens into the lower part of the coronary sinus. In addition, it also receives posterior vein of the left ventricle and oblique vein of the left atrium.

Nerve supply to the heart

Superficial cardiac plexus → Located below the arch of aorta.

Deep cardiac plexus → Located in front of the bifurcation of the trachea.

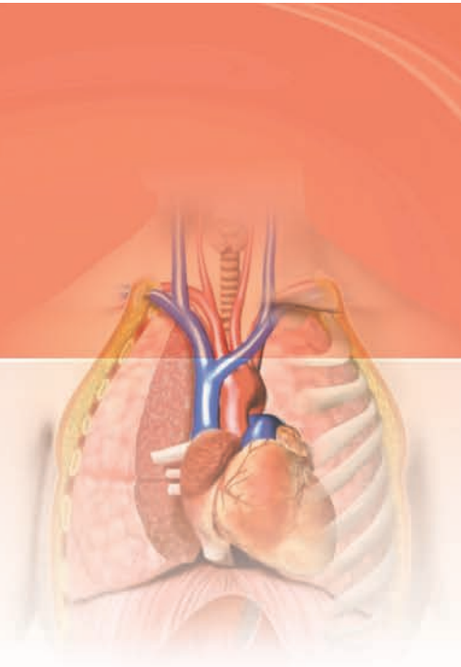
Parasympathetic vagal stimulation → Slows the heart rate, reduces the force of contraction and constricts the coronary arteries.

Sympathetic stimulation → Increases the heart rate, increases the impulse conduction, force of contraction and dilates the coronary vessels. The sympathetic fibres also carry pain sensation (because of ischemia of the heart) from the heart.

Conducting system of the heart → The sympathetic and parasympathetic fibres ends in SA node of the heart (pacemaker of the heart). The SA node is located in the upper part of the crista terminalis.

SA node → AV node → AV bundle → Right and left terminal branches → Purkinje fibres.

The AV node is located in the interatrial septum/ triangle of Koch while the AV bundle is located in the membranous part of the interventricular septum. The AV bundle gives right branch which traverses the septomarginal trabecula (moderator band) to reach the base of the anterior papillary muscles. The left branch of the AV bundle distributed through papillary muscles of the left ventricle. Purkinje fibres are located just beneath the endocardium of the ventricles. They are specialized to rapidly conduct impulses.



Chapter

45

Superior Mediastinum

Competencies: AN 21.11, 23.4, 24.4, 24.6, 25.1

Objectives

- To list the subdivisions of the mediastinum and to list the major structures present in each of them
- To describe the location, extent, relations and branches of the arch of the aorta
- To list the major vessels and nerves of the superior mediastinum and their relations
- To describe the extent, relations and microscopic structure of the trachea
- To describe the position, structure and functions of thymus
- To describe the origin, course and distributions of phrenic nerve and their clinical relevance
- To draw neat, labeled diagrams of the cross section of the thorax at sternal angle, at T3 vertebral level and the junction between T4 and T5 vertebrae
- To identify the structures in cross section of thorax in CT pictures at same levels

MEDIASTINUM

The mediastinum is the midline structures between the right and left pleural cavities of thorax. It is bounded in front by sternum, behind by thoracic vertebral bodies and on each side by mediastinal pleura and lungs. It is divided into superior and inferior parts by an imaginary line passing through sternal angle (manubriosternal joint) to the disc between T4 and T5 vertebrae. The inferior mediastinum is further divided into anterior, middle and posterior parts by the heart with pericardium (Fig. 45.1).

Superior Mediastinum

It is placed behind the manubrium sternum and in front of the upper four thoracic vertebral bodies. Its upper limit is the inlet of thorax, which is obliquely placed between sternal notch in front and disc between C7 and T1 vertebrae behind.

Contents

The arch of the aorta is the main content of the superior mediastinum. The sternohyoid and sternothyroid muscles are also the contents. The remnant of the thymus may be present at the superior mediastinum. The other contents include:

- Branches of arch of the aorta
- Superior vena cava, right and left brachiocephalic veins
- Right and left vagus and phrenic nerves, left recurrent laryngeal nerves
- Oesophagus, trachea and thoracic duct

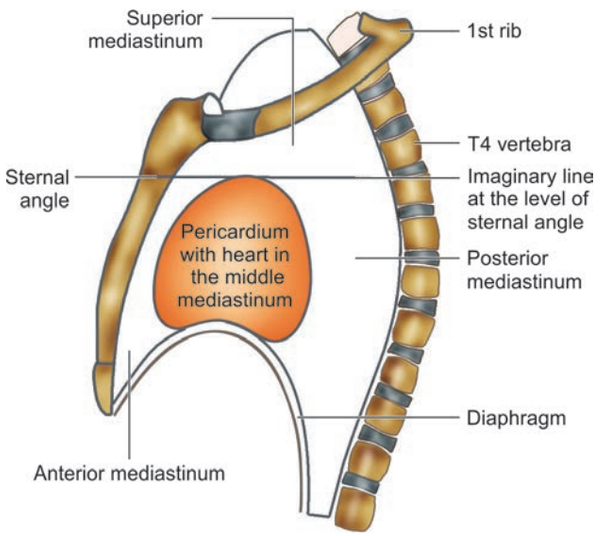


Fig. 45.1: Mediastinum and its subdivision (lateral view)

The study of the relations of the arch of the aorta explains all the structures in the superior mediastinum.

Anterior Mediastinum

It is the space behind the body of the sternum and in front of pericardium and heart. The pericardium is connected to inner surface of the body of sternum by sternopericardial ligaments.

Middle Mediastinum

It is the space between anterior and posterior mediastinum and is occupied by heart with pericardium.

Posterior Mediastinum

It is bound in front by pericardium with heart, bifurcation of trachea and pulmonary vessels in the upper part. Posteriorly it is related to lower eight thoracic vertebral bodies. Its contents include descending thoracic aorta, oesophagus, azygos and hemiazygos veins, thoracic duct, vagus nerves, thoracic part of the sympathetic chain with their splanchnic nerves.

ARCH OF THE AORTA (AORTIC ARCH)

It is the continuation of the ascending aorta at the level of sternal angle and continues as descending thoracic aorta at the level of lower border of body of T4 vertebra. It arches behind the manubrium sternum. It passes upwards, backwards and to the left forming an arch. This arch produces a deep groove on the medial surface of the left lung above the hilum.

Branches

It gives three branches (Fig. 45.2):

1. Brachiocephalic trunk (innominate artery): It further divides into right common carotid and right subclavian arteries.

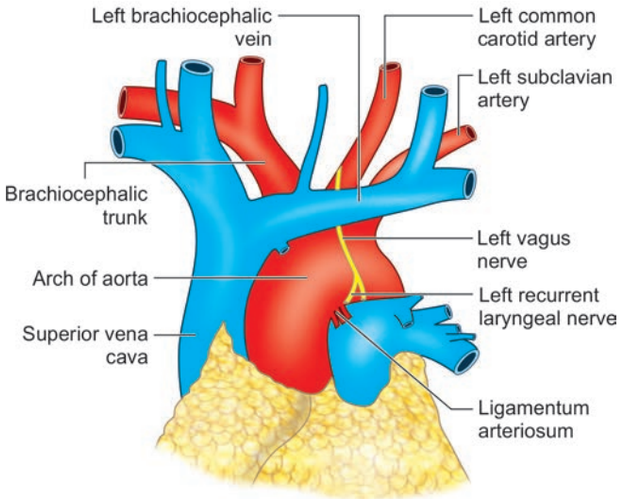


Fig. 45.2: Arch of aorta—anterior view

2. Left common carotid artery
3. Left subclavian artery

All these branches are crossed superficially by the left brachiocephalic vein. A fourth branch called arteria thyroidea ima may arise from arch of aorta. At times, the left vertebral artery can also arise from arch of aorta.

Relations

The aortic arch has several important relations with the organs and neurovascular structures of the mediastinum (Fig. 45.3).

Anteriorly and to the left (from anterior to posterior)

- Medial surface of the left lung with pleura
- Left phrenic nerve
- Left superior intercostal vein
- Left vagus nerve
- Inferior cervical cardiac branch of the left vagus nerve (to superficial cardiac plexus).

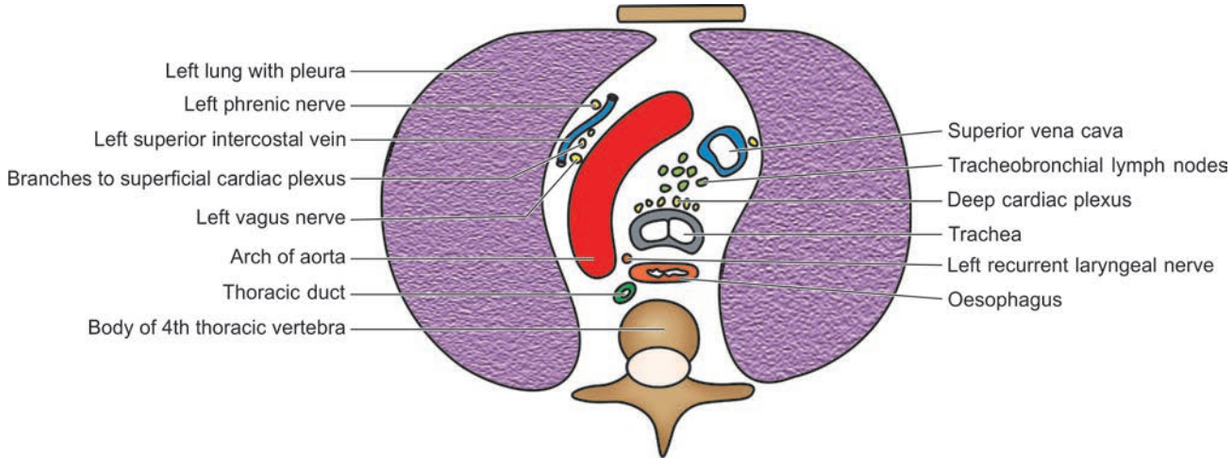


Fig. 45.3: Cross section of the thorax at the level of sternal angle (schematic)

- A branch from left superior cervical sympathetic ganglion (to superficial cardiac plexus).

Posteriorly and to the right (from anterior to posterior)

- Lower end of the trachea with deep cardiac plexus and tracheobronchial lymph nodes in front of it.
- Left recurrent laryngeal nerve
- Oesophagus
- Thoracic duct
- Body of the T4 vertebra

Inferiorly

- Bifurcation of pulmonary trunk
- Left pulmonary artery
- Left main bronchus.
- **Ligamentum arteriosum**

Ligamentum arteriosum is connected to under surface of arch of aorta (distal to the origin of the left subclavian artery) to the left pulmonary artery. The left recurrent laryngeal nerve winds around the ligament (Note: the right recurrent laryngeal nerve winds around the right subclavian artery in the neck) with superficial cardiac plexus present in front of it. The ligament represents embryological ductus arteriosus (refer to Chapter 47).

Superiorly

The three branches of the arch of aorta arise from its upper convex arch. The left brachiocephalic vein crosses in front of these branches.

A cross section CT image (Fig. 45.4A) at the level of the sternal angle and its schematic representation image (Fig. 45.4B) is provided to understand the important relations of the arch of the aorta. Note the reversal of right and left side in CT image and the same is depicted in the schematic image.

Clinical Notes

Aortic Aneurysm

It is a localized dilatation of the aorta (Fig. 45.5). It occurs due to weakness in the wall of the arch of the aorta. The dilated artery may occasionally cause discomfort, a greater concern is the risk of rupture, which causes severe pain, massive internal bleeding that can result in death if untreated. The change in the structure of the wall of the aorta can occur secondary to trauma, infection, an intrinsic defect in the protein construction of the aortic wall, or due to progressive destruction of aortic wall proteins by enzymes. The aneurysm usually causes compression of neighboring structures in the superior mediastinum. The signs and symptoms depend on what structure/s it compresses.

A common symptom is a hoarse voice as the left recurrent laryngeal nerve (a branch of the vagus nerve) is stretched. This is due to the recurrent laryngeal nerve winding around the arch of the aorta. The pressure on oesophagus can cause dysphagia, pressure on trachea causes stridor and dry cough, pressure on sympathetic chain can cause Horner's syndrome, pressure on veins can cause venous congestion in the neck and upper limb.

It can also cause tracheal tug, which can be felt at suprasternal notch in the extended position of the neck. The treatment of aortic aneurysm involves the placement of an endovascular stent via a percutaneous route (usually through the femoral artery) into the diseased portion of the aorta.

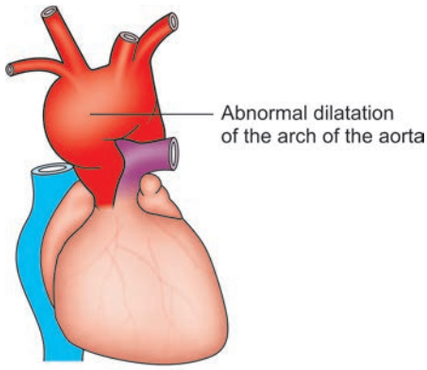


Fig. 45.5: Aortic aneurysm

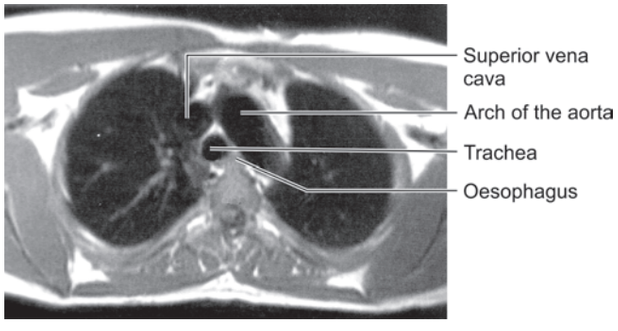


Fig. 45.4A: Cross sectional (axial) CT view of the thorax at the level of sternal angle

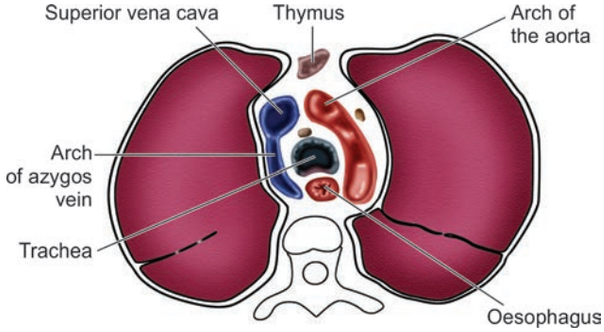


Fig. 45.4B: A schematic representation of the CT image—45.4A

CASE 1

A 52-year-old patient (with a history of syphilis in her youth) has a swelling that protrudes from the upper margin of the sternum in the midline of the neck. The swelling expands with each systole of the heart. On examination, the trachea is found to be displaced to the right in the neck, and there is a distinct tugging sensation felt on palpation of the trachea.

What anatomical structure lying within the superior mediastinum is likely to have an expansile swelling that tug at the trachea?

Clinical Notes

Coarctation of the Aorta

It is the narrowing of the lumen of the arch of the aorta distal to the origin of left subclavian artery. The narrowing is due to abnormality in the tunica media followed by proliferation of tunica intima. There are two types of aortic coarctation—preductal and postductal.

1. **Preductal Coarctation:** Narrowing occurs proximal to the attachment of the ductus arteriosus. In this case the ductus arteriosus lumen is patent. In this case the descending thoracic aorta receives deoxygenated blood through patent ductus arteriosus (Fig. 45.6).
2. **Postductal Coarctation:** Narrowing occurs distal to the attachment of the ductus arteriosus. The ductus arteriosus is usually obliterated. This variety of coarctation is more common and the descending thoracic aorta is filled by a collateral circulation. The blood from the subclavian artery enters the internal thoracic artery and its branches—anterior intercostal arteries (Fig. 45.7). They anastomose with posterior intercostal arteries (reversal blood flow) and the blood enters the thoracic aorta. This can cause dilatation of posterior intercostal arteries, consequently erosion of the lower border of the ribs. This is called 'notching of the ribs' which can be visualized by an X-ray picture (Fig. 45.8). This condition is characterized by reduced blood pressure in the lower limb (femoral) and elevated blood pressure in the upper limb (radial).

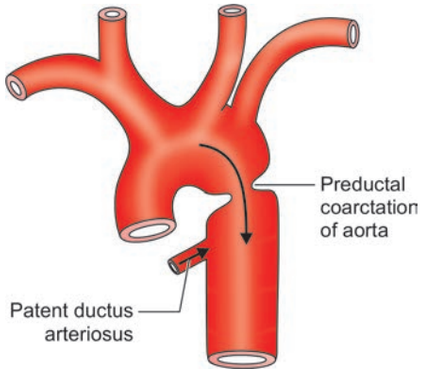


Fig. 45.6: Preductal coarctation

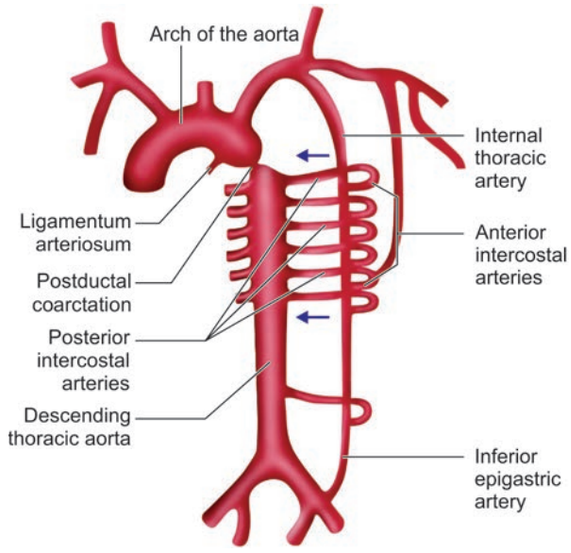


Fig. 45.7: Postductal coarctation and collateral circulation

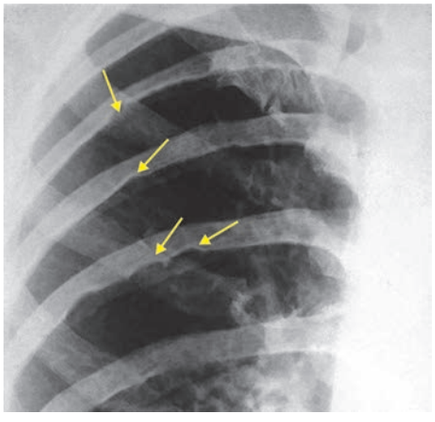


Fig. 45.8: Radiograph showing notching of the ribs in coarctation of aorta

CASE 2

A 23-year-old female visits the hospital with complaints of being easily tired, pain in her lower extremities with weakness and cold feet, an inability to tolerate vigorous exercise, frequent headaches, and epistaxis (nose bleed). The patient reports these are not new symptoms but have occurred over a number of years and have recently increased in their incidence. The physical examination revealed a cool lower extremity with an absence of dorsalis

pedis pulses and diminished femoral pulses, the blood pressure in the upper extremities is elevated (190/100), while the blood pressure in the lower extremities is 60/20; a systolic murmur is heard over the 5th left intercostal space which radiates to the interscapular region. A chest X-ray is performed, and significant rib notching is noted along with a visible dilation of the aorta in the region of the aortic knuckle. The patient is diagnosed with coarctation of the aorta based on physical exam and findings.

1. What is this lesion?
2. Is there a difference in the findings of such a lesion as an adult or as a child?
3. What were the diagnostic clinical features of the case?
4. What single diagnostic finding was found on the chest X-ray?
5. Explain why a postductal (inferior) lesion is more compatible with long term survival versus a preductal lesion?
6. What are the treatment options for a patient with this type of lesion?
7. What surgical complications would cause the greatest amount of concern?

VESSELS OF THE SUPERIOR MEDIASTINUM

Brachiocephalic Veins

Each brachiocephalic vein is formed by the union of internal jugular and subclavian veins posterior to the sternoclavicular joint. The left brachiocephalic vein is longer and crosses from left to right anterior to the three major arteries originating from arch of the aorta (brachiocephalic trunk, left common carotid artery and left subclavian artery).

At the level of the inferior border of the 1st right costal cartilage, the right and left brachiocephalic vein joins to form superior vena cava (Fig. 45.9).

The right brachiocephalic vein receives vertebral vein, the first right posterior intercostal vein and the right internal mammary vein. The left brachiocephalic vein receives left superior intercostal vein (draining 2nd, 3rd and 4th intercostal spaces on left side), left internal mammary vein, left vertebral vein, inferior thyroid veins and left first posterior intercostal vein.

Superior Vena Cava

It brings the venous blood from the parts of the body above the diaphragm except for heart and lungs. It extends from the lower border of the first right costal cartilage, vertically downwards to the level of right 3rd costal cartilage where it opens into right atrium. The right phrenic nerve descends on the right side of the superior vena cava. The lower end of the superior vena cava is covered by pericardium with ascending aorta on its left side. It forms the posterior boundary of the transverse sinus of the pericardium.

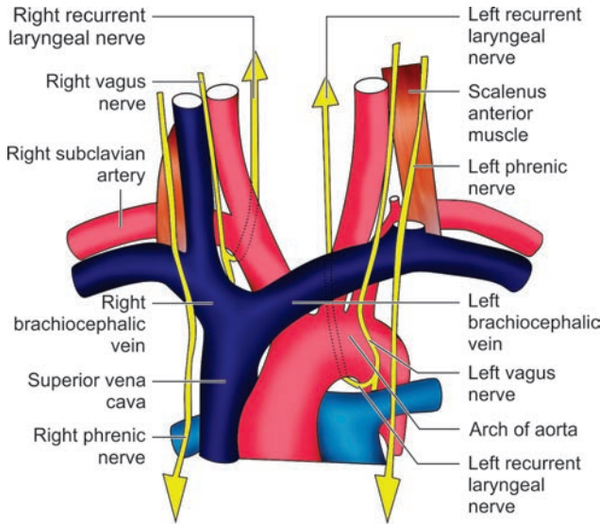


Fig. 45.9: Nerves of the superior mediastinum

The **azygos vein** after arching over the hilum of the right lung opens into superior vena cava before it pierces the pericardium. The arch of the azygos vein receives right superior intercostal vein just before it pierces the pericardium.

Ascending Aorta

It begins from aortic vestibule of the left ventricle and is covered by pericardium with superior vena cava on its right side. It has an anterior mild bulging called anterior aortic sinus which gives origin to right coronary artery. It has two posterior bulging called right and left posterior aortic sinuses. The left posterior aortic sinus gives origin to left coronary artery. The right posterior aortic sinus is referred as non-coronary which produces a bulge in the cavity of the right atrium called torus aorticus.

Brachiocephalic Trunk (Innominate Artery)

It is the first branch of the arch of the aorta, ascends behind the manubrium sternum and in front of the trachea. At the right sternoclavicular joint, it divides into right common carotid and right subclavian artery. The **left common carotid artery** ascends in front and to little left of the trachea. The **left subclavian artery** ascends lateral to the trachea.

NERVES OF THE SUPERIOR MEDIASTINUM

Vagus Nerve in the Thorax

- Each **vagus nerve** descends in the neck within the carotid sheath.

- The **right vagus nerve** enters the thorax anterior to the right subclavian artery (Fig. 45.9), then descends on the right side of the trachea posterior to superior vena cava and the root of the right lung. The nerve then descends on the right side of the oesophagus. Near the lower end of the oesophagus the right vagus passes posterior to the oesophagus and is called posterior gastric nerve. In the thorax it gives branches to cardiac plexus, pulmonary plexus and oesophageal plexus.
- The **right recurrent laryngeal nerve** arises from vagus just above the superior mediastinum (in the neck) and winds around the right subclavian artery (the right subclavian artery develops from the right 4th arch artery). It ascends between the trachea and oesophagus (tracheoesophageal groove) on its way to larynx.
- The **left vagus nerve** descends in front of the left common carotid artery and then anterolateral to the arch of the aorta (Fig. 45.9). Here the left vagus nerve is separated from left phrenic nerve by left superior intercostal vein. Further the left vagus descends posterior to the root of the left lung along the left side of the oesophagus.
- Near the lower end of the oesophagus the left vagus passes in front of the oesophagus as anterior gastric nerve. The left vagus gives branches to pulmonary plexus, cardiac plexus, oesophageal plexus and left recurrent laryngeal nerve.
- The **left recurrent laryngeal nerve** arises from left vagus close to the arch of aorta. The left recurrent laryngeal nerve winds around the ligamentum arteriosum and arch of aorta (arch of aorta is partly developed from left fourth arch artery), and then ascends between trachea and oesophagus on its way to larynx.
- The vagus nerve also carry sensory fibres (visceral afferent) from heart and lungs which are concerned with reflex activity of these organs.

PHRENIC NERVE

Origin

The phrenic nerve arises from ventral rami of C3, C4 and C5 with main contribution from C4 (Fig. 45.10).

Course

- In the neck the phrenic nerve **descends in front of the scalenus anterior muscle** but deep to the prevertebral fascia. The main anterior relations of the nerve in the neck include internal jugular vein and sternocleidomastoid muscle.
- The right and left phrenic nerve enters the superior mediastinum crossing the internal mammary artery on its anterior aspect.

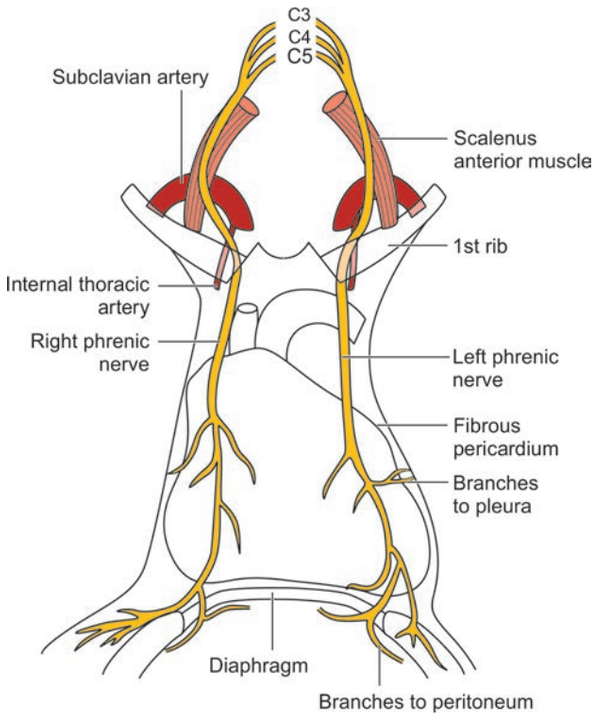


Fig. 45.10: Phrenic nerve schematic

- Each phrenic nerve descends in front of the hilum of lung along with pericardiophrenic vessels.
- The right phrenic nerve descends on the right side of the superior vena cava, close to the right border of the heart. It leaves the thorax along the inferior vena cava through the opening present in the central tendon of the diaphragm (some time it pierces the diaphragm).
- The left phrenic nerve descends in front and left of the arch of the aorta. Further its course is closely related to left surface of the heart. It pierces the diaphragm to the left of the central tendon.

Distribution

1. Motor fibres to diaphragm.
2. Sensory (proprioceptive) fibres from diaphragm.
3. Sensory fibres from mediastinal pleura and central part of the diaphragmatic pleura (in case of pleuritis referred pain is felt above the clavicle due to supraclavicular nerve sharing same root value) and also from parietal and fibrous pericardium.
4. Sensory fibres from parietal peritoneum lining the undersurface of the diaphragm. Hence, peritonitis involving under surface of diaphragm and adjacent area (ruptured cholecystitis, abscess around the kidney, sub-diaphragmatic abscesses) can cause referred pain above the clavicle.

Clinical Notes

Injury to phrenic nerve results in paralysis of the corresponding half of the diaphragm (hemi-diaphragm).

Phrenic nerve block: Phrenic nerve can be blocked by anesthetic injection. Under ultrasound control, the medication is injected at a point 1 inch above the clavicle, at the groove between the posterior border of the sternocleidomastoid muscle and the scalenus anterior muscle, with a slightly anterior trajectory. After inserting the needle to a depth of approximately 1 inch, aspiration is carried out to identify blood or elicitation of brachial plexus paresthesia; if negative, the solution was slowly injected. This procedure may be helpful in intractable hiccups (spasmodic contraction of the diaphragm due to irritation to phrenic nerve) in cancer patients or during lung surgeries.

Phrenic nerve crush: It is compressing the nerve injuriously with the forceps. It produces a longer period of paralysis of diaphragm (as it is required in surgical repair of diaphragmatic hernia).

Accessory phrenic nerve (a branch from nerve to subclavius/upper trunk of the brachial plexus having root value mainly C5) if present, it must also be crushed to produce complete paralysis of the hemidiaphragm).

Referred pain: Pain resulting from irritation of diaphragmatic and mediastinal pleura (in pleurisy) or from the parietal peritoneum lining under surface of the diaphragm (in ruptured gall bladder or abscess around the kidney) carried by phrenic nerve having root value C3, 4, 5 is referred to shoulder region. This is because skin over the shoulder is supplied by C3 to C5 segment of the spinal cord through supraclavicular nerve.

TRACHEA

- Trachea is a part of the respiratory tract.
- It extends from the lower border of the cricoid cartilage (opposite to C6 vertebra) to the lower border of T6 vertebra in the living, and in the standing position.
- The length of the trachea is about 10 to 11 cm.
- The trachea bifurcates at the level of sternal angle into right and left principal bronchi (Fig. 45.11), and enters the hilum of the corresponding lungs. The bronchus divides successively to give secondary bronchi, tertiary bronchi and bronchioles. Bronchioles also divide successively, to end in alveoli, where gaseous exchange takes place.
- The diameter of the trachea is 12 mm in adults, but in children it is in millimeters (corresponding almost to their age).

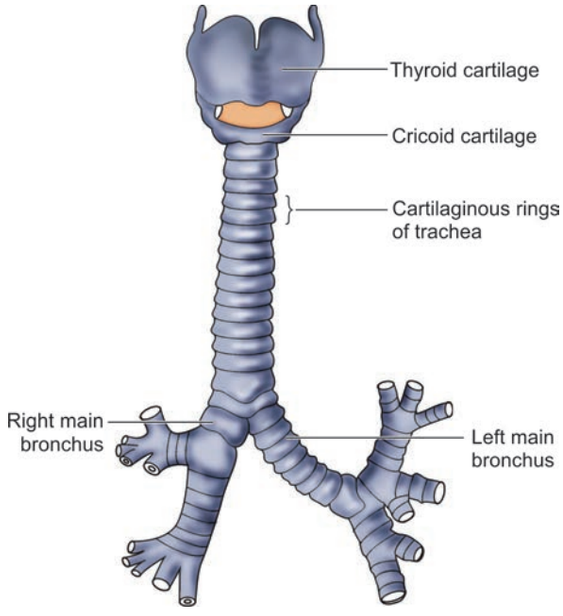


Fig. 45.11: Anterior view of the trachea

Relations of the Cervical Part of the Trachea and its Significance

In case of an upper respiratory obstruction, an emergency tracheostomy is performed in the neck region above the sternal notch. The following structures are related anterior to the upper part (cervical) of the trachea.

Skin, superficial fascia, deep fascia (investing layer), sternohyoid, sternothyroid, isthmus of the thyroid gland, inferior thyroid vein emerging from the lower border of the isthmus, jugular venous arch in the suprasternal space, arteria thyroidea ima (if present), pretracheal lymph nodes.

Oesophagus descends posterior to the trachea. Laterally the trachea is related to thyroid lobes (hence enlarged thyroid lobes can compress trachea) and carotid sheath.

Relations of the Thoracic Part of the Trachea

The anterior relations of trachea in the superior mediastinum include brachiocephalic trunk, left common carotid artery and more importantly the arch of aorta (anteriorly and to the left). An aneurysm of the arch of the aorta can compress this part of the trachea. The other anterior relations include deep cardiac plexus of nerves, tracheobronchial nodes and sometimes remains of thymus (Fig. 45.3).

The recurrent laryngeal nerve ascends in the tracheo-oesophageal groove on either side.

A cross section CT image (Fig. 45.12A) at the level of T3 vertebra and its schematic representation image (Fig. 45.12B) is provided to understand the important relations of the trachea. Note the reversal of right and

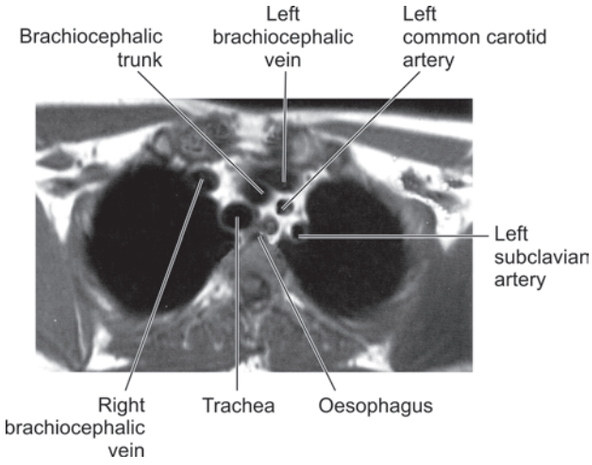


Fig. 45.12A: Cross sectional (axial) CT view of the thorax at the level of T3 vertebra

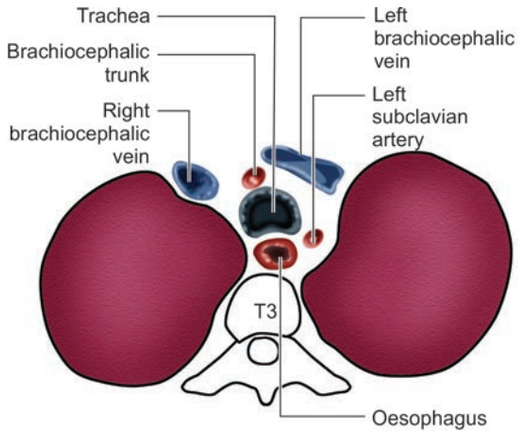


Fig. 45.12B: A schematic representation of the CT Fig. 45.12A

left side in CT image and the same is depicted in the schematic image.

Arterial Supply

Trachea is supplied by branches of inferior thyroid and bronchial arteries.

Lymphatic Drainage

It drains into lymph nodes present in front (pretracheal) and sides of the trachea (paratracheal).

Nerve Supply

It includes both sympathetic and parasympathetic nerves. The parasympathetic vagus is secretomotor to tracheal glands and also motor to trachealis muscle.

Carina

It is a hook-like ridge inside the trachea at the level of its bifurcation. It is formed by the lowest cartilaginous ring of the trachea. It is about 30 cm from nostrils and 25 cm from incisor teeth. The tracheobronchial lymph node placed just below the bifurcation, if enlarged (in case of carcinoma of the lung) can compress the carina and it becomes flattened and distorted. During bronchoscopy, the carina is examined for such changes (Fig. 45.13).

Microscopic Structure of the Trachea

The wall of the trachea is made up of mucosa, submucosa, cartilaginous/muscular layer and adventitia (Fig. 45.14 A and B).

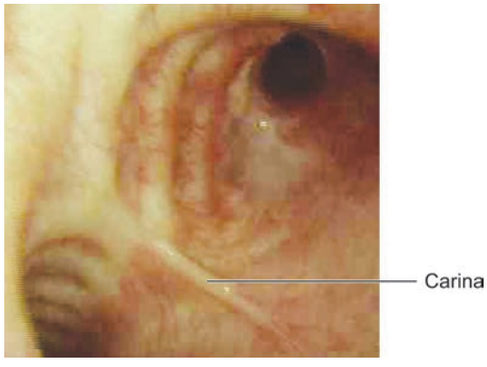


Fig. 45.13: Internal view at tracheal bifurcation shows carina

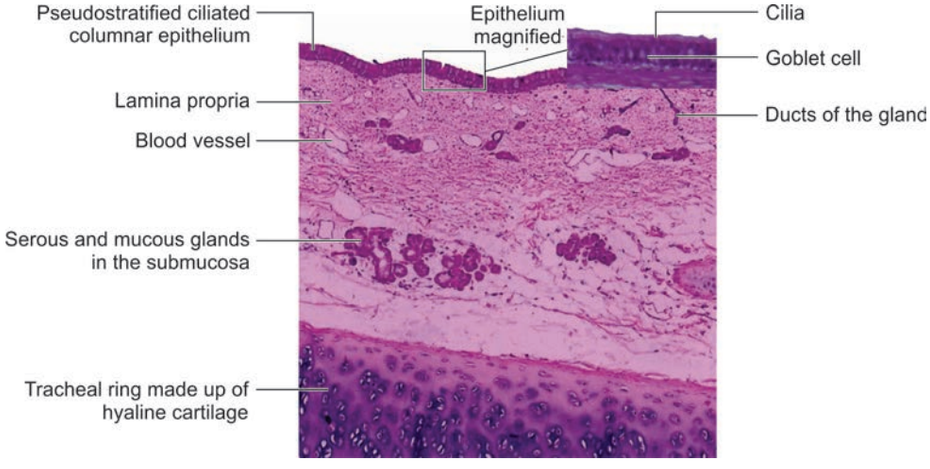


Fig. 45.14A: A photomicrograph showing histology of the trachea (H&E staining, under low magnification)

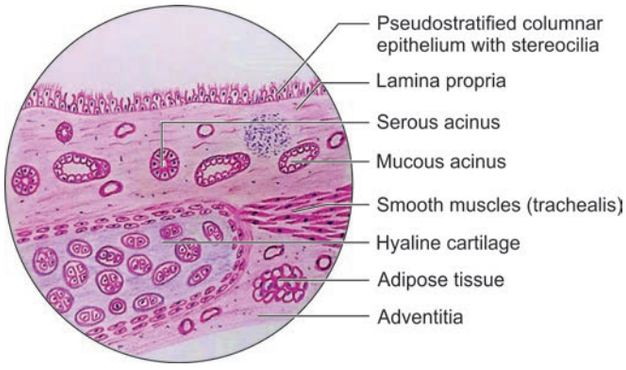


Fig. 45.14B: A schematic illustration showing histology of the trachea

Mucosa: The mucous membrane is having lining epithelium and the lamina propria. Trachea is lined by **pseudostratified ciliated columnar epithelium**. It consists of ciliated cells, mucous (goblet) cells, basal cells, granule cells and few brush cells. These cells rest on thick well defined basement membrane.

a. **Ciliated cells:** They are most numerous of the tracheal cell types. Each cell has approximately 250 cilia. The cilia provide a coordinated motion of the mucous coat from the lower air passages to the pharynx. They serve as an important protective mechanism for removing small, inhaled particles from the lungs.
b. **Mucous goblet cells:** These goblets-shaped cells are interspersed among the ciliated cells. Thb ey have mucinogen granules in their cytoplasm. In routine H&E staining preparation, these mucinogen granules get washed out giving clear/empty appearance. Their number increases during chronic irritation of the airway.
c. **Brush cells:** They are columnar cells that have blunt microvilli. The basal surface of the cells is in synaptic contact with an afferent nerve ending. Thus, the brush cells are referred as receptor cells.
d. **Small granule cells (Kulchitsky cells):** They belong to enteroendocrine cells. These cells secrete catecholamine, serotonin, calcitonin and gastrin-releasing peptide.
e. **Basal cells:** They serve as reserve cells that maintain individual cell replacement.

The basement membrane has densely packed collagen fibres immediately below the base of the lining epithelial cells basal lamina. The reticular layer is also thick. In smokers, those who experience chronic coughing, and also individuals with asthma, this layer will be considerably thick in response to mucosal irritation.

Lamina propria: It is made up of loose connective tissue and highly cellular. It contains numerous lymphocytes, plasma cells, eosinophils and fibroblasts. The lamina propria contains lymphoid tissue in both diffuse and nodular forms. An elastic membrane marks the boundary between the lamina propria and submucosa.

Submucosa: The connective tissue in the submucosa of the trachea is loose unlike many other organs where submucosa is dense. The lymphoid tissue often extends from lamina propria to the submucosa. Submucosal glands composed of mucus secreting acini with serous demilunes are also present in the submucosa. Their ducts traverse the lamina propria to deliver their product (mainly glycoproteins) on the epithelial surface. The submucosal layer ends where its connective tissue fibres blend with the perichondrium of the cartilage layer.
The tracheal cartilages and trachealis muscle separate submucosa from adventitia.

Tracheal rings: The anterior part of the trachea is composed of C-shaped cartilaginous rings (16 to 20 in number). Posteriorly, it is replaced by a fibrous membrane containing smooth muscle fibres (trachealis) which allows the expansion of oesophagus during the passage of food substances (Fig. 45.14). With age, the hyaline cartilage may be partially replaced by bone tissue, causing it to lose its flexibility. A cross section CT image (Fig. 45.15A) at the level of at intervertebral disc between T4 and T5 vertebrae and its schematic representation image (Fig. 45.15B) is provided to understand the important relations of the trachea. Note the reversal of right and left side in CT image and the same is depicted in the schematic image.

Adventitia: It is the outer layer, lies peripheral to the cartilage rings and trachealis muscle.

Clinical Notes

- Tracheal compressions cause difficulty in breathing (dyspnea). Tracheal compression can arise from enlarged thyroid gland, enlarged lymph nodes or from aneurysm of arch of aorta.
- Tracheostomy is a procedure to make an artificial opening just above the sternal notch in case of obstruction in upper airway.
- A bronchoscope introduced into trachea can also take biopsies from tracheobronchial lymph nodes at the tracheal bifurcation apart from internal visualization.
- The trachea can be felt just above the sternal notch. The deviation of trachea in case of pneumothorax can be felt at this site. The aneurysm of the arch of the aorta can cause tracheal tug.

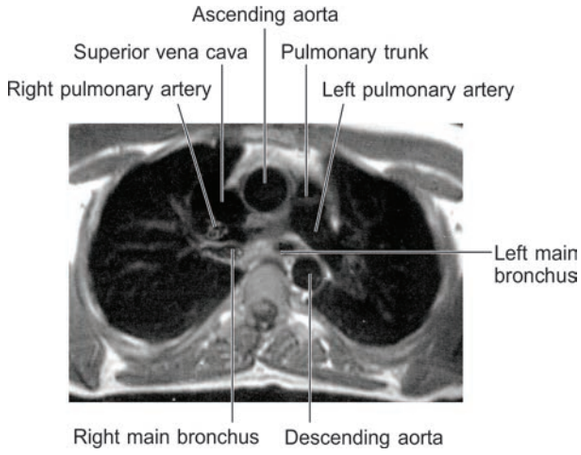


Fig. 45.15A: Cross sectional (axial) CT view of the thorax at the level of intervertebral disc between T4 and T5 vertebrae

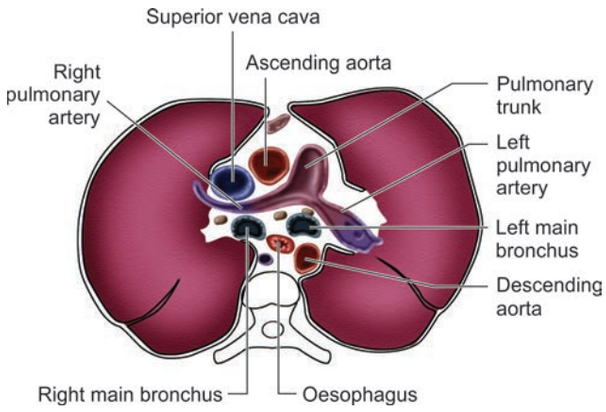


Fig. 45.15B: A schematic representation of the CT image—45.15A

THYMUS

Thymus is a central lymphatic organ placed in the superior and anterior mediastinum. It is placed in front of the arch of aorta and its branches, left brachiocephalic vein, trachea and upper part of the pericardium. It is irregular in shape, usually having two lobes (Fig. 12.7, Chapter 12). The size of the thymus progressively increases up to puberty (when it weighs about 20 to 30 gm). After puberty it undergoes involution and converted into fibrofatty mass. Thymus is developed from the endoderm of the third pharyngeal pouch, and it migrates down along with the inferior parathyroid. The microscopic structure and functions are discussed in Chapter 12.

Solutions to the clinical case studies

Case 1:

The patient has an aneurysm of the arch of the aorta. With each systole the aneurysm swells and recoils thus pushing down on the bifurcation of the trachea and left primary bronchus. That is a tracheal tug.

Case 2

1. A narrowing of the descending aorta usually found immediately near the attachment of the ligamentum arteriosum, distal to the left subclavian artery.
2. The most frequently occurring lesions are those which occur as an adult. These lesions are found in the postductal region of the aorta, and the patients are frequently asymptomatic presenting only with headaches and epistaxis. The average lifespan for a patient with this type of lesion is 30–40 years.
3. The most important clinical finding was the difference in blood pressure in the upper versus lower extremity. This presented as diminished pulse in the lower extremities, coolness, fatigue and pain in the lower extremities (subsequent to anaerobic metabolism and lactic acid buildup). The higher blood pressure in the upper extremities was evident not only by the blood pressure itself, but also by the headaches and nose bleeds. The systolic murmur indicates a fluid overload or, in this case, stricture of the aorta and an inability to completely eject the volume through the aorta.
4. Pre- and post-coarctation dilation was seen in the region of the aortic knob. There was also rib notching, which reflects the erosion of bone by intercostal arteries that have become dilated and tortuous by the great volume of blood they are carrying as collateral blood flow.
5. A postductal lesion allows good collateral circulation from proximal to distal portions of the aorta via the anterior intercostals from internal thoracic artery anastomosing with posterior intercostal branches of descending aorta. A preductal lesion presents a life-threatening situation early in infancy. The distal aorta is initially filled via a patent ductus arteriosus, but as the ductus closes blood flow to the distal aorta diminishes, and the infant's survival may be threatened.
6. Surgical intervention, which includes resection of the coarctation and end-to-end anastomosis, patch aortoplasty or a bypass with a prosthetic graft. The treatment of choice for this patient would most likely be a bypass with a prosthetic graft.
7. Significant hemorrhage secondary to damage to the dilated intercostal arteries. Because it is necessary to clamp the aorta for the procedure, paraplegia may result from diminished blood flow to the spinal cord.

MCQs

1. The ductus arteriosus sometimes remains open after birth, requiring a surgical closure. When placing a clamp on the ductus, care must be taken to avoid injury to what important structure immediately dorsal to it?
A. Left internal thoracic artery
B. Left phrenic nerve
C. Left recurrent laryngeal nerve
D. Thoracic duct

2. A 7-year-old boy is found to have a midline tumour of the thymus gland that is impinging posteriorly on a blood vessel. Which of these vessels is most likely to be affected?
A. Left brachiocephalic vein
B. Left pulmonary vein
C. Left bronchial vein
D. Right pulmonary artery

3. A 32-year-old woman presents to her physician with complains of headaches. Her blood pressure is 220/100 mmHg. Her heart rate is 58 beats per minute. Her radial pulses are intact but her femoral pulses are reduced. She undergoes diagnostic angiography. The catheter is advanced from the femoral artery retrograde to the region of the aortic valve and then pulled distally into the first branch of the arch of the aorta. This structure is the:
A. Brachiocephalic trunk
B. Left common carotid artery
C. Left subclavian artery
D. Right common carotid artery

4. Upon radiographic examination of the thorax, the doctor noticed that the patient's ribs were unusually thin (rib notching). He also had strong radial pulses but a diminished pulse in the lower limbs. Which of the following was most likely responsible for this condition?
A. Obstruction of arch of the aorta proximal to major branches
B. Obstruction of arch of the aorta immediately distal to major branches
C. Subclavian artery obstruction
D. Common carotid artery obstruction

5. Which of these cells lining the trachea act as receptor cells?
A. Basal cells
B. Granule cells
C. Brush cells
D. Goblet cells

6. A 21-year-old man is diagnosed to have high blood pressure. The blood pressure is significantly higher in both upper limbs than in both lower limbs. Imaging reveals bilateral erosion of the anterior and lateral parts of his ribs. The angiography reveals a narrowing of the aorta. Where is the most likely site of the aortic constriction?
A. Between the brachiocephalic trunk and the left common carotid artery
B. Just distal to the ligamentum arteriosum
C. Between the origin of the subclavian artery and the ligamentum arteriosum
D. In the middle mediastinum

7. In this patient in Question 6, which of the following vessels is there a retrograde flow of blood?
A. Anterior intercostal arteries
B. Posterior intercostal arteries
C. Internal thoracic arteries
D. Right subclavian arteries

8. A 57-year-old man, who has smoked cigarettes for 40 years, has lung cancer that invades his left third intercostal space at the midaxillary line. If cancer cells were carried in the venous drainage of that intercostal space, they would travel first to which of the following intrathoracic veins?
A. Accessory hemiazygos vein
B. Azygos vein
C. Hemiazygos vein
D. Left brachiocephalic vein

9. A patient with intractable hiccups is treated by crushing of the right phrenic nerve in the neck to paralyze the right hemidiaphragm. After this procedure, however, the physician finds that the right half of the patient's diaphragm is not completely paralyzed. The diaphragmatic function is probably being maintained by an accessory phrenic nerve. From which of the following nerves is an accessory phrenic nerve most likely to arise?
A. Fourth intercostal nerve
B. Left phrenic nerve in thorax
C. Nerve to subclavius
D. Right phrenic nerve in thorax

10. Pain from the diaphragmatic pleura or peritoneum may be referred to the ipsilateral shoulder via the phrenic nerve and a cutaneous nerve that is derived from the same spinal cord segments as the phrenic nerve. Which cutaneous branch of the cervical plexus is involved in this referred pain?
A. Greater occipital nerve
B. Lesser occipital nerve
C. Supraclavicular nerve
D. Suprascapular nerve

11. Traumatic, acceleration/deceleration injuries to the aorta usually occur where its mobile and fixed portions meet. This would be at the:
A. Ligamentum arteriosum
B. Junction of aortic arch with the descending portion
C. Junction of the ascending aorta with the heart
D. Origin of the brachiocephalic artery on the arch

ANSWERS TO MCQs

1. C	2. A	3. A	4. B	5. C
6. B	7. B	8. D	9. C	10. C
11. A				

JUST BEFORE THE EXAM

Contents of the superior mediastinum → Arch of the aorta, trachea, thymus (in children), vagus and phrenic nerves, brachiocephalic veins and branches of arch of the aorta.

Arch of the aorta → It is the continuation of the ascending aorta at the level of the sternal angle. It continues as descending thoracic aorta at the level of the lower border of the T4 vertebra. It gives brachiocephalic trunk, left common carotid artery and left subclavian artery.

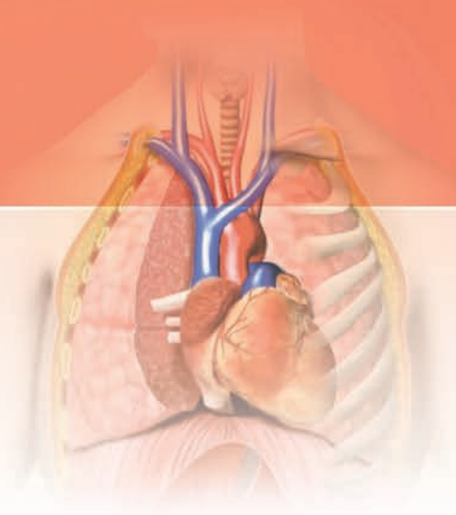
Major relations of arch of the aorta → Anteriorly and to the left—medial surface of the left lung, left phrenic nerve, left superior intercostal vein, left vagus nerve. Posteriorly and to the right—lower end of the trachea, oesophagus, left recurrent laryngeal nerve, thoracic duct, body of T4 vertebra.

Ligamentum arteriosum → It is connected to the under surface of the arch of the aorta (distal to the origin of the left subclavian artery) to the left pulmonary artery. Embryonic ductus arteriosus forms ligamentum arteriosum. The left recurrent laryngeal nerve winds around the ligamentum arteriosum.

Phrenic nerve → It arises from C3, C4 and C5 spinal nerves. In the neck, it descends in front of the scalenus anterior muscle. It supplies motor fibres to the diaphragm. It also supplies fibrous pericardium, parietal pleura (mediastinal and central diaphragmatic) and peritoneum covering undersurface of the diaphragm. Irritation of these structures can produce referred pain in the shoulder region because skin over the shoulder is supplied by supraclavicular nerve having root value C3 and C4.

Trachea → Length about 10 cm. It is the continuation of the larynx at the level of the lower border of the cricoid cartilage (opposite to C6 vertebra). It ends by diving into right and left principal bronchus at the level of lower border of T6 vertebra.

Microscopic structure of the trachea → It is lined by pseudostratified ciliated columnar epithelium. The submucosa presents many mucous glands. Outer to the submucosa, there are tracheal rings made up of hyaline cartilages which keep the lumen patent. Posteriorly the cartilages are absent and replaced by smooth muscles. The parasympathetic nerves (vagus) are secretomotor to tracheal glands and motor to the smooth muscles.



Chapter

46

Posterior Mediastinum

Competencies: AN 23.1 to 23.6, 25.8

Objectives

- To describe the parts and major relations of the oesophagus
- To locate the normal constrictions of the oesophagus
- To describe the microscopic structure of the oesophagus
- To describe the blood supply and lymphatic drainage of the oesophagus and its clinical relevance
- To locate the descending thoracic aorta and to list their branches
- To describe the formation, course, tributaries of azygos system of veins
- To describe the formation, course and termination of thoracic duct

OESOPHAGUS

It is a fibromuscular tube that transports food from the pharynx to the stomach. It is about 25 cm in length. It extends from the laryngopharynx (at the level of C6 vertebra/lower border of cricoid cartilage) to the cardiac end of the stomach (at the level of T11 vertebra). The oesophagus has three parts:
1. Cervical (4 cm)
2. Thoracic (20 cm)
3. Abdominal (1.25 cm).

Relations of the Cervical Part of the Oesophagus

Anteriorly: Trachea

Posteriorly: Prevertebral fascia and retropharyngeal space (this space is in front of the prevertebral fascia and posterior to the pharynx and upper part of the oesophagus).

Laterally: The recurrent laryngeal nerve ascends in the tracheoesophageal groove. The common carotid artery and lateral lobes of thyroid are related to oesophagus on either side (Fig. 46.1). The pharyngoesophageal junction is surrounded by the upper oesophageal sphincter, also known as the cricopharyngeus muscle (portion of the inferior pharyngeal constrictor muscle).

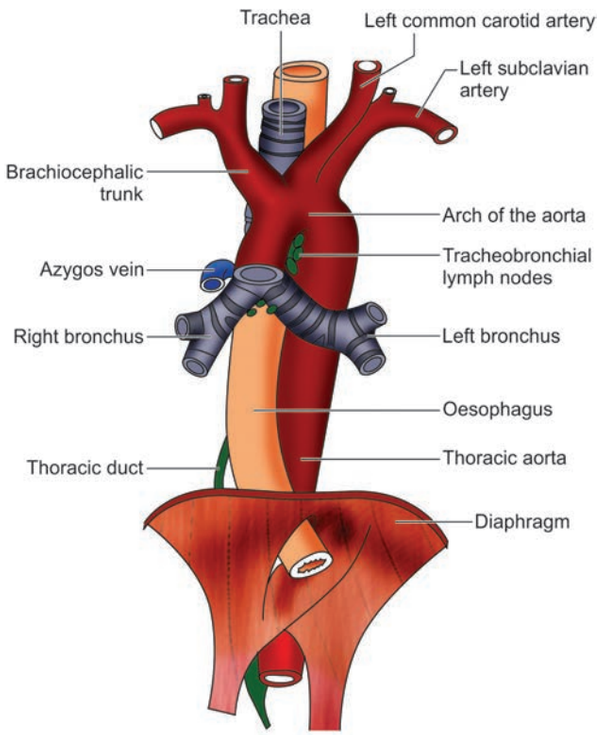


Fig. 46.1: Oesophagus (schematic)

Relations of the Thoracic Part of the Oesophagus

Anteriorly (from above downwards): Trachea, arch of the aorta, left main bronchus, oblique sinus of the pericardium (separating it from the left atrium).

Posteriorly: Thoracic part of the vertebral column, right posterior intercostal arteries, thoracic duct and azygos vein. The descending thoracic aorta is related to the left in the upper part of the posterior mediastinum and posterior to it in the lower part (Fig. 46.2).

To the left (in the superior mediastinum): Thoracic duct, left recurrent laryngeal nerve, left subclavian artery, upper lobe of the left lung. In the posterior mediastinum, oesophagus is related to left lung where it makes an impression.

To the right: Medial surface of the right lung behind the hilum.

- Oesophagus passes through the oesophageal orifice of the diaphragm (at the level of 10th thoracic vertebra) and enters the abdominal cavity along with the right and left vagus nerves (posterior and anterior gastric nerves).
- Though there is no anatomical sphincter at the lower end, the opening of the diaphragm acts as a **lower oesophageal sphincter**. This opening is formed by right crus of the diaphragm. The fascia covering the under surface of the diaphragm is attached to the margins of the oesophagus by **phreno-oesophageal ligament**. Food passes through oesophagus by peristaltic action of its musculature and not by gravity (one can still swallow if inverted). The lumen of the oesophagus is normally collapsed and prevents reflux of the stomach contents into the oesophagus.

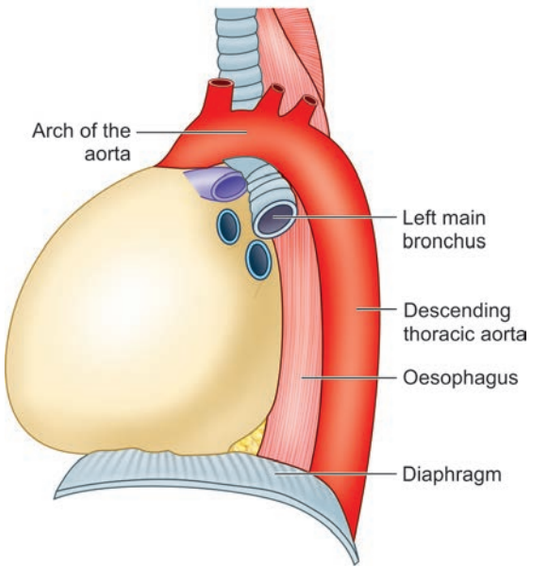


Fig. 46.2: Arch of the aorta—lateral view

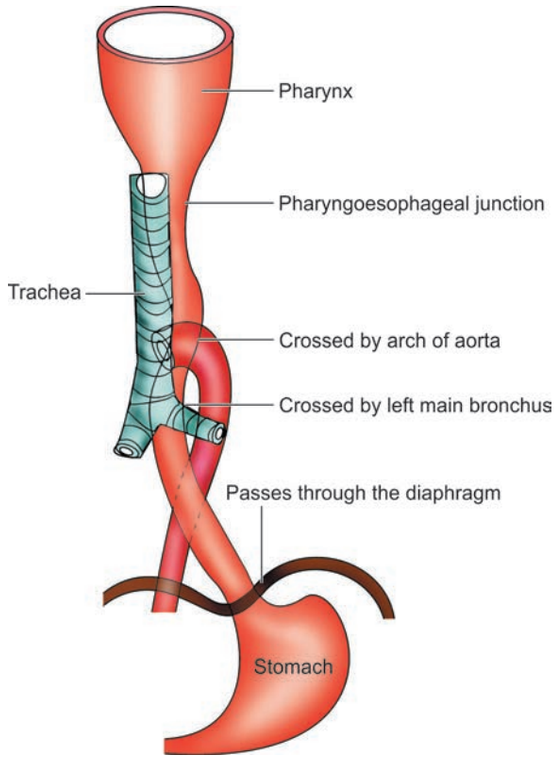


Fig. 46.3: Normal oesophageal constriction

Oesophagus presents **four normal constrictions**, which are important during instrumentation through it (Fig. 46.3).

1. **First constriction** is at the pharyngoesophageal junction (at the level of C6 vertebra). It is about 6 inches from the incisor teeth.
2. **Second constriction** is where it is crossed by arch of aorta (at the level of T4 vertebra). It is about 9 inches from the incisor teeth.
3. **Third constriction** is where it is crossed by left bronchus (at the level of T6 vertebra). It is about 11 inches from incisor teeth.
4. **Fourth constriction** is where the oesophagus passes through the diaphragm (at the level of T10 vertebra). It is about 15 or 16 inches from the incisor teeth.

Arterial Supply

The oesophagus is supplied by the branches of the following arteries: Inferior thyroid artery, descending thoracic aorta, bronchial arteries and left gastric artery.

The cervical part of the oesophagus drains into inferior thyroid vein, thoracic part into azygos and hemiazygos veins and abdominal part into left gastric vein (one of the sites of portocaval anastomosis).

Lymphatic Drainage

The cervical part drains into deep cervical lymph nodes, the thoracic part into posterior mediastinal nodes. The abdominal part drains into left gastric and then into coeliac group of lymph nodes.

Nerve Supply

The striated muscles of the upper part of the oesophagus are supplied by vagus nerve. The remaining part by oesophageal plexus which consists of sympathetic and parasympathetic nerve fibres. The sympathetic fibres are derived from T4 and T5 segments of the spinal cord and reach the oesophagus through greater splanchnic nerves. It carries pain sensation (especially from the lower part, which is vulnerable to acid peptic oesophagitis). The referred pain from such oesophagitis is felt at the lower thoracic and epigastric region. This is often referred as heart burn, sometimes mistaken for angina.

The parasympathetic nerves are derived from vagus and are motor to musculature of the oesophagus and secretomotor to oesophageal glands.

General Features of the Wall of the Digestive Tract

Before studying the microscopic structure of the oesophagus, you need to understand the general organization of the gastrointestinal (GI) tract. Most parts of the GI tract have similar arrangements with few exceptions. The wall of the GI tract consists of following layers from lumen to outside, they are (Fig. 46.4):

1. **Mucosa:** It has lining epithelium (which faces the lumen), lamina propria (mainly loose connective tissue, blood and lymphoid vessels) and muscularis mucosa (smooth muscles).
2. **Submucosa:** It contains dense irregular connective tissue, blood and lymphatic vessels, nerve plexus (Meissner's plexus). Some organs have glands and lymphoid nodules in this layer.
3. **Muscularis externa:** It is the thickest layer consisting of smooth muscles which are arranged circularly on the inner aspect and longitudinally on the outer aspect. In the intestine, they are responsible for peristalsis. Apart from blood and lymphoid plexus, they contain nerve plexus called Auerbach's plexus.
4. **Serosa or adventitia:** Externally the gastrointestinal tract is covered by a peritoneum which is called serosa. Wherever peritoneum is not there, the connective tissue forms adventitia.

Microscopic Structure of the Oesophagus

The lumen of the oesophagus is always in collapsed state, and they open only when food passes through it. The lumen shows branched appearance in cross section view because of longitudinal folds of mucous membrane. The wall of the oesophagus is made up of four layers from inside to outside (Fig. 46.5A and B); mucosa, submucosa, muscularis externa and adventitia.

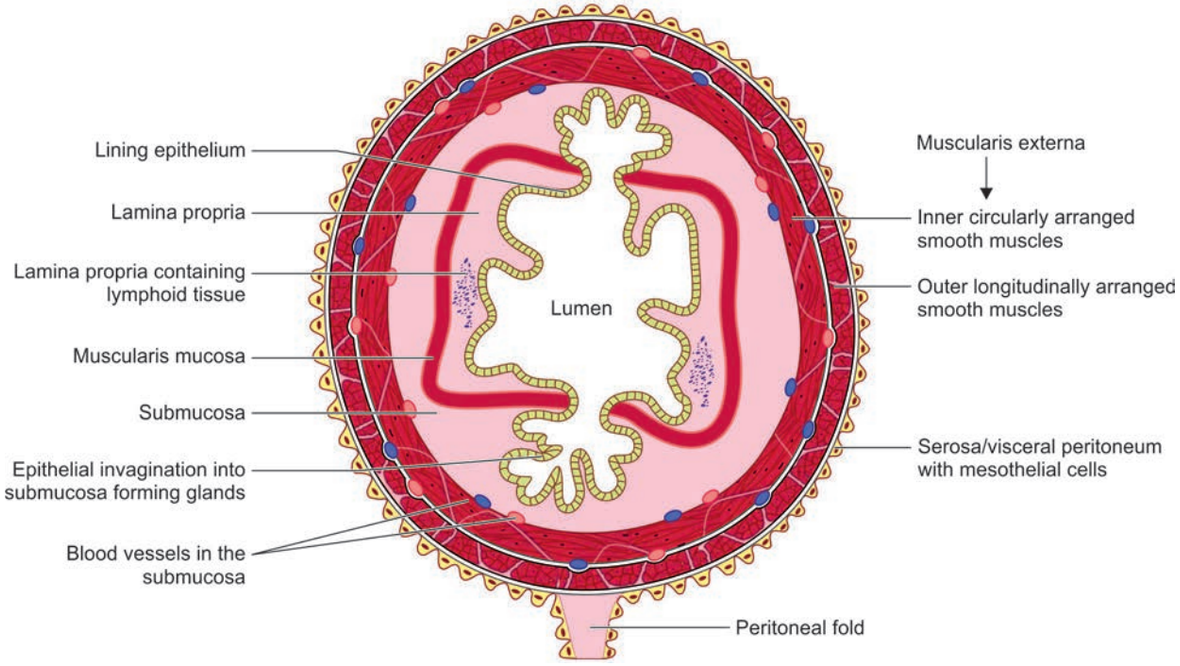


Fig. 46.4: A cross section through a gastrointestinal tract shows its layers (schematic)

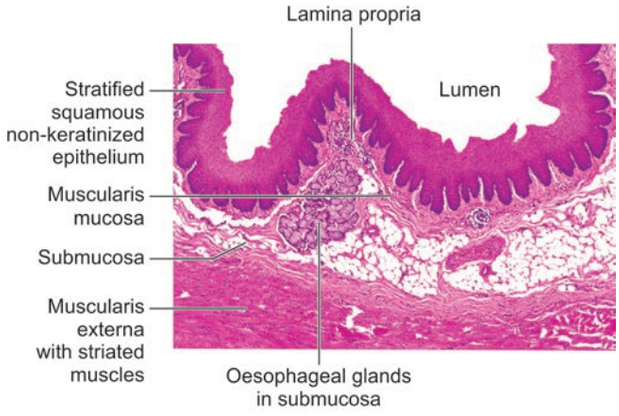


Fig. 46.5A: A photomicrograph showing the histology the oesophagus (cross section view, H&E staining)

1. Mucosa

a. **Lining epithelium:** The oesophagus is lined by stratified squamous non-keratinized epithelium. As food passes through oral cavity, pharynx and oesophagus, the mucosa requires protection hence lined by stratified squamous epithelium.

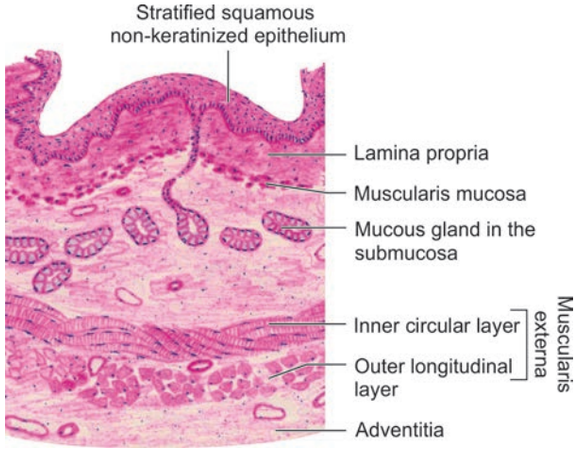


Fig. 46.5B: A schematic illustration showing histology of the oesophgus

b. **Lamina propria:** The lamina propria shows interdigitates of basal border of the epithelium. The connective tissue of the lamina propria has diffuse lymphoid tissue. The lamina propria in the lower part of the oesophagus presents **oesophageal cardiac glands**. They produce neutral mucus. These glands protect the oesophagus from regurgitated gastric contents (gastroesophageal reflux).

c. **Muscularis mucosa:** The muscularis mucosa has longitudinally arranged smooth muscles (in most other parts of the gastrointestinal tract, its inner circular and outer longitudinally arranged smooth muscles) and is very thick in the upper part of the oesophagus aiding the swallowing.

2. Submucosa

It consists of dense irregular connective tissue with blood and lymphatic vessels, nerve fibres. The nerve plexus (Meissner's plexus) contains ganglion cells. **The submucosa presents mucous secreting oesophageal glands proper**. They are more numerous in the upper part of the oesophagus. These are compound tubuloalveolar glands. Their ducts open into the lumen. Lymphoid tissue and lymphoid nodules are more towards upper and lower ends of the oesophagus.

3. Muscularis externa

It consists of two muscle layers, an inner circular layer and an outer longitudinal layer. In upper one-third it is striated (voluntary), in the middle one-third, it is mixed (both striated and smooth) and in the lower one-third it is smooth muscles. The myenteric plexus (Auerbach's plexus) is present between outer and inner muscle layers with ganglion cells. The muscles are responsible peristaltic activity. The striated muscles are supplied by vagus nerves.

4. Adventitia

It is the connective tissue layer connecting the oesophagus with adjoining structures.

Clinical Notes

Carcinoma of the oesophagus: The squamous cell carcinoma arises from the epithelium lining the oesophagus (associated with tobacco and alcohol consumption) and the adenocarcinoma arises from glandular cells that are present at the junction of the esophagus and stomach (associated with a history of gastroesophageal reflux disease/GERD). The oesophageal tumors usually lead to dysphagia (difficulty swallowing), pain and other symptoms, and are diagnosed with biopsy. The carcinoma spreads by lymphatics and involves posterior mediastinal lymph nodes, gastric and coeliac nodes. The direct infiltration can involve the lungs.

The gastroesophageal reflux disease (GERD): The lower end of the oesophagus is guarded by a physiological sphincter which prevents gastro-esophageal reflux. However, it can become compromised, usually by a loss of muscle tone or sliding hiatal hernia (explained in Chapter-Diaphragm). The acidic chyme burns and inflames the oesophageal mucosa (oesophagitis). It causes uncomfortable sensation or heartburn, and dysphagia.

Oesophageal varices: It occurs in portal hypertension. The anastomoses between the tributaries of systemic and portal vessels at the lower end of the oesophagus dilate. The varices (dilated veins) lie immediately beneath the mucosa, where they are

subjected to mechanical trauma during deglutition, or by the passage of diagnostic instruments. They produce no symptoms until they rupture, causing massive haematemesis (vomiting of blood). The oesophageal varices can be visualized radiographically by barium swallow.

Endoscopy: The interior of the oesophagus is examined directly through an instrument. Endoscopy is a very useful tool in the diagnosis and treatment of oesophageal diseases. It is a highly reliable diagnostic method for evaluating oesophageal disorders that affect the mucosa or alter the lumen of the organ. It allows the procurement of cytology and histology samples. The most common mucosal and luminal abnormalities diagnosed by endoscopy are foreign bodies, oesophagitis, strictures, oesophageal ulcers, fistula and neoplasia.

Achalasia cardia: In achalasia, the oesophageal sphincter remains contracted, the normal peristalsis is interrupted, and food cannot enter the stomach. It is due to congenital absence of the nerve cells of oesophagus. The most common symptom of achalasia is dysphagia.

Dysphagia: It means difficulty in swallowing. Any structure related to oesophagus can compress it, causing dysphagia. Such compression can be due to aneurysm of the arch of the aorta, enlarged lymph nodes, enlarged left atrium (mitral stenosis), retrosternal goiter, aberrant right subclavian artery. The oesophageal strictures and carcinoma can also cause dysphagia.

Radiological examination: The interior of the oesophagus can also be examined by a barium swallow radiological method (Fig. 46.6A and B).

CASE 1

A 55-year-old carpenter is admitted to the hospital as an emergency. He has severe shortness of breath (dyspnea) and great difficulty in swallowing (dysphagia). The patient states that for the past six months he had suffered increasing difficulty and pain in swallowing. He has to restrict himself with a liquid diet and has lost weight. His shortness of breath has been present for the past few weeks. From time to time, he has severe coughing spells, his sputum is blood-tinged, and occasionally he brings up as much as a cupful of blood. He states that for the last few weeks he has become quite hoarse. Fluoroscopic examination of the oesophagus with radiopaque barium demonstrates an obstruction at the level of the bifurcation of the trachea. It was diagnosed as oesophageal cancer that has obstructed the oesophagus at one of its most common site—the level of the tracheal bifurcation. The common sites of esophageal cancer correspond to the physiologic constrictions of the oesophagus.

1. Where are the oesophageal constrictions located?
2. What is the anatomical basis for dyspnea?
3. Why did the patient become hoarse?
4. What lymph nodes are likely to be involved?

DESCENDING THORACIC AORTA

It is the continuation of the arch of the aorta. It descends in the posterior mediastinum of the thorax. It enters the abdominal cavity by passing through the diaphragm (aortic opening) at the level of T12 vertebra, where it is accompanied by thoracic duct and azygos vein. In the abdomen it continues as abdominal aorta (Fig. 46.7).

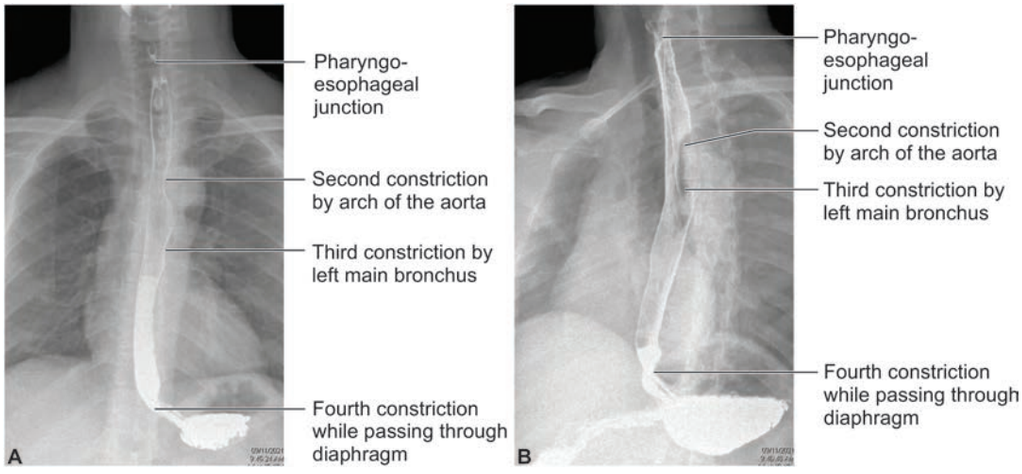


Fig. 46.6: Barium swallow. **A:** Anterior view; **B:** Lateral view

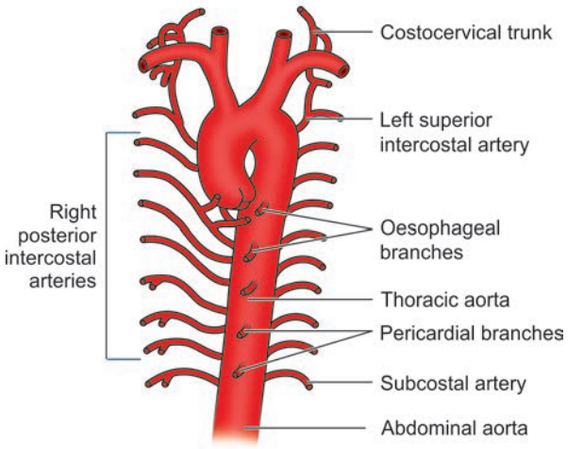


Fig. 46.7: Thoracic aorta

Relations

- Anteriorly: Root of the left lung, pericardium and heart and oesophagus in the lower part
- Posteriorly: Thoracic part of the vertebral column
- On right side: Thoracic duct and azygos vein
- On left side: It forms an impression on the medial surface of the left lung.

Branches

- They include third to eleventh posterior intercostal arteries on each side. These arteries supply the thoracic wall.
- The other branches from the thoracic aorta are oesophageal and mediastinal arteries, upper and lower left bronchial arteries and inferior phrenic arteries.

Clinical Notes

Dissecting Aneurysm (Aortic Dissection)

It is due to a tear in the wall of the aorta (usually affecting descending thoracic aorta), the blood in the lumen of the aorta enters tunica intima and media. It causes dilatation of the aorta. The dilated aorta can compress intercostal nerves causing pain in the thoracic wall. A ruptured aorta causes accumulation of blood in the left pleural cavity.

AZYGOS SYSTEM OF VEINS

The intercostal spaces of thorax are drained by anterior and posterior intercostal veins. The anterior intercostal veins terminate in internal thoracic vein. However, the mode of termination of posterior intercostal veins differs on two sides. They drain into azygos (azygos = unpaired) system of veins (Fig. 46.8).

Azygos Vein

It is an important vein draining the venous blood from the posterior abdominal wall and major portion of the thoracic wall.

Formation

It is formed within the abdominal cavity by many combinations.

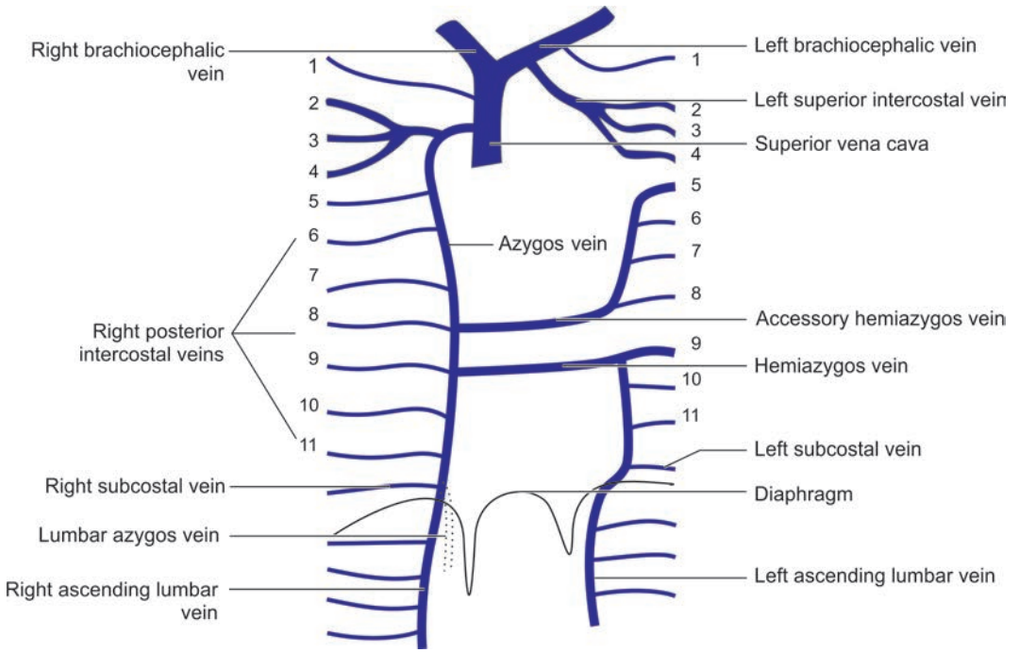


Fig. 46.8: Azygos system of veins in the posterior thoracic wall

- Usually, it is formed by the union of right ascending lumbar vein (which is formed by the union of four lumbar veins) and right subcostal vein.
- Sometimes a lumbar azygos vein (a vein arising from the inferior vena cava) can also contribute to the formation of azygos vein.
- It ascends through aortic opening of the diaphragm. It ascends in the posterior mediastinum on the right side.

Termination

It arches over the root of right lung and opens into the superior vena cava.

Tributaries

a. The right posterior intercostal veins (4th to 11th)
b. The right subcostal vein.
c. The right superior intercostal vein formed by the union of right 2nd, 3rd and 4th posterior intercostal veins.
d. **Accessory hemiazygos vein,** which is formed by the union of 5th to 8th left posterior intercostal veins. At the level of T7 vertebra it crosses to the right-side posterior to thoracic duct and descending thoracic aorta to join azygos vein.
e. **Hemiazygos vein,** which is formed by the union of left ascending lumbar vein and left subcostal vein. It enters the thorax by piercing the left crus of the diaphragm. It ascends in front of the thoracic vertebral bodies and crosses to the right side at the level of T8 vertebra to join azygos vein.
f. Right bronchial vein and also some oesophageal, pericardial and mediastinal veins.

Clinical Notes

The internal thoracic vein would provide a collateral route for drainage if the azygos vein is obstructed. In case of an obstruction, blood could flow from the posterior intercostal veins (which usually drain into the azygos) into the anterior intercostal veins, enter the internal thoracic vein, and drain into the right brachiocephalic vein. This would allow the blood to bypass the blockage.

THORACIC DUCT

It is a major lymphatic vessel draining lymph from the whole body except the right upper limb, right side of the head and neck and right half of the thorax.
It is about 45 cm in length and has beaded appearance with many valves inside.

It begins from the **cisterna chyli** (at the level of T12 vertebra) in the abdominal cavity and enters thorax by passing through aortic orifice where it is related to aorta and azygos vein (Fig. 46.9A to C).

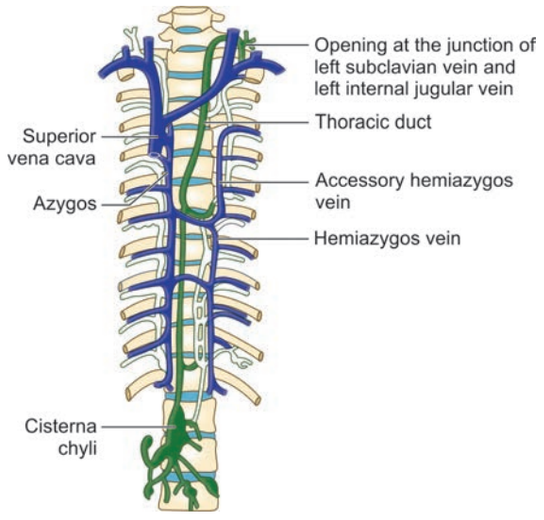


Fig. 46.9A: Thoracic duct and azygos system of veins

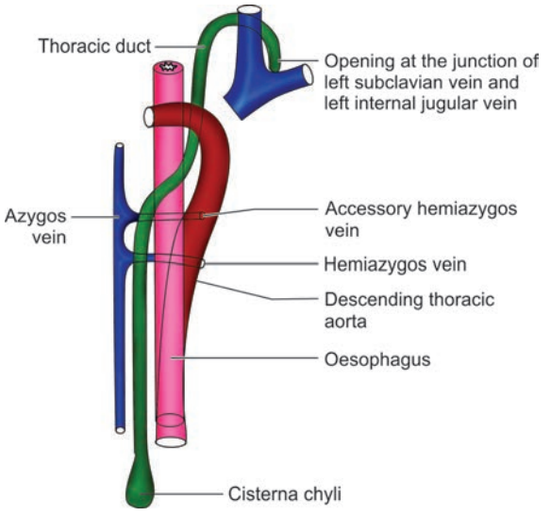


Fig. 46.9B: Thoracic duct (schematic)

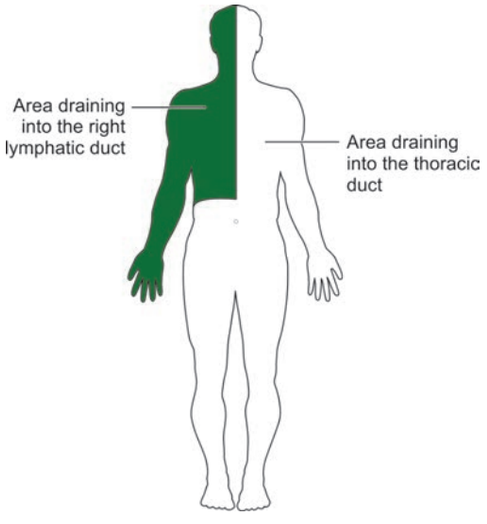


Fig. 46.9C: Area drained through thoracic duct

Course and Relations

- It ascends in the posterior mediastinum in front of the thoracic vertebral bodies and behind the oesophagus.
- At the level of T5 vertebra it inclines to the left and then ascends upwards in the superior mediastinum along the left edge of the oesophagus.
- At the root of the neck (at the level of transverse process of C7 vertebra), it arches laterally behind the lower end of the carotid sheath and in front of the vertebral artery and turns downwards.
- It terminates at the junction of left subclavian vein and left internal jugular vein and at this site it is guarded by a valve.

Tributaries

1. Left jugular lymph trunk bringing lymph from left half of the head and neck area.
2. Left subclavian lymph trunk bringing lymph from left upper limb including left mammary gland.
3. Left bronchomediastinal lymph trunk bringing lymph from left lung and left half of the mediastinum.
4. Lymph vessels draining from left posterior intercostal nodes of the upper six spaces of the left side.
5. Descending thoracic lymph trunks (right and left) draining from lower six spaces.
6. Ascending lymph trunks (right and left) draining from upper lumbar lymph nodes.

Clinical Notes

Filarial parasites may obstruct the thoracic duct and sometimes cause rupture of the duct. The chyle (lymph from intestine) may fill pleural (chylothorax) or peritoneal cavity (chyloperitoneum) and sometimes in cavity of the tunica vaginalis.
The terminal part of the thoracic duct may be injured during removal of supraclavicular lymph nodes.

CASE 2

A 48-year-old patient is currently recovering from a modified radical neck procedure for squamous cell carcinoma of the tongue. The patient presents tachycardia and was hypotensive with decreasing urinary output and poor skin turgor. He is intermittently combative and semiconscious. On a physical examination, you note the incision line on the left side of his neck to be intact with a bulb suction device protruding through the incision. The surrounding region of the neck is edematous, and a palpable mass roughly 8 cm in diameter is felt. You connect the bulb suction to the wall suction apparatus and approximately 600 ml of milky white fluid is immediately aspirated from the wound with a subsequent diminution in the size of the mass. Over the next few hours, you notice that the patient continues to have worsening hypotension, and the wound has now drained over 1 liter of milky white fluid in the period of six hours. The physician diagnosed a chylothorax.

1. What is chylothorax?
2. How would you explain the milky white fluid following this kind of operation?
3. Which lymphatic channel/duct would be involved?
4. What is the course of the thoracic duct?
5. What structures drain into the thoracic duct?
6. Which lymph nodes are found in the posterior mediastinum?

AUTONOMIC NERVES OF THE THORAX

The autonomic nervous system has two components —sympathetic and parasympathetic. The balanced activity between these two systems is important for normal functions of the organs like lungs and heart.

Thoracic Part of the Sympathetic Chain

- The right and left sympathetic chain is placed on either side of the thoracic vertebral bodies (paravertebral) close to the heads of the ribs (Fig. 46.10).
- Each sympathetic chain extends from the base of the skull and extends up to the coccyx. In the cervical region, the chain has three ganglia. The cervical part of the sympathetic chain continues as thoracic part of the sympathetic chain.

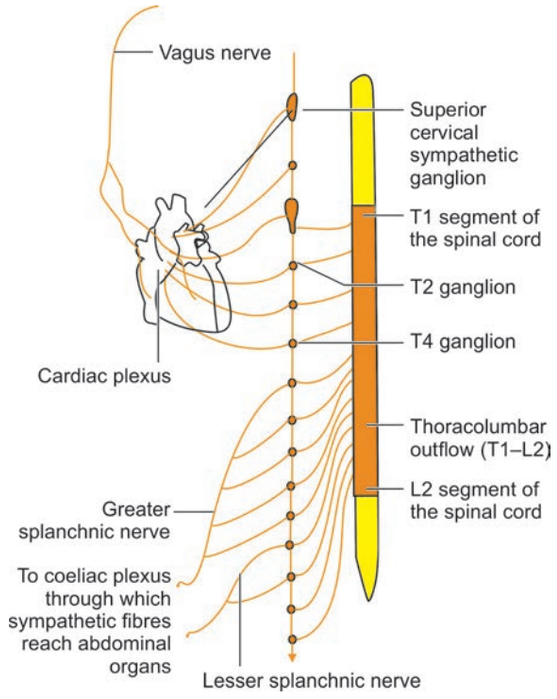


Fig. 46.10: Thoracic part of the sympathetic chain

- The thoracic part of the sympathetic chain continues as lumbar part of the sympathetic chain after descending deep to the medial arcuate ligament.
- The thoracic part of the sympathetic chain consists of 11 ganglia.
- The first thoracic ganglion is often fused with inferior cervical ganglion, which is star shaped (stellate ganglion) placed in front of the neck of the 1st rib.
- Each thoracic sympathetic ganglion is connected with corresponding thoracic spinal nerves by two communications, the pre- (white ramus) and post- (grey ramus) ganglionic communicants. The white rami communicantes bring preganglionic sympathetic fibres from the spinal cord (lateral horn), grey rami communicantes give postganglionic sympathetic fibres to thoracic spinal nerves (to sweat glands, arrector pilorum muscle and blood vessels).
- The **preganglionic sympathetic fibres** (without relaying in the ganglion) also pass out as splanchnic nerves.
  1. The **greater splanchnic nerve is derived from 5th to 8th thoracic sympathetic ganglia** on each side. It descends into the abdomen by piercing the crura of the diaphragm to terminate in coeliac ganglion in the coeliac plexus (providing sympathetic fibres to abdominal organs).
  2. The **lesser splanchnic nerve is derived from 9th and 10th thoracic sympathetic ganglia**. It ends in aorticorenal ganglion in the celiac plexus after piercing the crura of the diaphragm.
  3. The least splanchnic nerve (may be absent) from the 11th thoracic sympathetic ganglion ends in renal plexus.
- The thoracic splanchnic nerves lie on the anterior surfaces of the vertebral bodies.
- The splanchnic nerves lie medial to the sympathetic trunk, which is lying on the heads of the ribs.
- The upper 5 thoracic sympathetic ganglia give cardiac branches to cardiac plexus (for heart) from which the pulmonary plexus supplies the lung.
- The pain fibres from the viscera (visceral afferent) is also conveyed through these sympathetic nerves and ganglion (without relaying there) but reach spinal cord through dorsal root (neurons are located in the dorsal root ganglion).

Vagus Nerve

The parasympathetic fibres to the thoracic and majority of the abdominal organ are derived from vagus nerve. The preganglionic parasympathetic fibres are derived from dorsal nucleus of vagus present in the medulla oblongata.

The course and branches of vagus in the thorax is discussed in Chapter 45: Superior Mediastinum.

Solutions to the clinical case studies

Case 1

1. Refer to text
2. Dyspnea is due to compression of trachea at its bifurcation.
3. As a result of the tumor affecting the recurrent laryngeal nerve.
4. Posterior mediastinal lymph nodes, gastric and coeliac nodes.

Case 2

1. A pleural effusion composed of lymphatic fluid due to disruption of the thoracic duct.
2. The fluid is lymph, which contains lipids and hence presents as milky white drainage. Given the location of the surgical procedure—dissection of the left neck—there is a danger of injuring the thoracic duct or its major tributaries, particularly the jugular trunk found within the neck.
3. The thoracic duct begins at the cisterna chyli in the abdomen and extends cranially on the anterior surface of the vertebral bodies. It passes through the diaphragm along with the aorta at the T12 level. It then shifts to the left at T5 to T7 and then empties into the left subclavian vein.
4. The thoracic duct receives branches from the intercostal spaces, and the jugular, subclavian, and bronchomediastinal trunks of the lymphatic system.
5. The posterior mediastinal lymph nodes lie posterior to the pericardium. These lymph nodes receive lymph from the esophagus, the posterior aspect of the pericardium, and the middle posterior intercostal spaces.

MCQs

1. In which of these structures, the sympathetic fibres in the greater thoracic splanchnic nerve terminates?

A. Brainstem
B. Coeliac ganglion
C. Sympathetic chain ganglion
D. Spinal cord

2. Which nerve fibres has its cell body in the lateral horn of the spinal cord at segmental level T1?

A. Afferent fibres from skin around the nipple
B. Efferent fibres to sweat glands in the lumbar region
C. Efferent fibres to skin of the forehead
D. Parasympathetic fibres to the heart

3. The grey rami communicantes contain postganglionic sympathetic fibres that innervate which of the following structures in the thoracic region?

A. Aorta
B. Heart
C. Lung
D. Sweat glands

4. In the mid-region of the thorax the thoracic duct lies immediately posterior to which of this structure?
A. Azygos vein
B. Oesophagus
C. Superior vena cava
D. Trachea

5. Lymph nodes can be found in which mediastinal compartment(s)?
A. Anterior
B. Middle
C. Posterior
D. All of the above

6. Which posterior mediastinal structure is most closely applied to the posterior surface of the pericardial sac?
A. Aorta
B. Azygos vein
C. Oesophagus
D. Thoracic duct

7. A tumor of the posterior mediastinum is most likely to compress which of the following structures?
A. Arch of the aorta
B. Oesophagus
C. Inferior vena cava
D. Pulmonary trunk

8. While performing transoesophageal echocardiography on a patient, the posterior wall of the oesophagus, immediately behind the left atrium, was punctured from within. The patient subsequently developed an infection in which of these regions?
A. Anterior mediastinum
B. Middle mediastinum
C. Posterior mediastinum
D. Superior mediastinum

9. Since the puncture in the previous question was through the posterior wall of the oesophagus. Which of the following structures located posterior to the oesophagus may also be affected?
A. Hemiazygos vein
B. Left bronchial vein
C. Left pulmonary vein
D. Thoracic duct

10. During a surgical procedure, a patient's right sympathetic trunk was accidentally severed just cranial to the level of spinal nerve T1. Which function would be left intact in the affected region?
A. Arrector pili muscle activity
B. Dilation/constriction of blood vessels
C. Sweat production
D. Voluntary muscle activity

11. Most of the drainage of the thoracic body wall reaches the superior vena cava via the azygos vein. A notable exception is the left superior intercostal vein, which normally drains into which of these veins?
A. Left brachiocephalic vein
B. Left bronchial vein
C. Left pulmonary vein
D. Left subclavian vein

12. An enlarging lymph node gradually constricts the flow of blood in the azygos venous arch. Which vessel would enlarge as a result of collateral drainage?
A. Superior vena cava
B. Inferior vena cava
C. Internal thoracic vein
D. Right brachiocephalic vein

13. During a procedure to harvest lymph nodes in the posterior mediastinum, the thoracic duct is accidentally cut. Which of the following conditions best explains the accumulation of lymph in the pleural cavity?
A. Pleurisy
B. Chylothorax
C. Pyothorax
D. Haemothorax

14. A cancerous growth from the body of the ninth thoracic vertebra exerts pressure anterolaterally. Which structure lies in direct contact with this growth?
A. Right phrenic nerve
B. Right vagus nerve
C. Right sympathetic trunk
D. Right greater thoracic splanchnic nerve

15. A 48-year-old female patient complains of excessive sweating on the right side of the face and neck and in the right armpit region, which leaves her clothing constantly stained with moisture. Since no medical treatment has proven effective, she is considering surgical denervation of the sweat glands in the affected areas. Which structure(s) might be removed or cut in order to alleviate her condition?
A. Cervicothoracic (stellate) ganglion
B. Dorsal roots of cervical nerves
C. Greater thoracic splanchnic nerve
D. Lumbar sympathetic trunk

16. While viewing an exploratory surgery on a patient injured in an automobile accident, you see the surgeon elevate the oesophagus off the vertebral bodies and look in the area between the azygos vein and descending aorta. What structure was she most likely looking for?
A. Left recurrent laryngeal nerve
B. Right pulmonary artery
C. Sympathetic trunk
D. Thoracic duct

17. The ductus arteriosus sometimes remains open after birth, requiring surgical closure. When placing a clamp on the ductus, care must be taken to avoid injury to what important structure immediately dorsal to it?
A. Accessory hemiazygos vein
B. Left internal thoracic artery
C. Left phrenic nerve
D. Left recurrent laryngeal nerve

18. A 62-year-old man, suspected of having widespread cancer of the lungs and bronchi, is brought in for bronchoscopic examination. The instrument is inserted into the airway, where it accidentally punctures the thin, brittle posterior wall of the diseased right main bronchus. A sudden gush of blood immediately indicates that the instrument has also torn the wall of the blood vessel immediately behind the right main bronchus. Which blood vessel is torn?
A. Azygos vein
B. Left brachiocephalic artery
C. Pericardiophrenic artery
D. Right pulmonary vein

19. In obstruction of the superior or inferior vena cava, venous blood is returned to the heart by an alternate route via the azygos vein, which becomes dilated in the process. Which of the following structures might it compress as a result?
A. Trachea
B. Root of the left lung
C. Arch of the aorta
D. Thoracic duct

20. A 58-year-old man undergoes upper gastrointestinal endoscopy to investigate the source of his acute gastrointestinal bleeding. After completion of the

procedure, the patient complains of pain and the feeling of a foreign body lodged in his throat. A chest radiograph shows mediastinal air and a widening of the mediastinum. A barium swallow confirms esophageal perforation. Iatrogenic perforation of the esophagus occurs most commonly at which of the following levels?

A. Pharyngoesophageal junction
B. Oesophageal opening of the diaphragm
C. Gastroesophageal junction
D. Site of compression by left primary bronchus and aortic arch

21. Which of the following best describes the area drained by the thoracic duct?

A. All of the body above the diaphragm
B. All of the body except the head and neck
C. Most of the body below the diaphragm
D. Thorax and abdomen only

22. Which of the following statements is incorrect regarding microscopic structure of the oesophagus?

A. The muscularis mucosa has only longitudinally arranged smooth muscles
B. The mucous glands are present in both lamina propria and the submucosa
C. The muscularis externa consists of both smooth and striated muscles
D. It is lined by stratified squamous non-keratinized epithelium in the upper part and simple columnar in the lower part

ANSWERS TO MCQs

1. B	2. C	3. D	4. B	5. D
6. C	7. B	8. C	9. D	10. D
11. A	12. C	13. B	14. D	15. A
16. D	17. D	18. A	19. D	20. A
21. C	22. D			

JUST BEFORE THE EXAM

Contents of the posterior mediastinum → Oesophagus, descending thoracic aorta, azygos system of veins and thoracic duct.

Oesophagus → Length—25 cm, extends from the level of C6 vertebra to the level of T11 vertebra. It has cervical, thoracic and abdominal parts.

Major relations of the oesophagus → Anteriorly, trachea, arch of the aorta, left atrium and oblique sinus of the pericardium. The descending thoracic aorta is related to its left in the upper part of the posterior mediastinum and posterior to it in the lower part. The vagus nerve descends on either side of the oesophagus, in the lower part, the left vagus descends in front of the oesophagus as anterior gastric nerve while the right vagus nerve descends as posterior gastric nerve. The recurrent laryngeal nerve ascends in the groove between the trachea and the oesophagus.

Oesophagus passes through the oesophageal orifice of the diaphragm (**at the level of T10 vertebra**) to enter the abdominal cavity.

Normal constrictions of the oesophagus → There are 4 normal constrictions: (i) At pharyngo-esophageal junction (at the level of C6 vertebra), 6 inches from the incisor teeth; (ii) Where it is crossed by arch of the aorta (at the level of T4 vertebra), 9 inches from incisor teeth; (iii) Where it is crossed by left bronchus (at the level of T6 vertebra), about 11 inches from the incisor teeth; (iv) Where the oesophagus passes through the diaphragm (at the level of T10 vertebra), about 15 or 16 inches from incisor teeth.

Microscopic structure of the oesophagus → It is lined by stratified squamous non-keratinized epithelium. The lamina propria contains mucous glands in the lower part of the oesophagus. The muscularis mucosa has only longitudinally arranged smooth muscles. Its submucosa presents mucous secreting **oesophageal glands**. The muscularis externa consists of inner circular and longitudinally arranged muscles. These muscles are skeletal (voluntary) in the upper part, mixed (both skeletal and smooth muscles) in the middle part and completely smooth muscles in the lower part. The striated muscles are supplied by vagus nerves and smooth muscles by autonomic nerves.

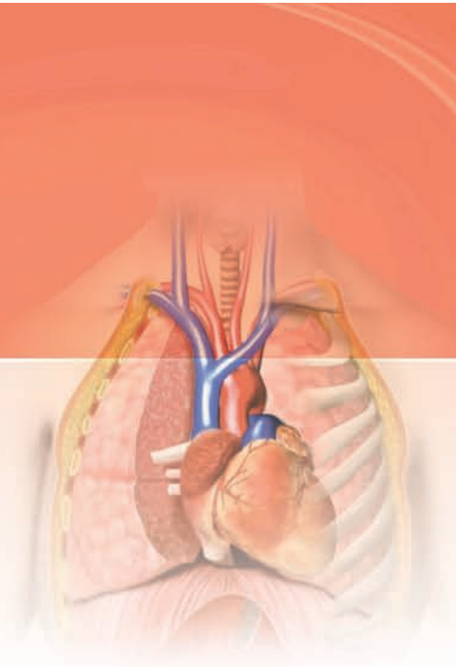
Descending thoracic aorta → It is the continuation of the arch of the aorta at the level of T4 vertebra. It descends in the posterior mediastinum and passes through the aortic opening of the diaphragm (at the level of T12 vertebra) where it is accompanied by thoracic duct and azygos vein. It gives 3 to 11 posterior intercostal arteries.

Azygos vein → It is formed by the union of right ascending lumbar vein (which is formed by the union of four lumbar veins) and right subcostal vein. It ascends through the aortic opening of the diaphragm. It arches over the root of the right lung and terminates in superior vena cava. It has many tributaries including accessory hemiazygos vein (5th to 8th left posterior intercostal veins) and hemiazygos vein (left ascending lumbar vein and left subcostal vein).

Thoracic duct → It is a lymphatic vessel which drains the lymph from the whole body except, right upper limb, right side of the head, neck and right side of the thorax. It is about 45 cm in length and has many valves inside. It begins from cisterna chyli (a lymphatic sac located in the abdomen at the level of T12 vertebra). Thoracic duct ascends through the aortic orifice of the diaphragm. At the level of T5 vertebra it inclines to the left side and

then ascends upwards in the superior mediastinum and enters the neck. It ends by joining the junction between left internal jugular and left subclavian veins.

Thoracic part of the sympathetic chain → It consists of 11 thoracic sympathetic ganglia. The splanchnic nerve arising from 5th to 8th thoracic sympathetic ganglia join together to form **greater splanchnic nerves** which end in the coeliac plexus (providing sympathetic fibres to abdominal organs). The splanchnic nerve arising from the 9th and 10th thoracic sympathetic ganglia forms **lesser splanchnic nerves** which also ends in coeliac plexus in the abdomen. The upper 5 thoracic sympathetic ganglia give branches to cardiac plexus to supply heart and lungs.



Chapter

47

Development of the Cardiovascular System

Competencies: AN 25.2 to 25.6

Objectives

- To describe the fate of five dilatations of the primitive heart tube, to explain the formation of inter-atrial and inter-ventricular septum and to discuss the anomalies related to them
- To summarize the development of right and left atria and right and left ventricles
- List the cyanotic and acyanotic congenital cardiac anomalies of the heart and to explain the Fallot's tetralogy
- List the cardiac anomalies with left to right shunt and right to left shunt
- To describe the fate of aortic arch arteries on each side and the embryology of patent ductus arteriosus (PDA)
- To describe the foetal circulation and series of events taking after birth in this circulation
- To describe the development of the superior and inferior vena cava and porta vein

DEVELOPMENT OF THE HEART

The cardiovascular system is the first organ system of an embryo to reach functional state.

Nutrition at the Early Stage of Development

In early stages of development, the morula is nourished by deutoplasm (cytoplasm of the ovum) and the blastocyst by the secretion from the uterine glands. In the first two weeks of development, the maternal blood present in the lacunar spaces of the syncytiotrophoblast reaches the embryo by diffusion. As embryo grows, this diffusion cannot meet the nutritional requirement, and this induces the formation of vascular system in the embryo.

- Vascular system of the human embryo appears in the middle of the 3rd week.
- The human embryonic heart begins beating around 21 days after conception and blood begins to circulate during 24th day.
- The first heart beat can be felt at 5–6 weeks of pregnancy in an ultrasound.

Cardiogenic Area

The splanchnopleuric layer of lateral plate mesoderm in the midline cranial to the prochordal plate is called cardiogenic area (Fig. 47.1). Some progenitor cells arise from the epiblast and migrate to the cardiogenic area. Initially these cells form cardiac myoblasts and blood islands that will form blood cells and vessels by

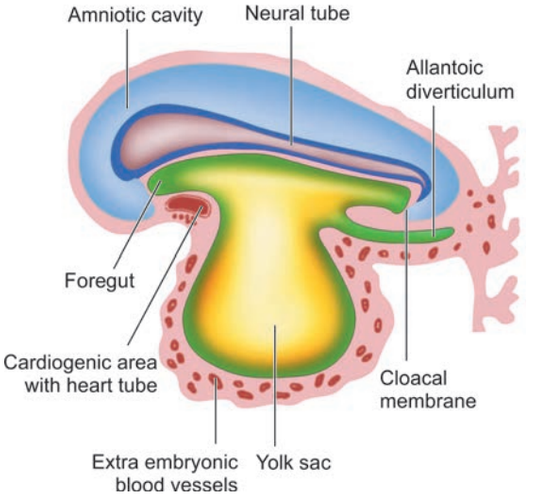


Fig. 47.1: Cardiogenic area (lateral view of the embryo)

the process called vasculogenesis. Two endothelial cells lined tube with myoblast surrounding them is formed in the cardiogenic area, below the floor of the pericardial sac. They are called primitive endothelial heart tubes.

Development of the Intraembryonic Blood Vessels

- Two longitudinal vessels are formed on either side of the notochord on dorsal wall of the yolk sac. These are called **dorsal aortae**.
- The cranial end of the dorsal aortae continues with primitive endothelial heart tube (Fig. 47.2).
- Caudally dorsal aortae continue with umbilical arteries (which are developed within the connecting stalk) and then break up into the capillary plexus in placenta.
- Capillary plexus in placenta forms venules which traverse the connecting stalk as umbilical veins.
- The umbilical veins continue with cranial end of the primitive heart tube.
- Thus, the caudal end of the primitive endothelial heart tube continues with dorsal aortae and cranial end with umbilical veins.
- The vitelline veins from the yolk sac and cardinal veins from the body wall also end at the cranial end of the primitive endothelial heart tubes (Fig. 47.2). These arrangements are seen before the head fold formation.

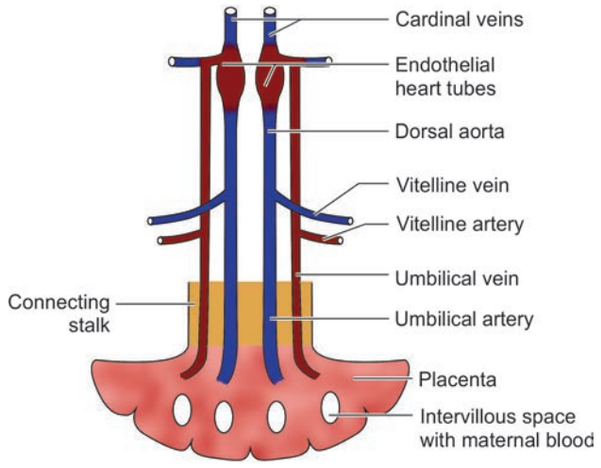


Fig. 47.2: Intraembryonic blood vessels

Effect of Head fold Formation on Cardiogenic Area

With the formation of head fold, there will be changes in the cardiogenic area (Fig. 47.3A and B).

- The heart tubes occupy dorsal to the pericardial cavity and the septum transversum lies still caudal to the cardiogenic area.

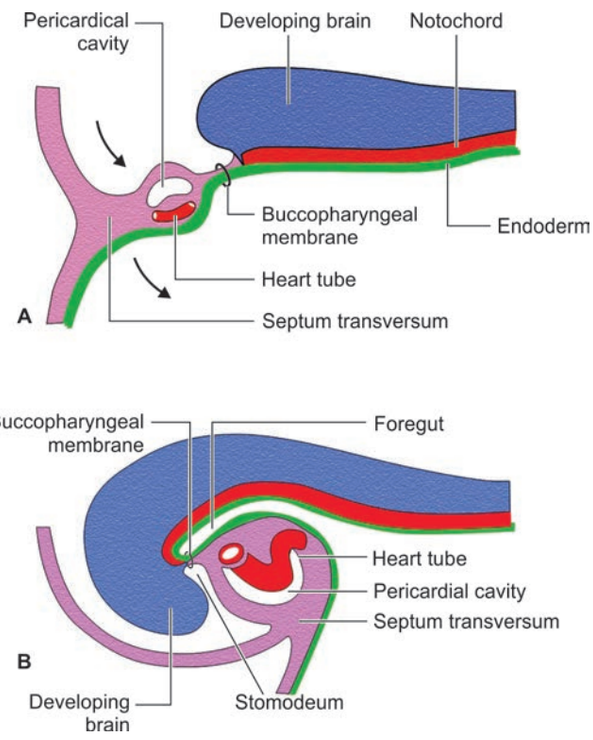


Fig. 47.3: Effect of head fold formation on cardiogenic area. **A:** Before head fold fomation; **B:** After head fold formation

- Now cranial end of the heart tube continues with dorsal aortae and the caudal end of the heart tube receives—vitelline veins, umbilical veins and common cardinal veins.

Definitive Heart Tube

The two heart tubes fuse to form a single heart tube (primitive heart). The cranial end is arterial (with dorsal aortae) and caudal end is venous (where umbilical,

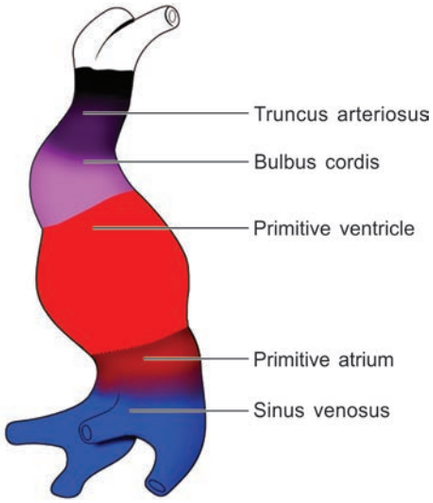


Fig. 47.4: Heart tube and its parts

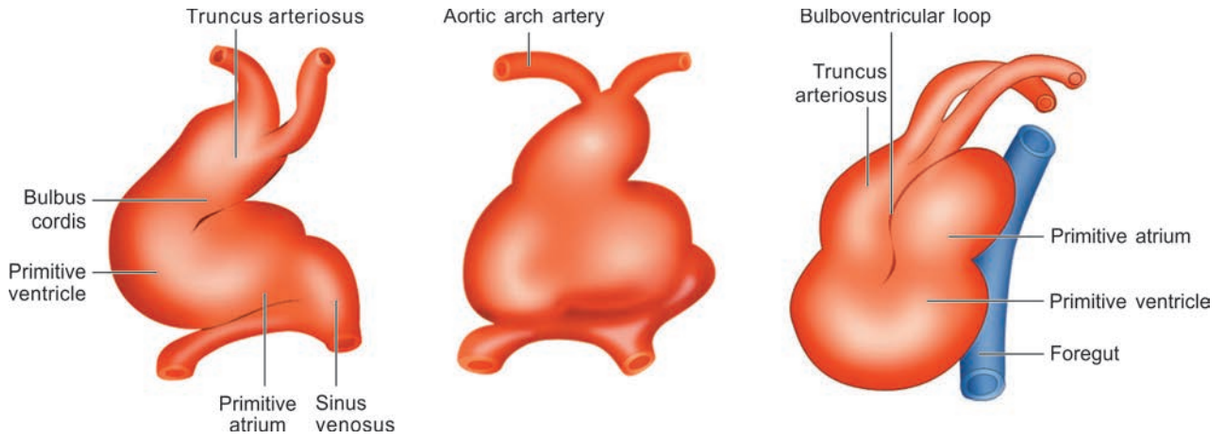


Fig. 47.5: Folding of the heart tube

vitelline and cardinal veins open). The primitive heart tube shows five dilatations with four constrictions. From cranial to caudal, these dilatations are (Fig. 47.4):

1. Truncus arteriosus
2. Bulbus cordis
3. Primitive ventricle
4. Primitive atrium
5. Sinus venosus

The bulbus cordis and truncus arteriosus form the outflowing tract. Some authors have labeled the proximal part of this outflowing part as conus and distal part as truncus and further distal portion (which is within the pericardial sac) as aortic sac. Others have called entire outflow part as bulbus. Because the term conus and truncus has been inconsistently used, we prefer to use the proximal portion of the outflow tract as bubus cordis and distal part as truncus arteriosus which continues with aortic sac.

Folding of the Heart Tube

The heart tube grows faster than the pericardial cavity. As venous and arterial ends are fixed by pericardium, the heart tube necessarily becomes bent (in order to accommodate itself within the pericardial cavity). Thus, a **bulboventricular loop** is formed between bulbus cordis and primitive ventricle. Internally these dilatations are separated by a bulboventricular ridge (Fig. 47.5).

The ventricle is projected ventrally and to the right side. At the caudal end of the heart tube, the primitive atrium undergoes transverse dilatation. The atrium and sinus venosus are gradually freed from septum transversum. Now the sinus venosus lies dorsal to the primitive atrium and their internal communication is called **sinoatrial orifice**. The caudal end of the heart tube remains separate by means of right and left horns of sinus venosus. Each horn receives three sets of veins.

The cranial end of the heart tube is connected on either side with corresponding dorsal aorta by 'first arch artery'. The aortic sac is the cranial end of the truncus arteriosus which divides into right and left horns. The atrium is sandwiched between foregut posteriorly and bulbus cordis anteriorly. The caudal part of the bulbus cordis is absorbed into the ventricle. The atrioventricular groove becomes narrow, and its lumen is called 'atrioventricular canal' (connecting primitive atrium with primitive ventricle).

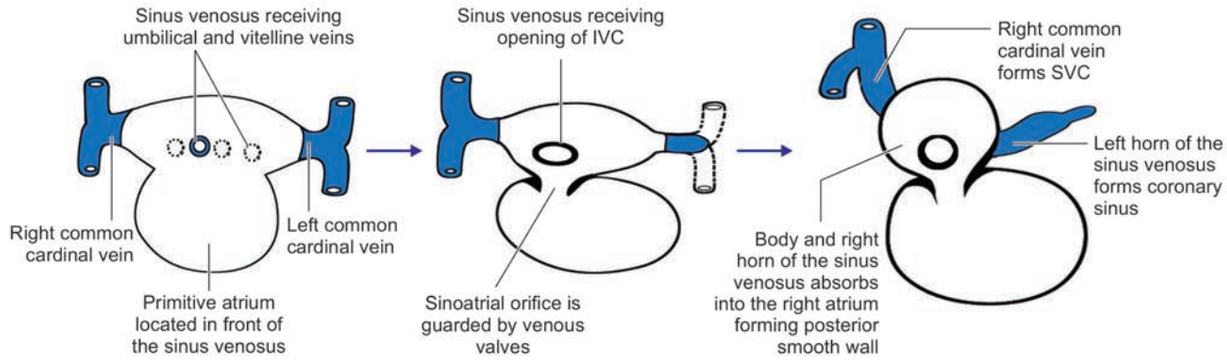


Fig. 47.6: Fate of the sinus venosus (schematic)

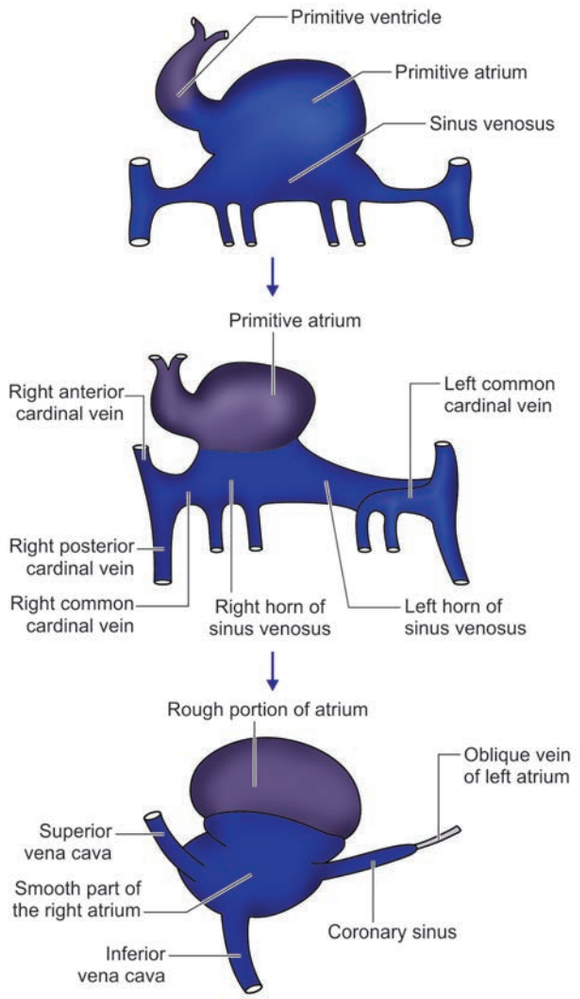


Fig. 47.7: Sinus venosus and its fate

Sinus Venosus and its Fate

The groove separating sinus venosus and primitive atrium deepens on left side and is called **sinoatrial fold.** Due to thickening of the sinoatrial fold, the sinoatrial orifice is shifted to the right side (Fig. 47.6). The vertically placed sinoatrial orifice is guarded by two valves projecting towards the atrium. Both these venous valves fuse above the orifice and form **septum spurium** and below as sinus septum. The right horn of the sinus venosus enlarges and left horn remains small due to major changes in the veins opening into the sinus venosus (Fig. 47.7).

- The left horn of the sinus venosus forms the coronary sinus.
- The right horn and body of the sinus venosus is absorbed into the primitive atrium forming smooth part of the right atrium.

Septal Formation in Atrioventricular Canal

From the ventral and dorsal wall of the atrioventricular canal, proliferation of mesenchymal tissue forms ventral and dorsal endocardial cushions. At the end of 5th week of intrauterine life, these endocardial cushions fuse to form fused **endocardial cushion (atrioventricular cushion or septum intermedium**). Thus, it divides the atrioventricular canal into right and left portions, so that the right half of the primitive atrium continues with right half of the ventricle and left half of the primitive atrium with left half of the ventricle (Fig. 47.8A and B).

Clinical Notes

Common Atrioventricular Canal

This is due to failure in the formation of atrioventricular cushion. It is associated with patent foramen primum and also interventricular foramen. The septal cusp of the tricuspid valve and ventral cusp of the mitral valve divides into ventral and dorsal parts, which fuse to form a common valve with five cusps at the single atrioventricular canal. This defect is a feature of Down syndrome.

Tricuspid Atresia

The right atrioventricular orifice is closed due to atresia of the tricuspid valve. The blood enters the right ventricle through patent foramen ovale

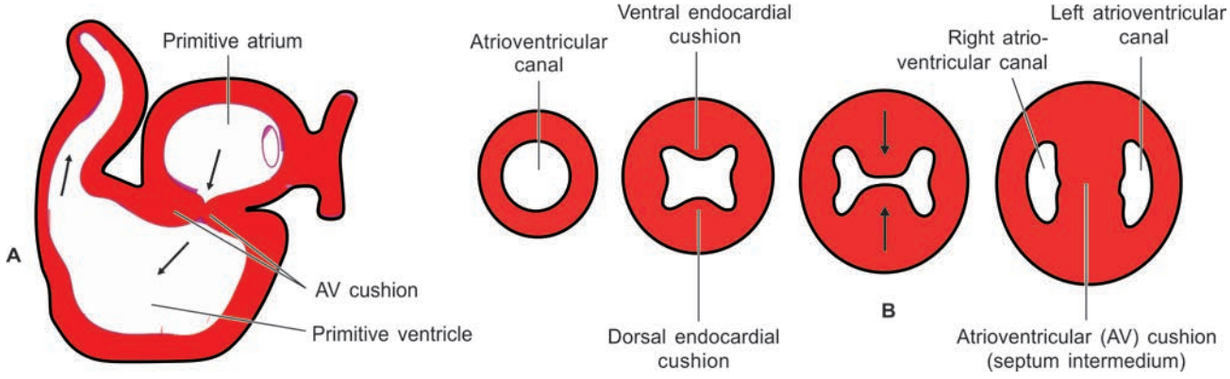


Fig. 47.8: **A:** Sagittal section and lateral view; **B:** Superior view

and the interventricular foramen. This will cause enlargement of left ventricle and right ventricle remains small.

Development of Interatrial Septum

- **Septum primum** (about 32nd day): A septum arises from the roof and dorsal wall of the primitive atrium (due to the pressure caused by bulbus cordis on primitive atrium) in the midline called septum primum.
- **Foramen primum:** The lower end of the septum primum is concave and growing towards atrio-ventricular cushion (septum intermedium). The gap between the lower end of the septum primum and atrioventricular cushion is called **foramen primum** (ostium primum).
- At this stage, the opening of the single vein can be found in dorsal wall of the left atrium. This vein taps venous plexus in developing lungs.
- The lower end of the septum primum grows down to fuse with atrioventricular cushions to obliterate the foramen primum (Fig. 47.9).
- Even before the obliteration of foramen primum, the cranial part of the septum primum shows perforation to establish new communication between the two atria.
- This communication is called **foramen secundum** (at the end of the 6th week of IUL). Hence, septum primum fails to make a partition between, as it is necessary to have communication between two atria for transferring the oxygenated blood from inferior vena cava to the left atrium.
- **Septum secundum** (during 7th week): It also grows downwards from the roof the atrium to the right of the septum primum.
- The lower end of septum secundum is free and has a thick edge called crescentic margin.
- The ventral end of this crescentic margin reaches the septum intermedium.
- The lower part of the septum secundum overlaps the upper end of the remaining part of the septum primum (which is attached to the septum intermedium).
- The valvular space between the two (between lower part of septum secundum and lower remaining part of septum primum) is called **foramen ovale.**
- The free margin of the septum secundum overrides the orifice of the inferior vena cava (IVC).
- The IVC blood rich in oxygen concentration, bypasses the right atrium by directly entering the left atrium through foramen ovale.
- For this reason, free margin of this septum is called crista dividens.
- The upper edge of the septum primum is called valve of foramen ovale.
- After birth, owing to the increased pressure in the left atrium (as pulmonary veins bring oxygenated blood to the left atrium), the valve of foramen ovale is pressed against the septum secundum.
- The functional closure takes palce at birth, but structurally it closes after few days.
- About 20% cases, the foramen ovale persists in adult heart (but blood will not mix) and is called **probe patency of foramen ovale.**
- In adult heart septum primum forms an oval depression called **fossa ovalis.**
- The upper, anterior and posterior margins of the fossa is sharp and is called limbus fossa ovalis (annulus ovalis) formed by the lower edge of the septum secundum.

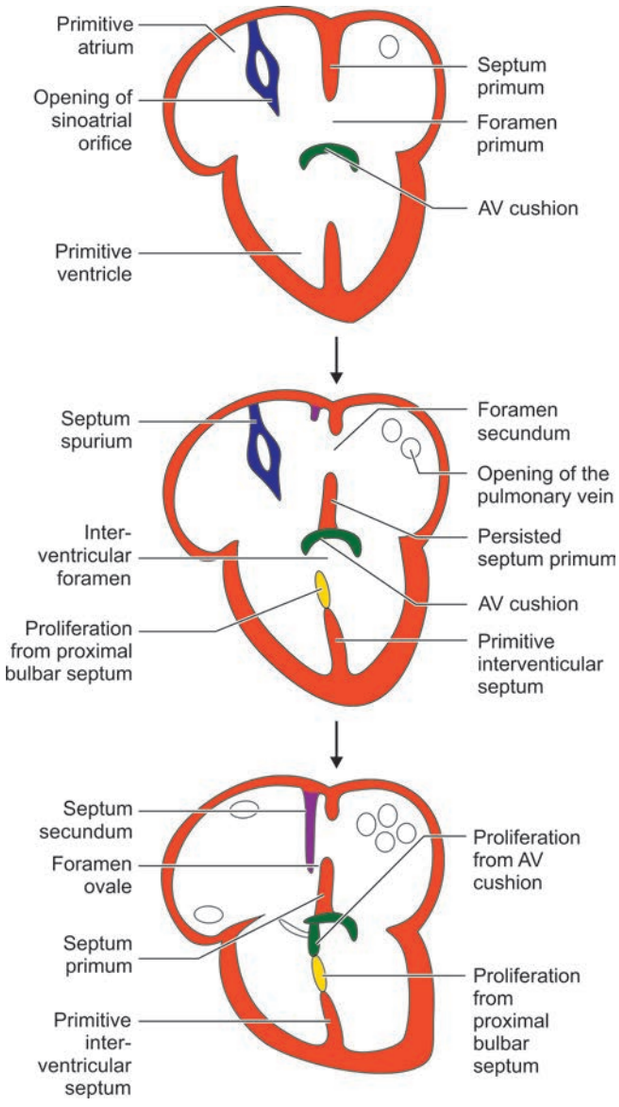


Fig. 47.9: Interatrial and ventricular septal formation (coronal section)

Fate of the Right and Left Venous Valves

- Left venous valve: It eventually fuses with septum secundum.

- Right venous valve: It is pushed ventrally and to the right. By superior and inferior limbic bands, it is divided into three parts and contributes to the formation of:
  1. **Crista terminalis:** The portion above the superior limbic band along with septum spurium.
  2. **Eustachian valve:** The portion between superior and inferior limbic band.
  3. **Valve of the coronary sinus:** The portion below the inferior limbic band
     (Look at these structures inter-relations in adult heart)

Development of the Left Atrium

- During foetal life, left atrium receives one pulmonary vein. This pulmonary vein divides into two branches for right and left lungs (each of them again divided into two).
- All the four pulmonary veins are absorbed into the posterior wall of the left atrium forming the major smooth part of the left atrium (Fig. 47.10).
- Left auricle (which is rough inside) is developed from left half of the primitive atrium.

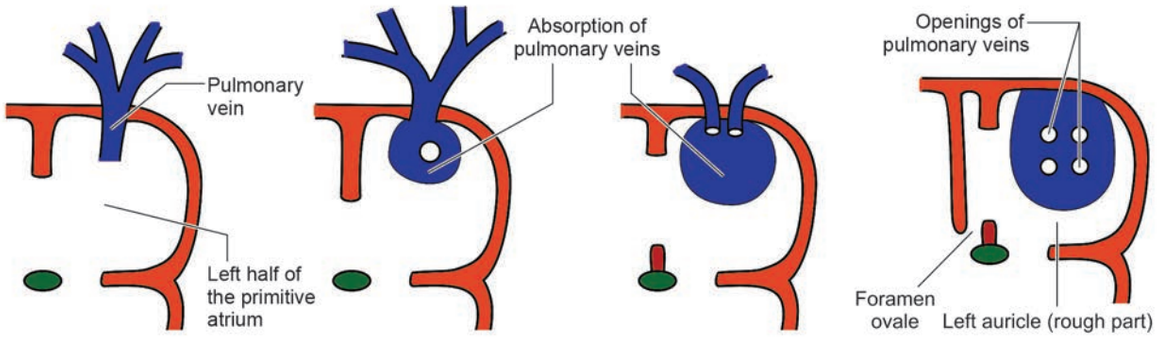


Fig. 47.10: Development of left atrium (coronal section)

Summary of the Development of the Right Atrium

1. Posterior smooth part of the right atrium: Absorbed part of the body and right horn of the sinus venosus.
2. Anterior rough wall of the right atrium: Right portion of the primitive atrium.
3. Interatrial septum—fossa ovalis from septum primum and remaining part of the interatrial septum including limbus fossa ovalis by septum secundum.
4. Crista terminalis, valve of IVC and valve of the coronary sinus by right venous valve.

Clinical Notes

Atrial Septal Defects (ASDs)

There are 3 types of ASDs resulting in left to right shunt.

1. **The ostium secundum defect** is the most common congenital defect of the heart.
   - The persistence of foramen secundum is due to excessive resorption of the septum primum or due to failure of development of septum secundum (Fig. 47.11).
   - The shunting of the blood is usually from left to right, hence does not cause cyanosis (usually the right to left shunt causes cyanosis but not left to right (until pulmonary hypertension), however severe pulmonary stenosis with ASD can cause cyanosis.
2. **The ostium primum defect** is due to either failure of septum primum to fuse with endocardial cushions (AV cushions) or defect in the endocardial cushions.
3. **Patent foramen ovale:** Failure of septum primum and septum secundum to fuse after birth. It may not have any clinical manifestation and there will not be mixing of blood.

In ASD there is increased load on the right side of the heart leading to progressive enlargement of right atrium, right ventricle and the pulmonary trunk.

The disease manifests as fatigue and breathlessness on exertion in the 3rd or 4th decade of life and thereafter.

Recently, GATA4 and NKX2.5 were reported as the disease genes of atrial septal defect (ASD) but the relationship between the locations of their mutations and phenotypes is not clear.

Prenatal Closure of Foramen Ovale

Though this is a rare anomaly, any early closure of foramen ovale during prenatal life can cause enlargement of right atrium. The affected baby usually dies after birth.

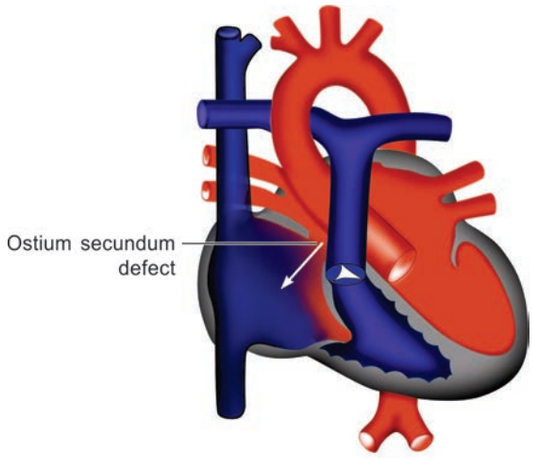


Fig. 47.11: Atrial septal defect—ostium secundum defect

Complete failure of partition of primitive atrium is a rare anomaly and is called bi-ventricular mono-atrial heart.

In dextrocardia the heart rotates to the right so that its apex is located in the right 5th intercostal space.

CASE 1

A 2-year-old boy was brought to the paediatric clinic by his mother who was concerned about the child's respiratory infection. During the physical examination, a heart murmur was detected. Antibiotics were prescribed for the infection and the child was referred to a pediatric cardiologist. The cardiologist ordered an ECG and echocardiography. The echocardiogram revealed a dilated right atrium and ventricle consistent with an ostium secundum atrial septal defect. The defect was surgically closed.

1. What are the normal events in the septation of the primitive atrium?
2. List the various types of atrial septal defect?

Development of the Ventricles and their Partition

The bulbus cordis gets absorbed into the primitive ventricle forming a bulboventricular cavity. This bulboventricular cavity has a lower dilated portion which communicates with atria and upper conical part which communicate with truncus arteriosus.

The lower dilated part of the bulboventricular cavity gives rise to part of the rough inflowing part of the adult ventricle while the upper conical part forms smooth outflowing part of the adult ventricle (infundibulum of right ventricle and aortic vestibule in the left ventricle).

Formation of Interventricular Septum

The ventricular septation takes place at almost same time as atrial septal formation (Fig. 47.12).

- Primitive interventricular septum: It grows upwards from the floor of the bulboventricular cavity, dividing the dilated part of the bulboventricular cavity into right and left portions (not the upper conical part, which continues with truncus arteriosus). This growth of interventricular septum is a passive process due to dilatation of bulboventricular cavity on each side of the partition.
- The upper margin of this septum is concave and free. The posterior portion of this free margin fuses with right edge of the atrioventricular cushion (endocardial cushion/septum intermedium) and anterior portion of this free margin fuses with left edge of the atrioventricular cushion.
- The gap between the right and left ventricles above the free margin of the interventricular septum is called **interventricular foramen.**
- This portion is closed by proliferation of tissues from two other sources and in adult heart, this portion forms **membranous part of the interventricular septum.**
- The right and left bulbar ridges appear in the proximal part of the bulbus cordis, fuse with each other to form **proximal bulbar septum**. This proximal bulbar septum grows downwards towards the interventricular septum partially closing interventricular foramen.
- The remaining portion of this foramen is closed by proliferation of tissue from atrioventricular cushions (endocardial cushions/septum intermedium).
- Thus, the membranous part of the interventricular septum has an anterior part separating right and left ventricles (interventricular), which is developed from proliferation of tissue from proximal bulbar septum and a posterior part which separates right atrium from the left ventricle (atrioventricular), which is developed from proliferation from AV cushion (from right edge of the septum intermedium).

Summary of the Development of the Ventricles

Right Ventricle

1. Rough inflowing part is by right part of the primitive ventricle and proximal dilated part of the bulboventricular cavity.
2. The smooth outflowing part (infundibulum) is by distal conical part of the bulboventricular cavity.

Left Ventricle

1. Rough inflowing part is by left part of the primitive ventricle.
2. The smooth outflowing part (aortic vestibule) is by distal conical part of the bulboventricular cavity.

Interventricular Septum

1. Lower rough part by primitive interventricular septum.

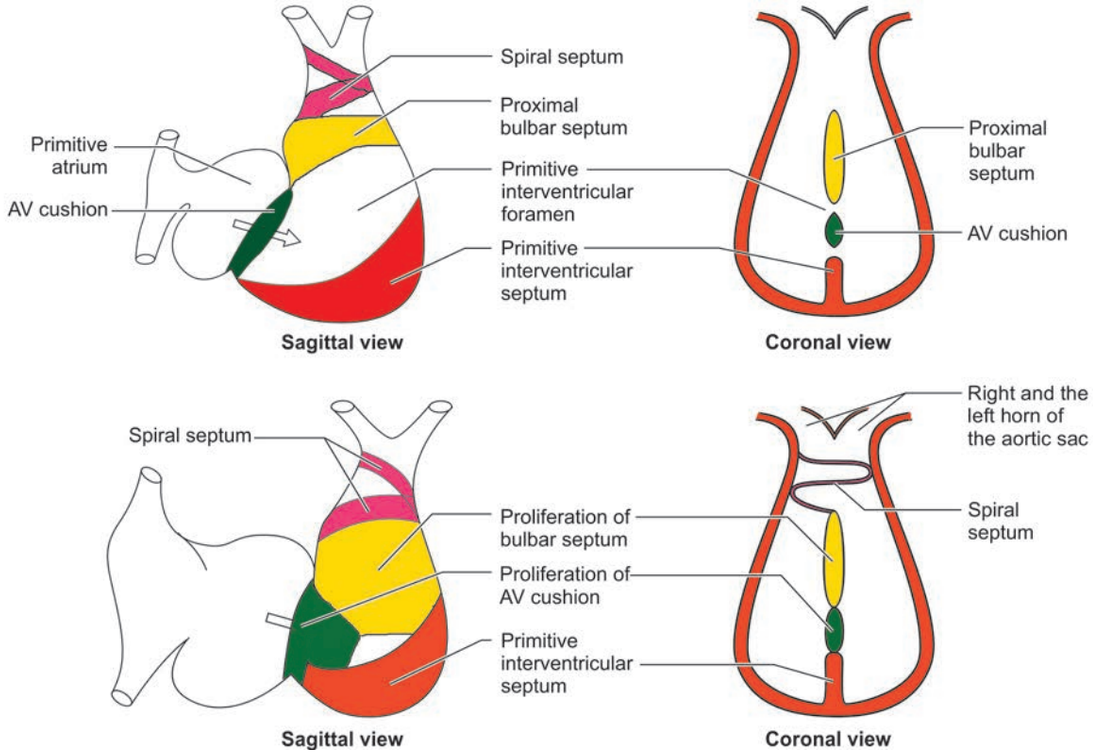


Fig. 47.12: Development of interventricular septum

2. Upper membranous part by two sources: The anterior part by proliferation of tissue by proximal bulbar septum while the posterior part by proliferation of tissue by endocardial cushion (septum intermedium).

Clinical Notes

Ventricular Septal Defects (VSDs)

Persistent Interventricular Foramen

This defect is usually associated with other cardiac anomalies, but it is also possible to have a defect in the membranous part alone. This defect could be due to failure in the contribution from any one or two sources (out of three) involved in interventricular septum. The blood flows from left to right and then into pulmonary artery. Hence, it causes enlargement of right ventricle, pulmonary trunk and pulmonary arteries (Fig. 47.13).

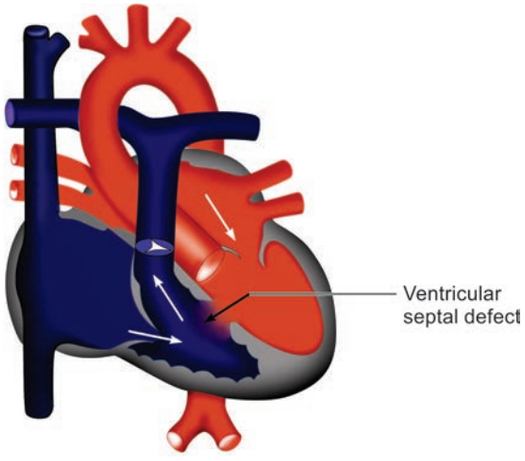


Fig. 47.13: Interventricular septal defect

Truncus Arteriosus and its Fate

The upper part of the truncus arteriosus dilates to form aortic sac, which further divides into right and left horns.

Each horn of the aortic sac is connected to the corresponding dorsal aortae by six pairs of aortic arch arteries.

The truncus arteriosus is internally divided by a **spiral-shaped aorticopulmonary septum** into two vessels—the ascending aorta and pulmonary trunk (Fig. 47.14).

The upper end of the aorticopulmonary spiral septum fuses with the dorsal wall of the aortic sac between fifth and sixth pairs of the aortic arch arteries. This will ensure that the pulmonary trunk continues with sixth arch arteries and ascending aorta with upper five pair of aortic arch arteries.

We studied that proximal bulbar septum is formed at the proximal end of the bulbus cordis and contributes to the formation of membranous part of the interventricular septum. Now at the junction of bulbus cordis and

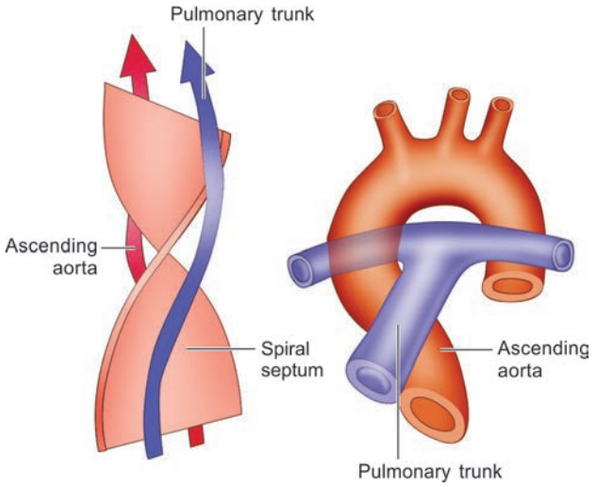


Fig. 47.14: Fate of truncus arteriosus

truncus arteriosus, a distal bulbar septum is formed. The portion in front of this distal bulbar septum is pulmonary orifice and behind is aortic orifice.

Pulmonary and Aortic Valve

At this time, there are four endocardial cushions growing towards the lumen and are named ventral, dorsal, right and left. The distal pulmonary septum formed at this site will divide right and left cushions into ventral and dorsal cusps. Thus, both pulmonary and aortic orifices are guarded by semilunar valves of three cusps (Fig. 47.15).

The lower end of the aorticopulmonary septum continues with distal bulbar septum, which intern continues with proximal bulbar septum. The fusion ensures that the pulmonary orifice is connected to right ventricle and aortic orifice with left ventricle.

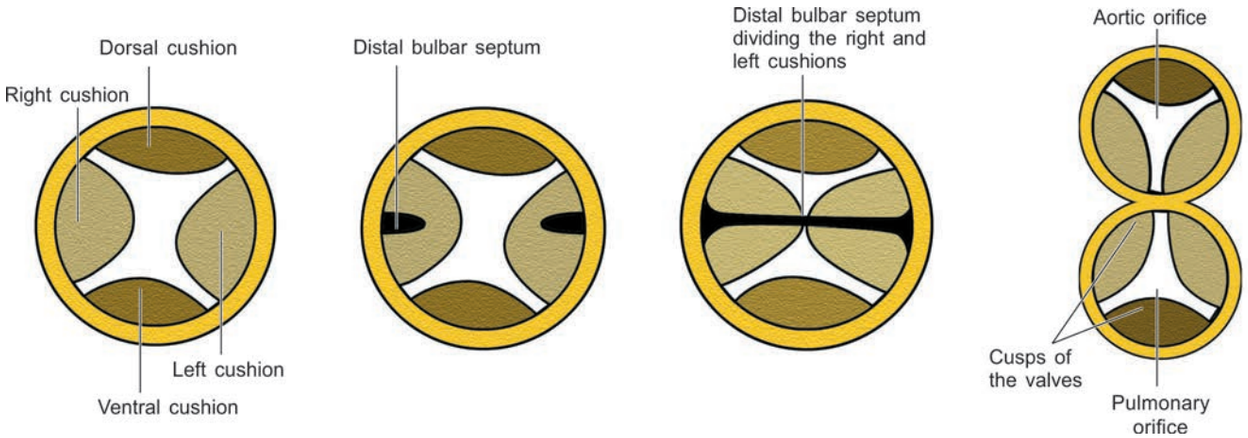


Fig. 47.15: Formation of aortic and pulmonary valves

Clinical Notes

Persistent (Patent) Truncus Arteriosus

The truncus arteriosus fails to divide due to defective aorticopulmonary septum or its agenesis. The pulmonary artery arises some distance above the origin of the undivided truncus (Fig. 47.16A). It is always accompanied by a defective interventricular septum. The undivided truncus thus overrides both ventricles and receives blood from both sides.

Transposition of Great Vessels (Ascending Aorta and Pulmonary Trunk)

The ascending aorta arises from right ventricle and pulmonary trunk from left ventricle. This is due to reverse attachment of lower end of aorticopulmonary septum (Fig. 47.16B):

This anomaly can be associated with patent interventricular foramen and is called **Taussig-Bing syndrome.**

Fallot's Tetralogy

It is a combination of four defects (Fig. 47.17):

1. Ventricular septal defect (VSD)
2. Overriding of aorta (ascending aorta having connection to both ventricles)
3. Pulmonary stenosis
4. Right ventricular hypertrophy

The effects of Fallot's tetralogy are:

- The right chambers of the heart enlarge (right ventricular hypertrophy)
- The pulmonary circulation does not receive much blood due to pulmonary stenosis
- The child may have cyanotic spells especially during crying
- There is shortness of breath or dyspnea on exertion, which is relieved by assuming squatting position for few minutes (squatting blocks the venous return and increases the peripheral resistance of arteries so that more blood reaches the lungs.

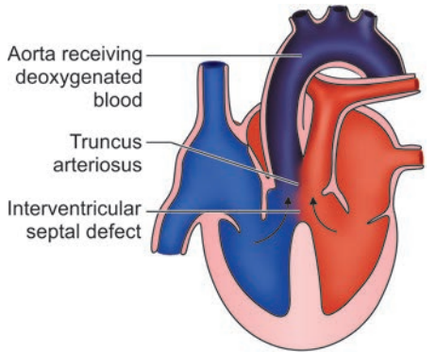


Fig. 47.16A: Persistent truncus arteriosus

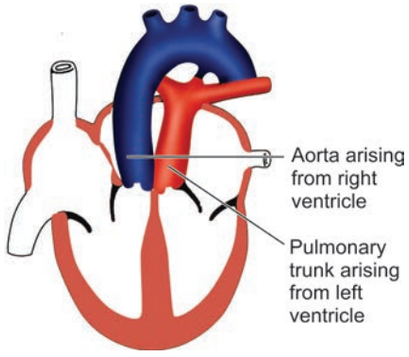


Fig. 47.16B: Transposition of the great vessels

- The growth of the child is retarded due to hyp-oxia.

Acyanotic Heart Disease

It is a broad term for any congenital heart defect in which all of the blood returning to the right side of the heart passes through the lungs and pulmonary vasculature in the normal fashion.

1. Patent ductus arteriosus (PDA)
2. Coarctation of the aorta
3. Atrial septal defect (ASD)
4. Ventricular septal defect (VSD)
5. Aortic stenosis (AS)
6. Pulmonary stenosis (PS)

In **cyanotic defects**, a shunt bypasses the lungs and delivers venous (deoxygenated) blood from the right side of the heart into the arterial circulation.

1. Tetralogy of Fallot
2. Transposition of the great vessels
3. Truncus arteriosus persistent
4. Tricuspid atresia

Remember all these cyanotic defects start with letter T. ☺

Cardiac Shunt

Cardiac shunt is when the blood flow follows a pattern in the heart that deviates from the normal circuit of the circulatory system. It may be described as **right-to-left, left-to-right or bidirectional**, or as systemic-to-pulmonary or pulmonary-to-systemic. The direction may be controlled by left and/or right heart pressure, a biological or artificial heart valve or both. The presence of a shunt may also affect left and/or right heart pressure either benificial or detrimental.

1. A **left-to-right shunt** is when blood from the left side of the heart goes to the right side of the heart. This can occur either through a hole in the ventricular or atrial septum that divides the left and the right heart or through a hole in the walls of the arteries leaving the heart, called great vessels. Left-to-right shunts occur when the systolic blood pressure in the left side of the heart is higher than the right side of the heart.
   - Patent ductus arteriosus (PDA)
   - Atrial septal defect (ASD)
   - Ventricular septal defect (VSD)
   - Persistent truncus arteriosus

   Atrial septal defects and patent ductus arteriosus are not clinically apparent during childhood. Ventricular septal defects are the most common cardiac congenital defects, but they do not present with early cyanosis.
2. A **right-to-left shunt** is a cardiac shunt which allows, or is designed to cause, blood to flow from the right side of the heart to the left side of the heart. For example the tetralogy of Fallot.
3. **No shunt**
   - Coarctation of the aorta
   - Aortic stenosis (AS)
   - Pulmonary stenosis (PS)
   - Transposition of the great vessels

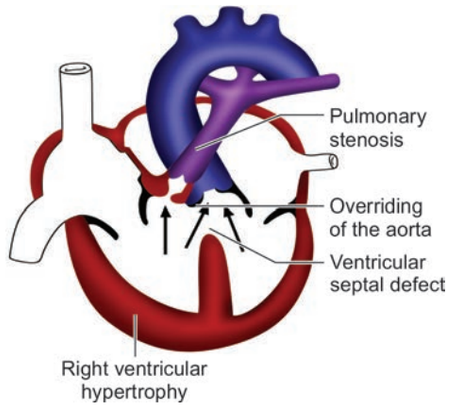


Fig. 47.17: Fallot's tetralogy

DEVELOPMENT OF AORTIC ARCH ARTERIES

The primitive endothelial heart tubes continue cranially with **ventral aortae**, which are placed ventral to the foregut. Each ventral aorta is connected with corresponding **dorsal aorta** (which are placed dorsal to the foregut) through **first aortic arch artery** which traverses first pharyngeal arch.

The first arch artery formed is connected ventrally to right or left horn of the aortic sac and dorsally to the dorsal aorta. The two dorsal aortae fuse to form single aorta at the level of fourth thoracic segment and extend downwards up to fourth lumbar segment.

Successively six arch arteries are formed within the pharyngeal arches (in the developing neck region), each of them are connected ventrally to respective aortic sac and dorsally to dorsal aorta (Fig. 47.18).

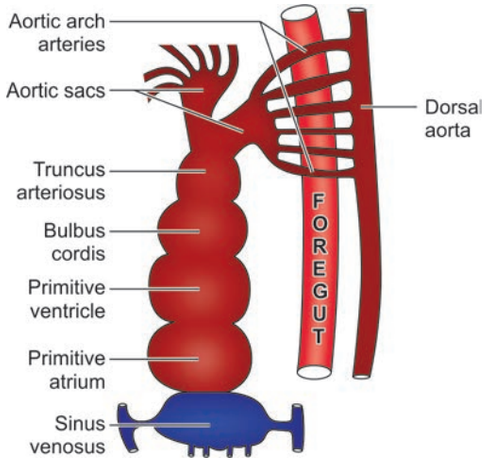


Fig. 47.18: Aortic arch arteries—lateral view

Fate of Aortic Arch Arteries

First arch artery: It mostly disappears except partly for maxillary artery.

Second arch artery: It mostly regresses except dorsal part for the stapedial artery.

Fifth arch artery: It disappears entirely (as the fifth pharyngeal arch itself disappear).

The portion of the dorsal aorta, between the attachment of the 3rd and 4th arch arteries (**ductus caroticus**) disappears on both sides. The aortic sac is now connected only with 3rd, 4th and 6th arch arteries (Fig. 47.19A).

The 3rd and 4rth arch arteries open into ventral part and the 6th arch artery into the dorsal part of the aortic sac. The truncus arteriosus is divided by the spiral-shaped aorticopulmonary septum into ascending aorta and pulmonary trunk. **The blood from the pulmonary trunk passes only into the 6th arch artery, while that from the ascending aorta passes into the 3rd and 4th arch arteries.**

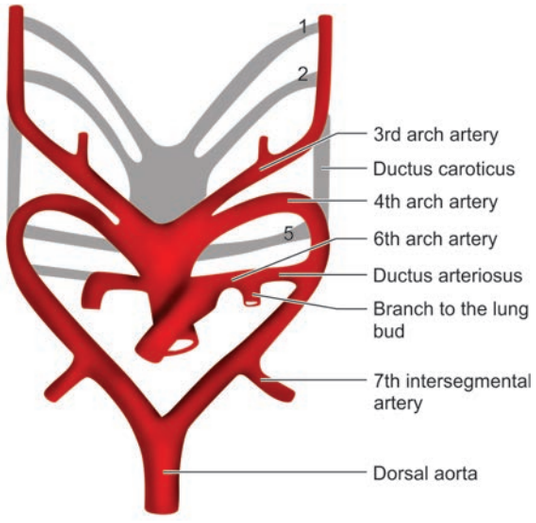


Fig. 47.19A: Fate of the aortic arch arteries

- The portion of the right dorsal aorta, between the attachment of 4th arch artery and the point of fusion between the two dorsal aortae disappears (Fig. 47.19B).

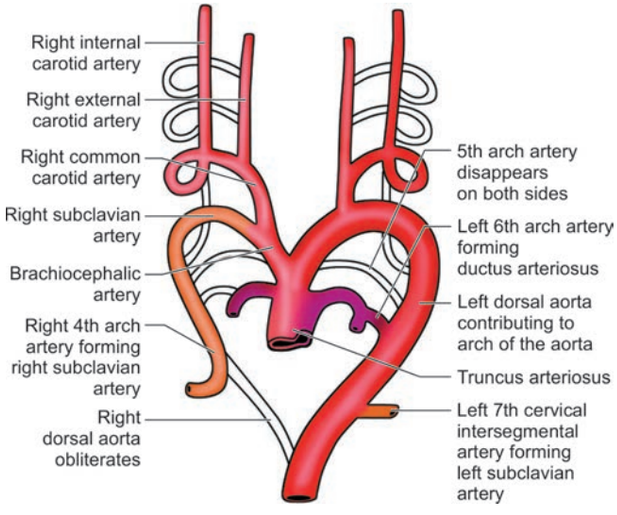


Fig. 47.19B: Fate of aortic arch arteries

- Each 6th arch artery gives off an artery to the developing lung bud (Fig. 47.19A).
- On right side, portion of the 6th arch artery between this bud and the dorsal aorta disappears.
- On the left side it remains patent and forms the **ductus arteriosus.**
- The 6th arch artery (ventral part) forms **pulmonary arteries.**
- The ductus arteriosus carries most of the blood from the right ventricle to the dorsal aorta. After birth it is obliterated to form **ligamentum arteriosum.**

Summary of the Aortic Arch Arteries

First arch artery: Mostly disappears except partly for maxillary artery.

Second arch artery: Mostly regresses except dorsal part for the stapedial artery.

Third arch artery: Ventral part forms common carotid artery, dorsal part forms stem of internal carotid artery.

Fourth arch artery: Right side it forms proximal part of right subclavian artery and on left it persists as part of arch of the aorta.

Fifth arch artery: Disappears entirely.

Sixth arch artery: On right side the ventral part persists as right pulmonary artery and dorsal part disappears. On the left side the ventral part forms the left pulmonary artery and the dorsal part persists as ductus arteriosus in fetal life /ligamentum arteriosum after birth.

Clinical Notes

Patent Ductus Arteriosus (PDA)

When the ductus arteriosus remains patent, blood from the aorta flushes through the ductus into the pulmonary artery (Fig. 47.20).

- Overloading of pulmonary circulation results in enlargement of left atrium, left ventricle and ascending aorta.
- PDA is commonly seen in rubella syndrome, which occurs in children whose mother had German measles during pregnancy.
- PDA is more common in females than in males and in populations living in high altitudes.

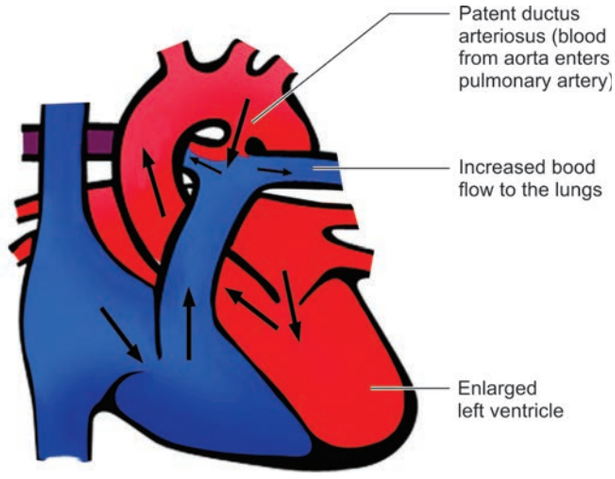


Fig. 47.20: Patent ductus arteriosus (PDA)

CASE 2

Parents bring their 13-year-old boy to the physician because the boy was getting tired easily while playing in the school. During examination, a long continuous heart murmur at the second intercostal space near the left sternal border and a systolic thrill is heard in the same region. When questioned, the parents mother recalled that the boy had periods of cyanosis and breathlessness as an infant. During that time the paediatrician said that the murmur and symptoms were nothing to be concerned about. The chest X-ray indicated slight left ventricular hypertrophy and Doppler ultrasound revealed a patent ductus arteriosus. A surgery is planned to ligate the ductus arteriosus. The surgery resulted in successful ligation of the ductus arteriosus; however, later the boy experienced hoarseness when speaking. Laryngoscopy revealed paralysis of the left vocal cord.

1. What is ductus arteriosus and where is it located?
2. What is the prenatal function of the ductus arteriosus, and what usually happens to it after birth?
3. What are the eventual consequences if the ductus arteriosus is not closed?
4. What likely caused paralysis of the left vocal cord?
5. Why would Doppler ultrasound be used to diagnose a patent ductus arteriosus?

Each third arch artery gives off a bud that grows cranially to form the **external carotid** artery. The dorsal aortae give off a series of lateral intersegmental branches to the body wall, of which the **7th cervical intersegmental artery supplies the upper limb bud.** It comes to be attached to the dorsal aorta near the attachment of the 4th arch artery.

Development of Arch of the Aorta

The arch of aorta is developed from following sources (Fig. 47.21):

1. The ventral part of the aortic sac
2. The left horn of the aortic sac
3. The left 4th arch artery
4. The left dorsal aorta

Clinical Notes

Double Aortic Arches

It occurs due to persistence of the right dorsal aorta distal to the origin of the seventh cervical intersegmental artery. Double aortic arch embraces the trachea and oesophagus (Fig. 47.22).

Right Aortic Arch

Right dorsal aorta persists below the 7th cervical intersegmental artery and the corresponding portion of the left dorsal aorta disappears.

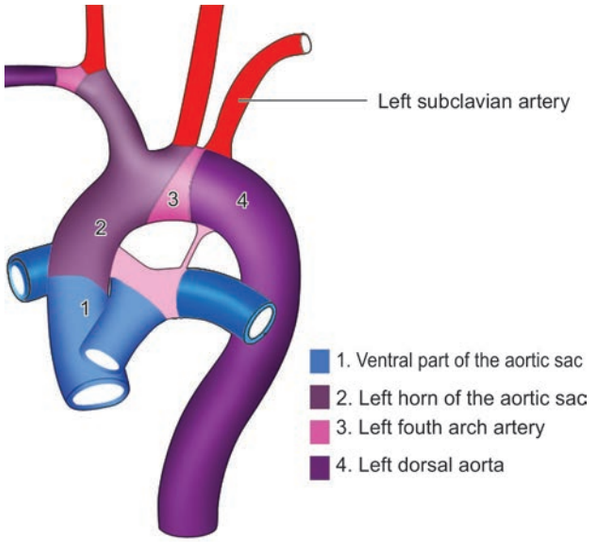


Fig. 47.21: Development of arch of the aorta

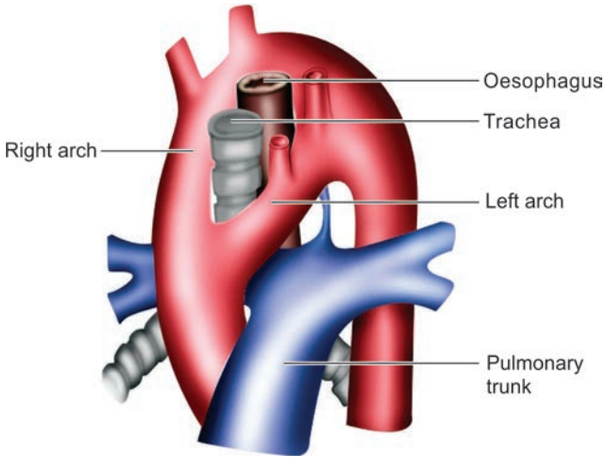


Fig. 47.22: Double aortic arch

Development of Brachiocephalic Trunk

The right horn of the aortic sac (which is connected with 3rd and 4th aortic arch arteries) forms the brachiocephalic trunk.

Development of Descending Aorta

The left dorsal aorta below the attachment of the 4th arch artery.

Development of Subclavian Artery

- On right side by right 4th arch artery, part of the right dorsal aorta and right 7th cervical intersegmental artery.
- On left side entirely by left 7th cervical intersegmental artery.

Relation between Recurrent Laryngeal Nerve and 6th Arch Artery

Initially each recurrent laryngeal nerve winds around the 6th arch artery and then ascends to the larynx. With the degeneration of right 6th arch artery, the right recurrent laryngeal nerve winds around the right 4th artery, which forms the proximal part of the right subclavian artery. Remember that the 5th arch artery disappears early. On the left side the dorsal part of the 6th artery persists as ductus arteriosus and the left recurrent laryngeal nerve winds around it. The ductus arteriosus forms the ligamentum arteriosum in the adult.

Clinical Notes

Abnormal Origin of the Right Subclavian Artery

Sometimes the right subclavian artery arises from the junction of the arch of aorta and descending aorta, and courses upwards and to the right behind the trachea and oesophagus (Fig. 47.23). This is due to degeneration of the right 4th arch artery, so that the right 7th intersegmental artery and right dorsal aorta caudal to it are continued as right subclavian artery.

- The ventral part of the 3rd arch artery persists as **common carotid artery.**
- The dorsal part of the 3rd arch artery and dorsal aorta cephalic to the ductus caroticus forms **internal carotid artery.**

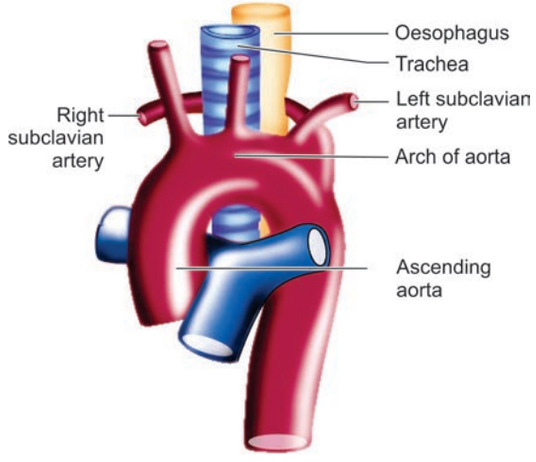


Fig. 47.23: Abnormal origin of the right subclavian artery

DEVELOPMENT OF MAJOR VEINS

Development of the Superior Vena Cava

The anterior cardinal vein brings blood from head end of the embryo while posterior cardinal vein from the caudal end. The anterior and posterior cardinal veins of the two sides join to form **common cardinal vein (duct of Cuvier)** on each side and opens into corresponding horns of the sinus venosus. The venous blood from the upper limb will drain into anterior cardinal vein through subclavian vein (Fig. 47.24).

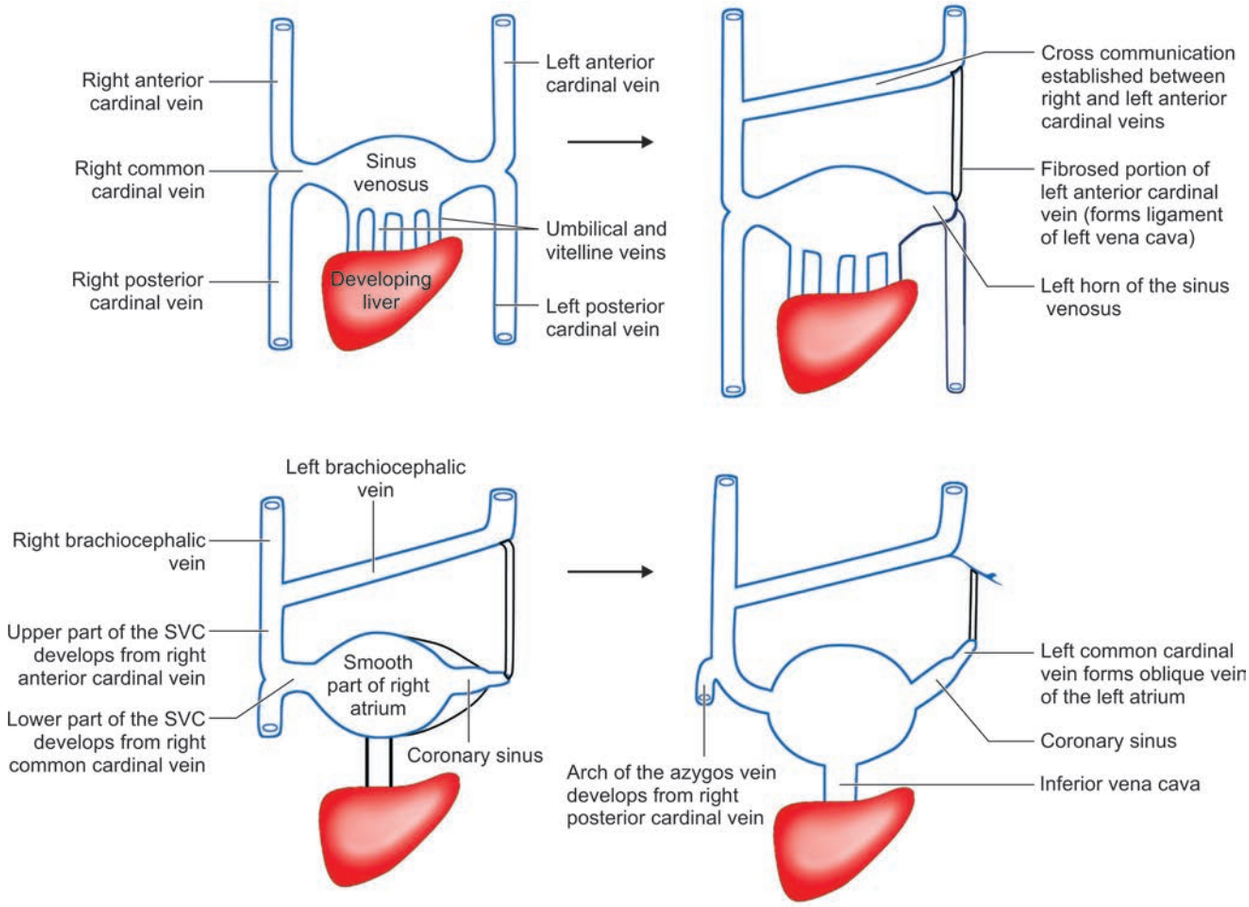


Fig. 47.24: Development of the superior vena cava

Now the two anterior cardinal veins are interconnected by a transverse anastomosis. This communication is established proximal to the junction of anterior cardinal vein with subclavian vein. The part of the left cardinal vein caudal to this anastomosis regresses and also major part of the left common cardinal vein (except for its caudal end where it opens into left horn of the sinus venosus). The left horn of the sinus venosus forms coronary sinus while this persistent terminal end of the left common cardinal vein forms oblique vein of left atrium (of Marshall).

The superior vena cava is developed from

1. The right anterior cardinal vein (caudal to the transverse anastomosis)—extra pericardial portion.
2. The right common cardinal vein—intrapericardial portion.

The transverse anastomosis between the two anterior cardinal veins contributes to the development of left brachiocephalic vein. In adults note that left brachiocephalic vein is oblique in course, passing in front of the branches of arch of aorta.

Development of the Inferior Vena Cava

- The lower (caudal) ends of the **posterior cardinal vein** receive blood from developing lower limb and pelvis. The caudal part of the right and left posterior cardinal veins is interconnected by a transverse anastomosis.
- The **subcardinal veins** are formed in relation to the mesonephros. The upper and lower ends of the subcardinal veins are connected to respective posterior cardinal veins. These subcardinal veins bring blood from developing kidneys (renal veins). At this level the right and left subcardinal veins are also connected by a transverse anastomosis. The cranial end of the right vein is connected to right hepatocardiac channel (Fig. 47.25A and B).
- The **supracardinal veins** (thoracolumbar veins) are formed parallel to subcardinal veins. These supracardinal veins also connect cranially and caudally with posterior cardinal veins. Each supracardinal veins also connect to respective subcardinal vein just below the renal veins.

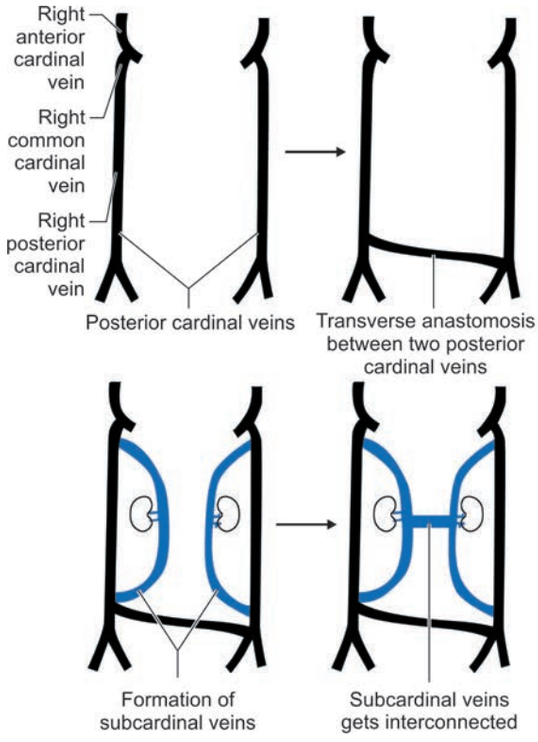


Fig. 47.25A: Development of the inferior vena cava

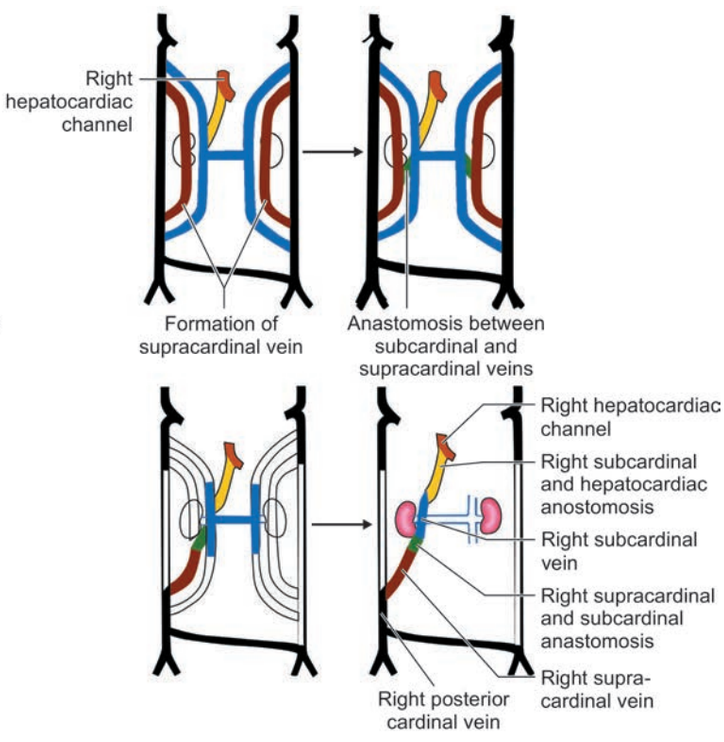


Fig. 47.25B: Summary of the development of the inferior vena cava

- A major part of these longitudinal venous channels disappear, and the adult form is achieved like this.
- The **inferior vena cava** is developed from following sources:
  1. The lower end of the right posterior cardinal vein.
  2. The lower part of the right supracardinal vein (between its junction with the posterior cardinal vein, and supracardinal and subcardinal anastomosis).
  3. The anastomosis between right supracardinal and right subcardinal veins.
  4. A small portion of the right subcardinal vein.
  5. The anastomosis between right subcardinal vein and right hepatocardiac channel.
  6. The right hepatocardiac channel (the terminal ends of the vitelline veins opening into the sinus venosus) forms hepatocardiac channel and with regression of the left horn of the sinus venosus, the left hepatocardiac channel disappears and right hepatocardiac channel contributes to the development of cranial most part of the inferior vena cava.

Hepatocardiac Channel

The hepatic bud grows into the septum transversum (unsplit intraembryonic mesoderm) to form the liver. The umbilical and vitelline veins open into the sinus venosus, and the terminal part of these veins is traversing the septum transversum. These vessels break down to form sinusoids of the liver. These sinusoids of the liver will open into sinus venosus through small persistent terminal part of the vitelline veins. These are called **right and left hepatocardiac channels**. With regression of the left horn of the sinus venosus, the left hepatocardiac channel disappears. All the blood from vitelline and umbilical veins will now pass through right hepatocardiac channel (Fig. 47.26A and B).

With the regression of the right umbilical vein, the oxygenated blood from the placenta will reach the liver through left umbilical vein. Within the developing liver a vascular channel is formed between left umbilical vein and right hepatocardiac channel to facilitate the blood flow. This vascular passage is called **ductus venosus.**

Development of the Portal Vein

We have studied the fate of terminal part of the vitelline veins traversing the septum transversum. The portion of the right and left vitelline veins outside the developing liver contributes to the formation of portal vein (Fig. 47.27A to D).

The right and left vitelline veins ascend on either side of the midgut (future duodenum). The right and left vitelline veins are connected to each other by

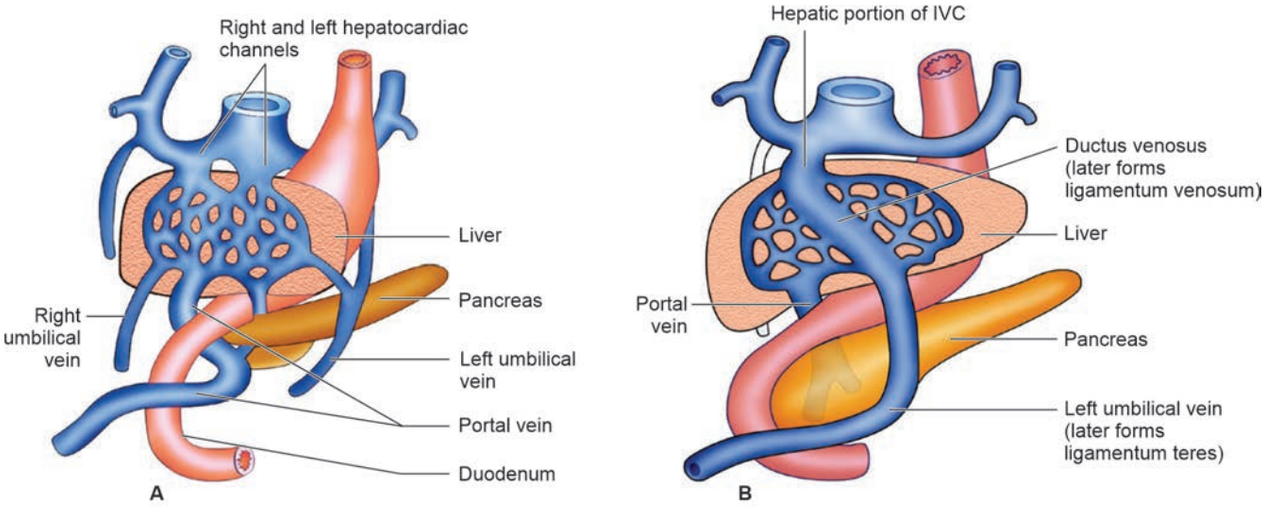


Fig. 47.26A and B: Formation of hepatocardiac channel

3 transverse anastomoses, of which the upper and lower anastomoses are ventral to the duodenum, while the middle anastomosis is dorsal. The superior mesenteric and splenic veins join left vitelline vein, little caudal to the middle dorsal anastomosis. With the disappearance of some part of the vitelline vein, the adult portal vein is developed from following sources:

1. The left vitelline vein between the entry of superior mesenteric vein and splenic vein (infraduodenal part of the portal vein).
2. Dorsal anastomosis between right and left vitelline veins (retroduodenal part of the portal vein).
3. Upper part of the right vitelline vein (supraduodenal part of the portal vein).

The left terminal branch of the portal vein is formed by the cranial ventral anastomosis and also by a small portion of the left vitelline vein. The short right terminal branch of the portal vein is developed from upper part of the right vitelline vein.

The left umbilical vein is now opening into the left terminal branch of the portal vein, while ductus venosus (within the liver) connects the left terminal branch of the portal vein into the right hepatocardiac channel (inferior vena cava). Later the left umbilical vein forms **ligamentum teres** and ductus venosus is fibrosed to form **ligamentum venosum.**

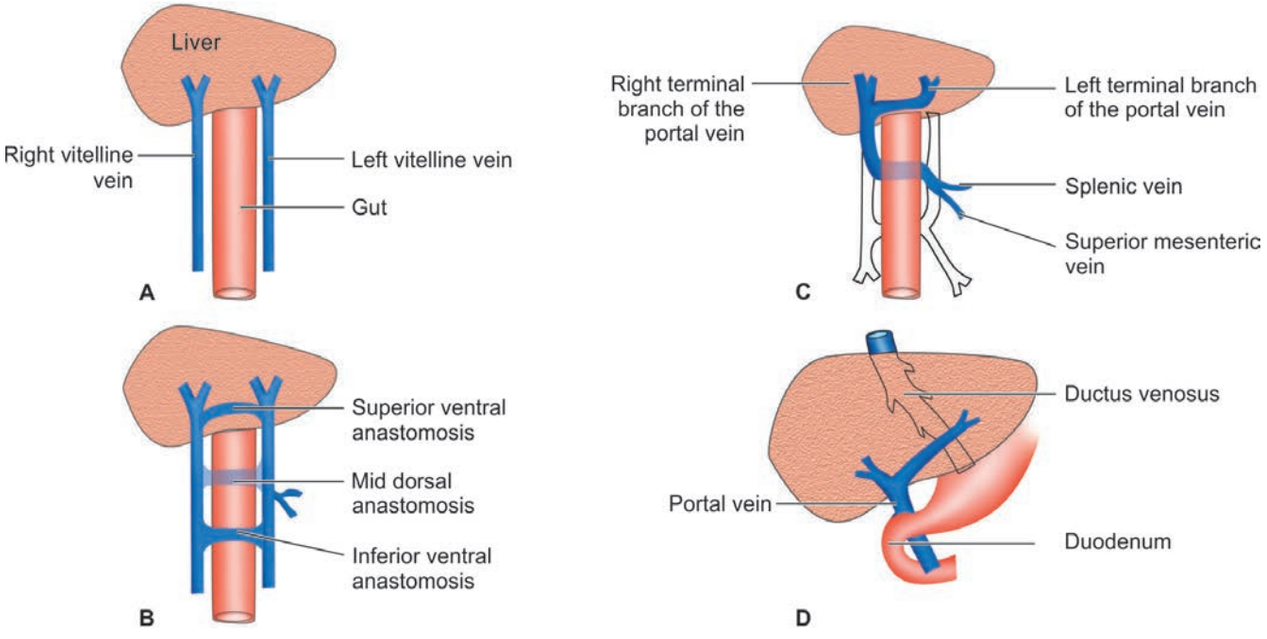


Fig. 47.27A to D: Development of the portal vein (A to D represents sequence of development)

CIRCULATION BEFORE AND AFTER BIRTH

Foetal Circulation

- During foetal life, the oxygenated blood (about 80% saturated) reaches the foetus from the placenta by left umbilical vein.
- This umbilical vein ends in developing liver, where most of its blood enters ductus venosus and then into the inferior vena cava (short circuiting the liver).
- But small amount of blood from umbilical vein enters the liver sinusoids and mixes with blood from portal circulation (vitelline veins which form portal vein also end in liver sinusoids), which accounts for the enlargement of the liver in foetal life and in the newborn. Hence, blood from the liver sinusoids also enters inferior vena cava, which opens into the right atrium (Fig. 47.28).
- A sphincter in the ductus venosus near the entrance of the umbilical vein regulates flow of umbilical blood through the liver sinusoids. When this sphincter relaxes, the more oxygenated blood from the umbilical vein enters inferior vena cava. When the sphincter constricts, the blood entering inferior vena cava is less oxygenated (venous blood from the lower limb ascending through inferior vena cava). The sphincter of the ductus venosus prevents the overloading of the heart. It is said that the sphincter action is due to uterine contraction.
- Hence, the blood in the terminal part of the inferior vena cava entering right atrium is mixed (oxygenated blood from umbilical vein and less oxygenated blood from lower limb passing through inferior vena cava).
- From the right atrium most of the blood enters the left atrium through foramen ovale. The blood flow is guided by valve of the inferior vena cava.
- A small amount of the blood, which does not enter left atrium mixes with deoxygenated blood entering the right atrium from superior vena cava.
- The blood that has entered left atrium mixes with small amount of desaturated blood returning from the lung via pulmonary veins.
- From the left atrium, the blood enters left ventricle and then into ascending and arch of aorta. This blood is more oxygenated and supplies vital organs like brain (through carotid arteries) and musculature of heart (coronary arteries), which are vulnerable to the oxygen lack.
- The less oxygenated blood from the right atrium enters the right ventricle and then into the pulmonary trunk.
- From the pulmonary trunk, small amount of blood enters the lung through right and left branches of the pulmonary artery, but major amount of blood enters the distal part of the arch of the aorta through ductus arteriosus.
- The arch of the aorta carrying more oxygenated blood from left ventricle and ductus arteriosus carrying less oxygenated blood. These two streams of blood get mixed at the distal end of the arch of the aorta.
- After coursing through the descending aorta, blood enters the umbilical arteries and finally reaches placenta. The oxygen saturation in the umbilical arteries is about 58%.

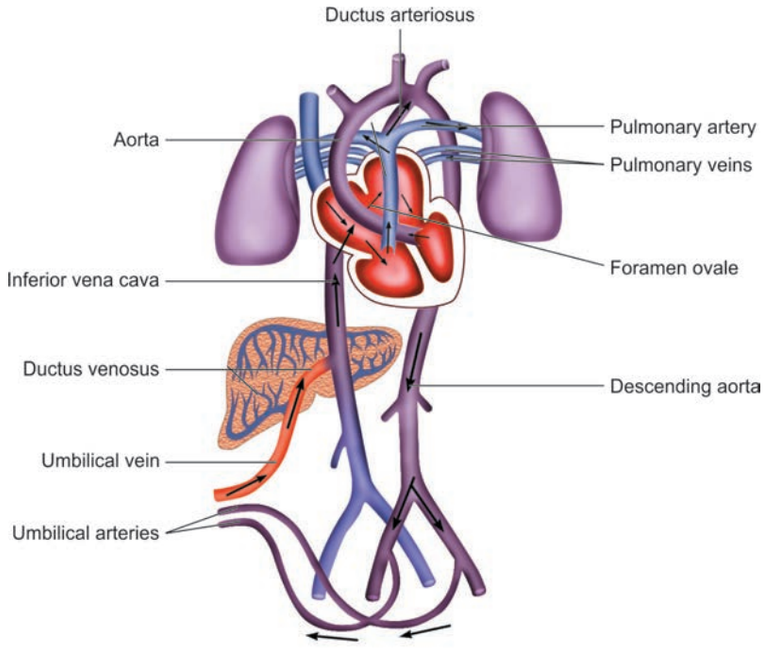


Fig. 47.28: Foetal circulation

The oxygenated blood from the placenta passing through umbilical vein into various organs of the foetus, gets mixed with desaturated blood. The mixing occurs in the following places:

a. In the liver—by small amount of blood returning from portal system (vitelline veins).
b. In the inferior vena cava—by venous blood returning from lower limbs, kidneys, pelvis.
c. In the right atrium—by venous blood returning from head and upper limb through superior vena cava
d. In the left atrium—by venous blood returning from lungs through pulmonary veins.
e. At the entrance of the ductus arteriosus into the aorta by venous blood from pulmonary trunk.

Circulatory Changes at Birth

1. **Closure of the foramen ovale:** With functioning of the lungs after birth, more amount of blood rushes into the left atrium, which raises the pressure inside the left atrium. The septum primum is mechanically pushed towards the septum secundum to obliterate the foramen ovale. The anatomical closure of this foramen may take one year. In about 20% of the individuals, the foramen may remain patent without mixing of the blood (probe patent foramen ovale). Crying by the baby creates a shunt from right to left, which may cause cyanotic episodes in the newborn.
2. **Closure of the ductus arteriosus:** It is closed immediately after birth under the influence of bradykinin, a substance released from the lung during initial inflation. Closure of the ductus arteriosus after birth is by high oxygen tension, and by the administration of prostaglandin inhibitor substances. The patency of the ductus arteriosus is maintained by low oxygen tension of foetal blood and by prostaglandin E2. In adults, the obliterated ductus arteriosus forms ligamentum arteriosum.
3. **Closure of the umbilical arteries:** The umbilical arteries are closed immediately after birth, ensuring that no blood is permitted after birth to leave the foetus. After 2 to 3 months, the umbilical arteries fibrose to form **medial umbilical ligaments,** but its proximal part remains patent forming superior vesical arteries.
4. **Closure of the umbilical vein and ductus venosus:** It occurs shortly after the closure of umbilical arteries. Hence, blood from the placenta may enter the newborn for some time after birth. The umbilical vein gets obliterated to form ligamentum teres, which occupies a fissure in the liver. The ductus venosus (the vascular channel connecting umbilical vein to right hepatocardiac channel), is also obliterated and forms ligamentum venosum in the liver.

Molecular Regulation of Heart Development

Laterality refers to left-right side development of the embryo which is regulated by many genes especially for those structures which do not follow the right and left symmetry. For example, the liver, heart, spleen, etc. Serotonin (5-HT) and NODAL protein concentration on the left side of the cardiogenic area is key for the location of the heart on the left side. The transcription factor MAD3 restricts the NODAL expression to the left side. This NODAL protein upregulates the expression of PITX2 (a homeobox gene) which is considered as master gene for the left sidedness of heart, stomach and spleen. Individuals with laterality defects, such as heterotaxy, often have different types of heart defects like dextrocardia, VSDs, ASDs, transposition of great vessels.

Mutation in the heart specifying gene NKX2.5, on chromosome 5q35 can cause ASDs, Fallot's tetralogy. Mutation in the TBX5 gene results in Holt-Oram syndrome which is characterized limb abnormalities with ASDs.

Solutions to the clinical case studies

Case 1

a. Refer to text
b. Refer to text

Case 2

1. The ductus arteriosus is a foetal shunt between the pulmonary artery and the arch of the aorta.
2. In the foetus, the ductus arteriosus allows oxygenated blood returning to the heart from the placenta to bypass the uninflated lungs and enter the systemic circulation. Following birth (usually within a few days), the ductus arteriosus functionally closes off and forms a fibrous cord called the ligamentum arteriosum. Complete anatomic closure of the ductus arteriosus may take up to 6 weeks. If the ductus arteriosus remains open, it forms a left-to-right shunt which carries some blood from the left side of the heart into the pulmonary trunk.
3. Initial consequences of a patent ductus arteriosus include cardiac failure and pulmonary edema in infants (accounting for the cyanosis and breathlessness experienced by the boy); however, a patent ductus arteriosus is often compatible with survival to adulthood. Cardiac failure (which may be the reason for the slight left ventricular hypertrophy observed in this case) and bacterial endocarditis are common complications. If left untreated, pulmonary hypertension develops, resulting in hypertrophy of the right ventricle and eventually in a reversal

of flow (to right-to-left), leading to cyanosis, clubbing of fingers and toes, and polycythemia due to systemic circulation of large amounts of deoxygenated blood, as well as right heart failure.

4. Paralysis of the left vocal fold resulted from damage to the left recurrent laryngeal nerve, which loops under the arch of the aorta adjacent to the ligamentum arteriosum (ductus arteriosus) after branching out from the vagus nerve. The left recurrent laryngeal nerve innervates the muscles of the left half of the larynx with the exception of the left cricothyroid muscle, supplied by the external laryngeal nerve (branch of the vagus) (the right recurrent laryngeal nerve, which loops similarly under the right subclavian artery). Surgeons must take great care in identifying and protecting the left recurrent laryngeal nerve when performing procedures in the region of the aortic arch.
5. Doppler ultrasound permits the visualization of blood flow and can thus be used to identify a patent ductus arteriosus. This technique is preferable to traditional angiography, which may also be used, because it is noninvasive, involves no radiation, and is fairly inexpensive.

MCQs

1. Once the infant is delivered and its first breath, which structure immediately closes to block the right-to-left shunt?

A. Allantois
B. Ductus arteriosus
C. Ductus venosus
D. Foramen ovale

2. Physical examination of a 5-year-old child reveals a heart murmur. An echocardiogram shows an ostium primum type of atrial septal defect. Which of the following is responsible for this anomaly?

A. Ostium primum to form within the septum primum
B. Ostium secundum to form within the septum primum
C. Septum primum to fuse with the endocardial cushions
D. Septum primum to fuse with the septum secundum

3. Which of the following statements best describes the development of interatrial septum?

A. Foramen secundum appears in septum secundum
B. Foramen primum is closed when septum secundum reaches endocardial cushions
C. The abnormal flow of blood is from right to left
D. Complete and timely closure of the endocardial cushions is essential

4. A newborn baby is known to have multiple cardiac anomalies. An echocardiogram shows a ventricular septal defect, hypertrophy of the right ventricle, pulmonary stenosis and an overriding aorta. Which of the following embryologic defect underlies this condition?

A. Fallot's tetralogy
B. Patent ductus arteriosus
C. Interatrial septal defect
D. Mitral stenosis

5. A newborn baby is cyanotic at birth. As the child grows older, the parents notice that he is always squatting. The X-ray film of the chest shows an enlarged boot-shaped heart that is consistent with right ventricular hypertrophy. The echocardiogram revealed ventricular septal defect. Which of the following other defects would most likely have been noted?

A. Overriding pulmonary artery
B. Left ventricular hypertrophy
C. Atrial septal defect
D. Pulmonary stenosis

6. A 36-year-old woman with a history of type 2 diabetes mellitus gives birth to a term male infant. Immediately after birth, the infant is noted to be cyanotic and tachypneic. His hypoxemia quickly worsens over minutes. After stabilizing the hypoxia, the infant is taken for corrective surgery. Which of the following congenital anomaly is most likely to be associated with this infant?

A. Coarctation of the aorta
B. Ventricular septal defect
C. Delayed closure of the ductus arteriosus
D. Failure of the aorticopulmonary septum to spiral

7. A newborn baby develops a bluish color when crying. Which of the following congenital defects may be the cause of the cyanosis?

A. ASD—septum secundum type
B. Persistent truncus arteriosus
C. Primum type atrial septal defect
D. ASD—septum primum type

8. An autopsy of an infant who died with multiple congenital anomalies reveals a malformed heart. The aorta arises from right ventricle. The pulmonary artery overrides ventricular septal defect. Which of the following terms best describes this infant's heart?

A. ASD
B. Right ventricular hypertrophy
C. Taussig-Bing malformation
D. Tetralogy of Fallot

9. A 6-year-old boy who was born prematurely brought to his pediatrician because his mother says that he tired easily. She also says that he had several respiratory infections. On examination, the boy is noted to be below the 5th percentile in height: Jugular venous pressure is elevated; lips are slightly cyanotic; and a continuous machine-like murmur is heard over the left upper sternal border. The congenital anomaly responsible for these signs and symptoms produces which of the following patterns of blood flow in fetal life?

A. It shunts blood from the inferior vena cava to the aorta
B. It shunts blood from the left pulmonary artery to the aorta
C. It shunts blood from the left ventricle to the right ventricle
D. It shunts blood from the portal vein to the inferior vena cava

10. A term infant is born after an uncomplicated pregnancy to a 35-year-old woman. On cutting the umbilical cord, the physician notes an abnormality' that leads him to consult a pediatric cardiologist. Which of the following abnormalities did this physician most likely observe?

A. Single umbilical vein
B. Single umbilical artery
C. Single allantoic duct
D. Two umbilical arteries

11. A baby was observed at birth to be non-cyanotic. The mother was known to have been infected with rubella during pregnancy. On physical examination, the patient is found to have a continuous murmur that is present in both systole and diastole. The patient also has digital cyanosis. Which of the following is the most likely congenital anomaly?

A. Patent ductus arteriosus
B. Tetralogy of Fallot
C. Transposition of the great vessels
D. Ventricular septal defect

12. A newborn infant displays wheezing respiration, which is aggravated when she was fed, flexes her neck and cries. Radio imaging studies of her chest revealed double aortic arches compressing her trachea and esophagus.Which of the following cause this defect?

A. Persistence of the right dorsal aorta distal to the origin of the 7th cervical intersegmental artery
B. Ductus caroticus fails to disappear
C. 5th pair of aortic arch artery fails to disappear
D. Degeneration of right 4th arch artery

13. The heart of an embryo first begins beating at which of the following ages?

A. 2 weeks
B. 3 weeks
C. 4 weeks
D. 6 weeks

14. In the developing fetus, which of the following provides a bypass from portal circulation?

A. Ductus venosus
B. Ductus arteriosus
C. Foramen ovale
D. Umbilical vein

15. Which of the following is a remnant of a structure that allowed bypass from pulmonary circulation in the developing foetus?

A. Ligamentum teres
B. Ligamentum venosum
C. Ductus arteriosus
D. Ligamentum arteriosum

16. An autopsy is performed on a man who died of an unknown cause. The pathologist discovers that the man has a small atrial septal defect. The defect is seen in the portion of the atrial septum near the upper border of the fossa ovalis. Which of the following was the likely functional manifestation of this defect during life?

A. No cyanosis occurred prenatally or postnatally
B. Postnatal cyanosis due to a shunt of blood from the left atrium to the right atrium
C. Postnatal cyanosis due to a shunt of blood from the right atrium to the left atrium
D. Prenatal cyanosis due to a shunt of blood from the right atrium to the left atrium

17. A patient is complaining of difficulty swallowing. A barium contrast X-ray shows a constriction of the esophagus at the level of the third thoracic vertebra. An aortogram shows that the patient has a double aortic arch. Which of the following developmental abnormalities explains this finding?

A. Abnormal persistence of the right dorsal aorta
B. Abnormal persistence of the right 4th aortic arch
C. Abnormal persistence of the right 7th intersegmental artery
D. Abnormal persistence of the right 6th aortic arch

18. While many congenital cardiac defects can be discovered and monitored before birth, others present in a delayed fashion. Pediatric clinics often see patients who present with early cyanosis, which is later found to exist in the context of a congenital heart defect. Which of the following is the most common cause of cyanosis within the first few weeks of life?

A. Atrial septal defect
B. Patent ductus arteriosus
C. Tetralogy of Fallot
D. Ventricular septal defect

ANSWER TO THE MCQs

1. D	2. C	3. D	4. A	5. D
6. D	7. B	8. C	9. B	10. B
11. A	12. A	13. C	14. A	15. C
16. A	17. A	18. C		

JUST BEFORE THE EXAM

- The heart develops from splanchnic mesoderm in the cardiogenic area. Initially the heart tube presents five dilatations. Each of these dilatations is shown below

Part of the developing heart tube	Fate
Sinus venosus	Body and right horn form posterior smooth wall of the right atrium + Left horn forms the coronary sinus
Primitive atrium	Rough part of the right atrium (anterior wall) and rough part of the left atrium (left auricle)
Primitive ventricle	Inflowing rough parts of the right and left ventricles
Bulbus cordis	Smooth outflowing parts of the right and left ventricles
Truncus arteriosus	Pulmonary trunk and ascending aorta

Chambers of the heart	Developmental source
Right atrium	Rough anterior wall → Right portion of primitive atrium Posterior smooth wall → Body and right horn of the sinus venosus Interatrial septum → Septum primum (at the fossa ovalis of the adult heart) and septum secondum (at the limbus fossa ovalis of the adult heart) Crista terminalis + valves of IVC and coronary sinus → Right venous valve

Left atrium	Major smooth portion → Absorption of the pulmonary veins Left auricle → Left half of the primitive atrium
Right ventricle	Rough part → Right half of the primitive ventricle Smooth part → Absorption of the bulbus cordis Interventricular septum → Formed by 3 tissues—primitive ventricular septum (lower rough wall of the adult interventricular septum), proliferation of tissue from septum intermedium (AV cushions) and proliferation of tissue from the proximal bulbar septum. The latter two forms the membranous part of the interventricular septum
Left ventricle	Rough part → Left half of the primitive ventricle Smooth part → Absorption of the bulbus cordis

- **Atrial septal defects (ASDs)** → Septum primum or septum secondum defect or probed patency.
- **Congenital heart defect which can cause cyanosis immediately** → Includes transposition of the great vessels, truncus arteriosus patent and tetralogy of the Fallot (remember 3 Ts).
- **Fallot's tetralogy** → It is a combination of four defects: (1) Ventricular septal defect (VSD); (2) Overriding of aorta (ascending aorta having connection to both ventricles); (3) Pulmonary stenosis; (4) Right ventricular hypertrophy.

Aortic arch artery	**Fate**
First	Mostly disappears except partly for maxillary artery
Second	Mostly regresses except dorsal-part for the stapedial artery
Third	Ventral part forms common carotid artery dorsal part forms stem of internal carotid artery
Fourth	Right side it forms proximal part of right subclavian artery and on the left side it persists as part of arch of aorta
Fifth	Disappears early
Sixth	Proximal part forms pulmonary arteries + on left side the distal part forms ductus arteriosus connecting pulmonary artery with left dorsal aorta bypassing the lungs. After birth it forms ligamentum arteriosum. It can remain patent at birth and thereafter and is called patent ductus arteriosus (PDA).

- **Development of the arch of the aorta** → Ventral part of the aortic sac + left horn of the aortic sac + left 4th arch artery + part of the left dorsal aorta
- **Portal veins** → Develop from the vitelline veins. After birth, the umbilical arteries fibrose to form medial umbilical ligament (its proximal part remains patent and forms superior vesical artery). The left umbilical vein forms ligamentum teres of the liver.
- **Foetal circulation:** The left umbilical vein carries oxygen rich blood from the placenta through the developing liver (within the liver it forms ductus venosus) and upper terminal part of the inferior vena cava to the right atrium. The blood from the right atrium enters the left atrium (bypassing the pulmonary circulation) through foramen ovale. From the left atrium, blood enters the left ventricle and then ascending aorta, arch of the aorta. The arch of the aorta carries more oxygenated blood while ductus arteriosus (pulmonary artery to arch of the aorta) carries less oxygenated blood. They get mixed at the distal end of the arch of the aorta. After coursing through the descending aorta, the less oxygenated blood enters the umbilical arteries and finally reach the placenta.

Exam Material

Major Questions in Thorax

1. Define a typical intercostal space. Name its contents. Describe the course, branches, distribution and applied anatomy of a typical intercostal nerve.
2. Define bronchopulmonary segments. Name the bronchopulmonary segments of the right and left lung. Discuss their applied aspects.
3. Describe the pleura under—parts of parietal pleura, pleural reflection, nerve supply to the pleura, pleural recesses and their applied aspects.
4. Draw a neat, labeled diagram of medial surface of right/left lung.
5. Describe the right atrium under—external features, internal features, development and its anomalies.
6. Describe the right ventricle under—external features, internal features, development and its anomalies.
7. Describe the blood supply of the heart in detail. Discuss its applied anatomy.
8. Describe the nerve supply of the heart and trace the pain pathway in angina and discuss the areas of referred pain.
9. Describe the arch of aorta under—extent, relations, branches, development and applied anatomy.
10. Describe the oesophagus under—parts, major relations, lymphatic drainage, microscopic structure and applied anatomy.

Short Questions in Thorax

1. External intercostal muscle
2. Internal thoracic artery
3. Apex of the lung
4. Root of the lung
5. Hilum of the lung
6. Costodiaphragmatic recess
7. Pericardial sinuses
8. Bronchopulmonary segments
9. Lymphatic drainage of the lung and its clinical significance
10. Phrenic nerve and its applied anatomy
11. Right coronary artery
12. Left coronary artery
13. Cardiac plexus
14. Coronary sinus
15. Coronary sulcus
16. Interventricular septum
17. Ligamentum arteriosum
18. Azygos vein
19. Thoracic duct
20. Normal constrictions of oesophagus
21. Patent ductus arteriosus
22. Fallot's tetralogy
23. Sinus venosus and its fate
24. Fourth arch artery
25. Development of interatrial septum and its defects
26. Development of interventricular septum and its defects
27. Trachea
28. Microscopic structure of trachea
29. Greater and lesser splanchnic nerves

Spotters/OSPE Questions in Thorax

1. Id. of internal thoracic artery, its origin or terminal branches or naming its any 2 branches.
2. Id. of external intercostal muscle, its nerve supply and action.
3. Id. of intercostal nerve, naming the structures supplied by it.
4. Id. of posterior intercostal artery, its origin.
5. Id. of structures at the hilum of the lung (bronchus, pulmonary artery, vein).
6. Id. of transverse or oblique fissure of the lung, their surface marking.
7. Id. of lingual and naming the bronchopulmonary segments present in it.
8. Id. of major impression on medial surface of right (superior vena cava, arch of the azygos vein, inferior vena cava, cardiac impression) or left (arch of the aorta, descending aorta) lung.
9. Id. of apex of the heart, its surface marking or what chamber of the heart does it belongs.
10. Id. of interior of the right atrium, naming the openings (tributaries) present in it.
11. Id. of crista terminalis, its development or naming the structure present in its upper part.
12. Id. of fossa ovalis or limbus fossa ovalis, its development.
13. Id. of anterior papillary muscles in the right ventricle, naming the structure connected to its base.
14. Id. of septomarginal trabaculae, naming what part of conducting system passes through it?
15. Id. of interior of the left atrium, its posterior relations or name the vessels opening into it.
16. Id. of pulmonary trunk and its development.
17. Id. of ascending aorta, naming the arteries arising from it or its development.
18. Id. of right coronary artery, naming its branches or naming the parts of the conducting system supplied by it.
19. Id. of posterior interventricular artery, naming the vein accompanying it.
20. Id. of circumflex artery, its origin or any 2 branches or area supplied by it.
21. Id. of LAD, naming the vein accompanying it or naming its any 2 branches or area supplied by it.
22. Id. of coronary sinus, where does it terminate? or its tributaries or development.

23. Id. of arch of the aorta, naming its branches or its development.
24. Id. of ligamentum arteriosum, its embryological basis or naming the nerve winding around it.
25. Id. of descending thoracic aorta, naming its any 2 branches.
26. Id. of azygos vein, its termination or any 2 tributaries.
27. Id. of oesophagus and its normal constrictions.
28. Id. of thoracic duct and its termination.
29. Id. of thoracic part of the sympathetic chain.

Osteology

30. Naming the structure posterior to manubrium sterni
31. Id. of sternal angle and its significance
32. Naming the structures related to neck of the first rib
33. Naming the structure related to the groove on the upper surface of the first rib or structure attached to the scalene tubercle
34. Id. of typical rib, its specific articulation and naming the structure traversing the costal groove
35. Id. of 12th rib, giving reasons
36. Id. of typical thoracic vertebra, giving specific reasons, or naming its parts

Histology Identification Points

Lung

1. Alveoli lined by simple squamous epithelium
2. Cross section of bronchus and bronchioles

Trachea

1. The mucous membrane is lined by pseudostratified cilated columnar epithelium
2. Presence of hyaline cartilage pieces in the wall

Oesophagus

1. The mucous membrane is lined by stratified squamous nonkeratinized epithelium
2. Presence of mucous glands in the submucosa

Must Draw Diagrams

1. Typical intercostal nerve—Fig. 39.13
2. Pleural recesses—Fig. 40.2A and B
3. Apex of the lung—Fig. 41.3
4. Medial surface of the right and left lungs—Fig. 41.6A and B
5. Hilum of the lung—Fig. 41.8
6. Bronchopulmonary segments—Fig. 41.10
7. Bronchopulmonary segments of right and left lungs—Figs 41.11 and 41.12
8. Pericardial sinuses—Fig. 43.2
9. Interior of the right atrium—Fig. 43.9
10. Interior of the right ventricle—Fig. 43.13a
11. Arterial supply to the heart—Figs 44.1 and 44.2
12. Venous drainage of the heart—Fig. 44.5
13. Conducting system of the heart—Fig. 44.10
14. Relations of the arch of the aorta—Fig. 45.3
15. Azygos system of veins—Fig. 46.8
16. Thoracic duct—Fig. 46.9b