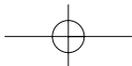
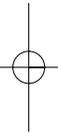
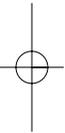
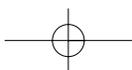
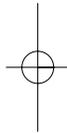
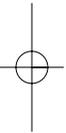
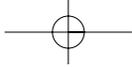


Part 1
The Thorax





Surface anatomy and surface markings

The experienced clinician spends much of his working life relating the surface anatomy of his patients to their deep structures (Fig. 1; see also Figs. 11 and 22).

The following bony prominences can usually be palpated in the living subject (corresponding vertebral levels are given in brackets):

- superior angle of the scapula (T2);
- upper border of the manubrium sterni, the suprasternal notch (T2/3);
- spine of the scapula (T3);
- sternal angle (of Louis)—the transverse ridge at the manubrio-sternal junction (T4/5);
- inferior angle of scapula (T8);
- xiphisternal joint (T9);
- lowest part of costal margin—10th rib (the subcostal line passes through L3).

Note from Fig. 1 that the manubrium corresponds to the 3rd and 4th thoracic vertebrae and overlies the aortic arch, and that the sternum corresponds to the 5th to 8th vertebrae and neatly overlies the heart.

Since the 1st and 12th ribs are difficult to feel, the ribs should be enumerated from the 2nd costal cartilage, which articulates with the sternum at the angle of Louis.

The spinous processes of all the thoracic vertebrae can be palpated in the midline posteriorly, but it should be remembered that the first spinous process that can be felt is that of C7 (the vertebra prominens).

The position of the *nipple* varies considerably in the female, but in the male it usually lies in the 4th intercostal space about 4 in (10 cm) from the midline. The *apex beat*, which marks the lowest and outermost point at which the cardiac impulse can be palpated, is normally in the 5th intercostal space 3.5 in (9 cm) from the midline (just below and medial to the nipple).

The *trachea* is palpable in the suprasternal notch midway between the heads of the two clavicles.

Surface markings of the more important thoracic contents (Figs 2–4)

The trachea

The trachea commences in the neck at the level of the lower border of the cricoid cartilage (C6) and runs vertically downwards to end at the level of the sternal angle of Louis (T4/5), just to the right of the mid-line, by dividing to form the right and left main bronchi. In the erect position and in full inspiration the level of bifurcation is at T6.

4 The Thorax

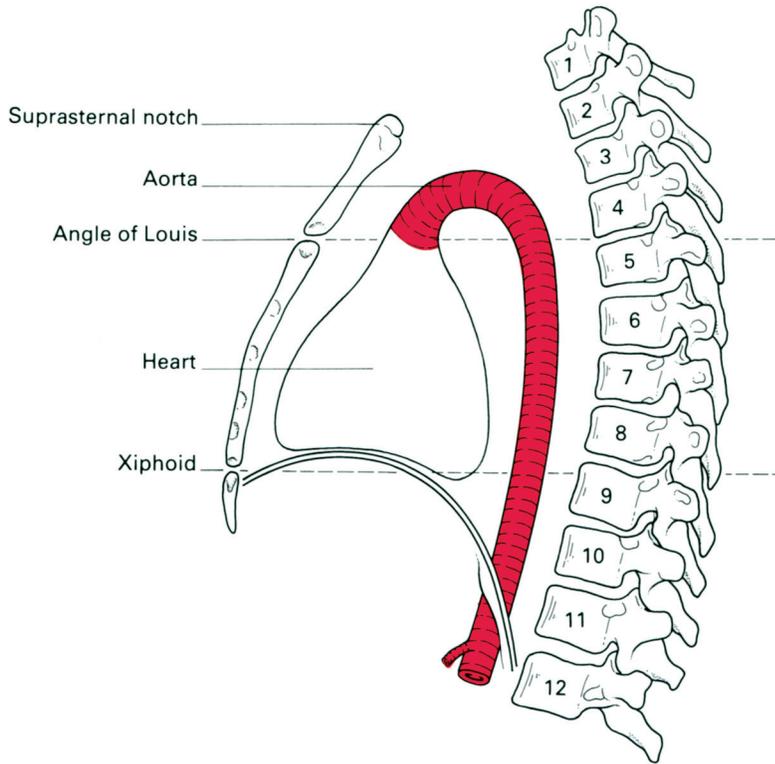


Fig. 1 Lateral view of the thorax—its surface markings and vertebral levels. (Note that the angle of Louis (T4/5) demarcates the superior mediastinum, the upper margin of the heart and the beginning and end of the aortic arch.)

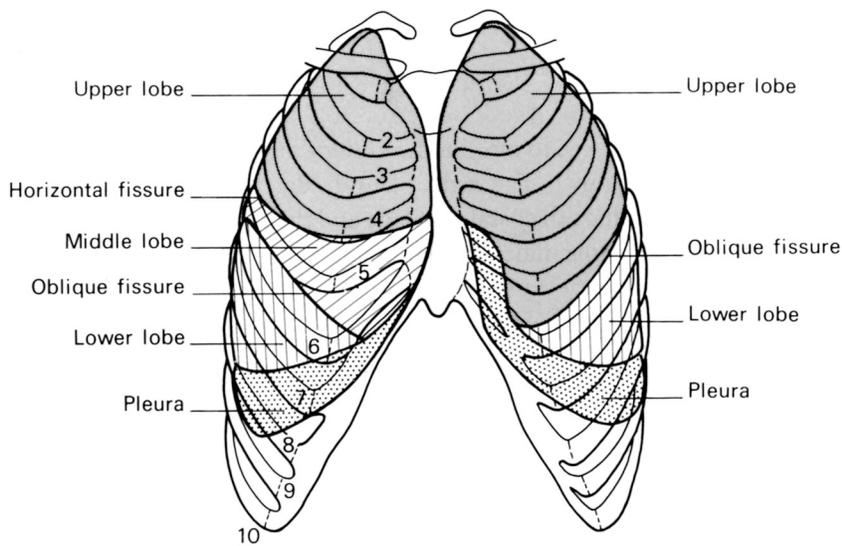


Fig. 2 The surface markings of the lungs and pleura—anterior view.

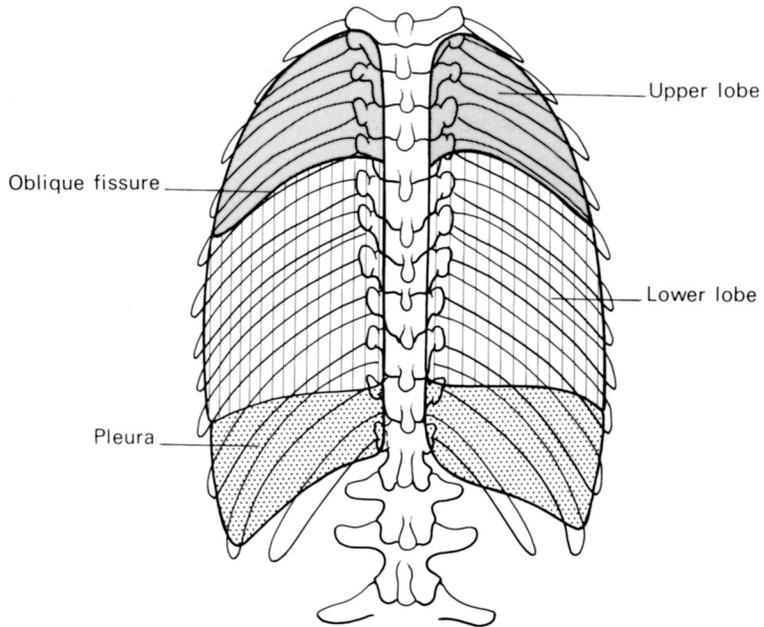


Fig. 3 The surface markings of the lungs and pleura—posterior view.

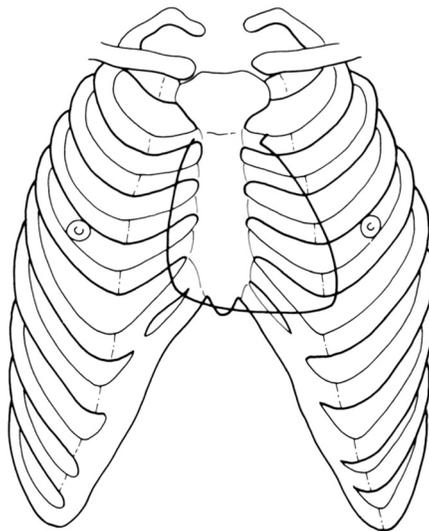


Fig. 4 The surface markings of the heart (see text).

The pleura

The *cervical pleura* can be marked out on the surface by a curved line drawn from the sternoclavicular joint to the junction of the medial and middle thirds of the clavicle; the apex of the pleura is about 1 in (2.5cm) above the clavicle. This fact is easily explained by the oblique slope of the first rib. It is important because the pleura can be wounded (with consequent

6 The Thorax

pneumothorax) by a stab wound — and this includes the surgeon's knife and the anaesthetist's needle—above the clavicle.

The lines of pleural reflexion pass from behind the sternoclavicular joint on each side to meet in the midline at the 2nd costal cartilage (the angle of Louis). The right pleural edge then passes vertically downwards to the 6th costal cartilage and then crosses:

- the 8th rib in the midclavicular line;
- the 10th rib in the midaxillary line;
- the 12th rib at the lateral border of the erector spinae.

On the left side the pleural edge arches laterally at the 4th costal cartilage and descends lateral to the border of the sternum, due, of course, to its lateral displacement by the heart; apart from this, its relationships are those of the right side.

The pleura actually descends just below the 12th rib margin at its medial extremity — or even below the edge of the 11th rib if the 12th is unusually short; obviously in this situation the pleura may be opened accidentally in making a loin incision to expose the kidney, perform an adrenalectomy or to drain a subphrenic abscess.

The lungs

The surface projection of the lung is somewhat less extensive than that of the parietal pleura as outlined above, and in addition it varies quite considerably with the phase of respiration. The *apex* of the lung closely follows the line of the cervical pleura and the surface marking of the *anterior border of the right lung* corresponds to that of the right mediastinal pleura. On the left side, however, the *anterior border* has a distinct notch (the *cardiac notch*) which passes behind the 5th and 6th costal cartilages. The *lower border* of the lung has an excursion of as much as 2–3 in (5–8 cm) in the extremes of respiration, but in the neutral position (midway between inspiration and expiration) it lies along a line which crosses the 6th rib in the midclavicular line, the 8th rib in the midaxillary line, and reaches the 10th rib adjacent to the vertebral column posteriorly.

The *oblique fissure*, which divides the lung into upper and lower lobes, is indicated on the surface by a line drawn obliquely downwards and outwards from 1 in (2.5 cm) lateral to the spine of the 5th thoracic vertebra to the 6th costal cartilage about 1.5 in (4 cm) from the midline. This can be represented approximately by abducting the shoulder to its full extent; the line of the oblique fissure then corresponds to the position of the medial border of the scapula.

The surface markings of the *transverse fissure* (separating the middle and upper lobes of the right lung) is a line drawn horizontally along the 4th costal cartilage and meeting the oblique fissure where the latter crosses the 5th rib.

The heart

The outline of the heart can be represented on the surface by the irregular quadrangle bounded by the following four points (Fig. 4):

- 1 the 2nd *left* costal cartilage 0.5 in (12 mm) from the edge of the sternum;
- 2 the 3rd *right* costal cartilage 0.5 in (12 mm) from the sternal edge;
- 3 the 6th *right* costal cartilage 0.5 in (12 mm) from the sternum;
- 4 the 5th *left* intercostal space 3.5 in (9 cm) from the midline (corresponding to the apex beat).

The *left border* of the heart (indicated by the curved line joining points 1 and 4) is formed almost entirely by the left ventricle (the auricular appendage of the left atrium peeping around this border superiorly), the *lower border* (the horizontal line joining points 3 and 4) corresponds to the right ventricle and the apical part of the left ventricle; the *right border* (marked by the line joining points 2 and 3) is formed by the right atrium (see Fig. 24a).

A good guide to the size and position of your own heart is given by placing your clenched right fist palmar surface down immediately inferior to the manubriosternal junction. Note that the heart is about the size of the subject's fist, lies behind the body of the sternum (therefore anterior to thoracic vertebrae 5–8), and bulges over to the left side.

The surface markings of the vessels of the thoracic wall are of importance if these structures are to be avoided in performing aspiration of the chest. The *internal thoracic (internal mammary) vessels* run vertically downwards behind the costal cartilages half an inch from the lateral border of the sternum. The intercostal vessels lie immediately below their corresponding ribs (the vein above the artery) so that it is safe to pass a needle immediately *above* a rib, dangerous to pass it immediately *below* (see Fig. 8).

The thoracic cage

The thoracic cage is formed by the vertebral column behind, the ribs and intercostal spaces on either side and the sternum and costal cartilages in front. Above, it communicates through the 'thoracic inlet' with the root of the neck; below, it is separated from the abdominal cavity by the diaphragm (Fig. 1).

The thoracic vertebrae

See 'vertebral column', page 327.

The ribs

The greater part of the thoracic cage is formed by the twelve pairs of ribs. Of these, the first seven are connected anteriorly by way of their costal cartilages to the sternum, the cartilages of the 8th, 9th and 10th articulate each with the cartilage of the rib above ('false ribs') and the last two ribs are free anteriorly ('floating ribs').

Each typical rib (Fig. 5) has a *head* bearing two articular facets, for

8 The Thorax

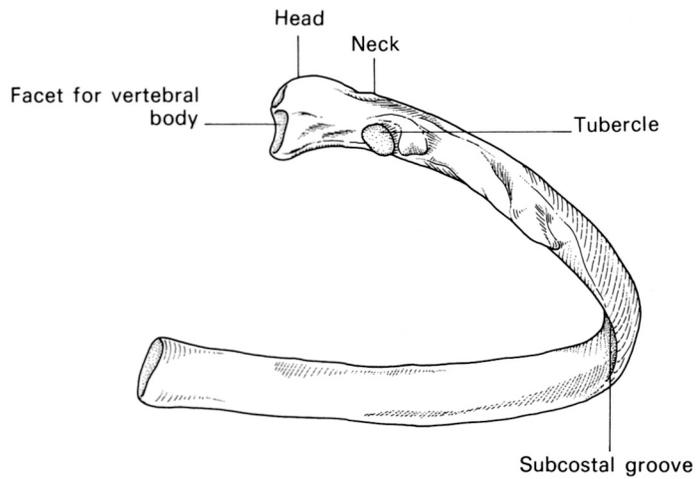


Fig. 5 A typical rib.

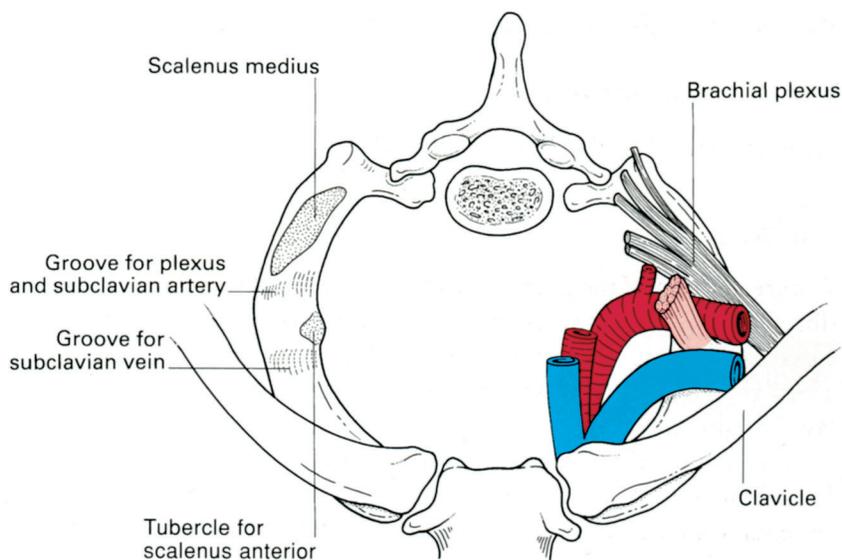


Fig. 6 Structures crossing the first rib.

articulation with the numerically corresponding vertebra and the vertebra above, a stout *neck*, which gives attachment to the costotransverse ligaments, a *tubercle* with a rough non-articular portion and a smooth facet, for articulation with the transverse process of the corresponding vertebra, and a long shaft flattened from side to side and divided into two parts by the 'angle' of the rib. The angle demarcates the lateral limit of attachment of the erector spinae muscle.

The following are the significant features of the 'atypical' ribs.

1st Rib (Fig. 6). This is flattened from above downwards. It is not only the flattest but also the shortest and most curvaceous of all the ribs. It has a prominent *tubercle* on the inner border of its upper surface for the

insertion of scalenus anterior. In front of this tubercle, the subclavian vein crosses the rib; behind the tubercle is the *subclavian groove* where the subclavian artery and lowest trunk of the brachial plexus lie in relation to the bone. It is here that the anaesthetist can infiltrate the plexus with local anaesthetic.

Crossing the neck of the first rib from the medial to the lateral side are the sympathetic trunk, the superior intercostal artery (from the costocervical trunk) and the large branch of the first thoracic nerve to the brachial plexus.

The *2nd rib* is much less curved than the 1st and about twice as long.

The *10th rib* has only one articular facet on the head.

The *11th* and *12th ribs* are short, have no tubercles and only a single facet on the head. The 11th rib has a slight angle and a shallow subcostal groove; the 12th has neither of these features.

Clinical features

Rib fractures

The chest wall of the child is highly elastic and therefore fractures of the rib in children are rare. In adults, the ribs may be fractured by direct violence or indirectly by crushing injuries; in the latter the rib tends to give way at its weakest part in the region of its angle. Not unnaturally, the upper two ribs, which are protected by the clavicle, and the lower two ribs, which are unattached and therefore swing free, are the least commonly injured.

In a severe crush injury to the chest several ribs may fracture in front and behind so that a whole segment of the thoracic cage becomes torn free ('stove-in chest'). With each inspiration this loose flap sucks in, with each expiration it blows out, thus undergoing paradoxical respiratory movement. The associated swinging movements of the mediastinum produce severe shock and this injury calls for urgent treatment by insertion of a chest drain with underwater seal, followed by endotracheal intubation, or tracheostomy, combined with positive pressure respiration.

Coarctation of the aorta (see Fig. 34b and page 41)

In coarctation of the aorta, the intercostal arteries derived from the aorta receive blood from the superior intercostals (from the costocervical trunk of the subclavian artery), from the anterior intercostal branches of the internal thoracic artery (arising from the subclavian artery) and from the arteries anastomosing around the scapula. Together with the communication between the internal thoracic and inferior epigastric arteries, they provide the principal collaterals between the aorta above and below the block. In consequence, the intercostal arteries undergo dilatation and tortuosity and erode the lower borders of the corresponding ribs to give the characteristic irregular *notching of the ribs*, which is very useful in the radiographic confirmation of this lesion.

10 The Thorax

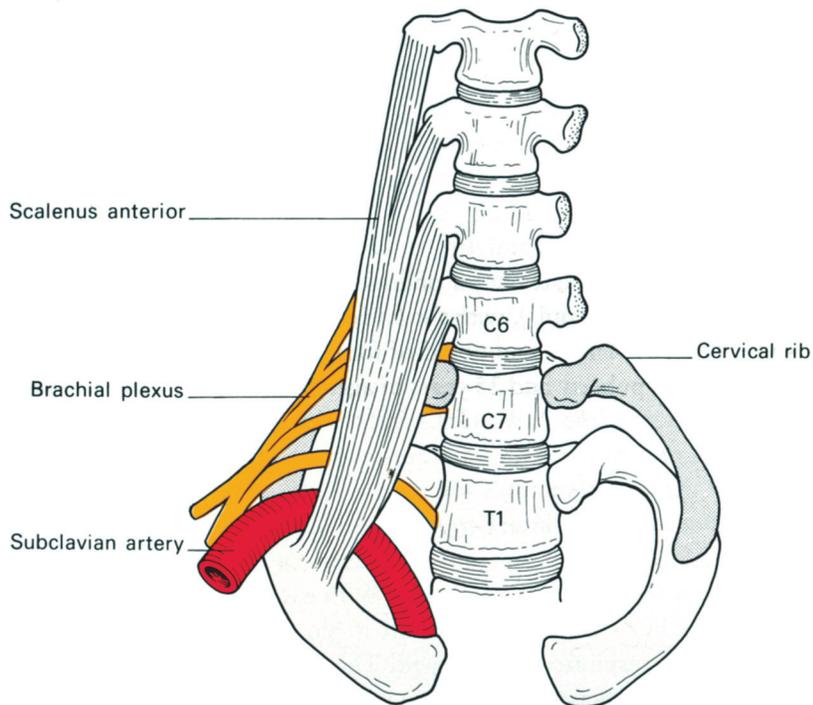


Fig. 7 Bilateral cervical ribs. On the right side the brachial plexus is shown arching over the rib and stretching its lowest trunk.

Cervical rib

A cervical rib (Fig. 7) occurs in 0.5% of subjects and is bilateral in half of these. It is attached to the transverse process of the 7th cervical vertebra and articulates with the 1st (thoracic) rib or, if short, has a free distal extremity which usually attaches by a fibrous strand to the (normal) first rib. Pressure of such a rib on the lowest trunk of the brachial plexus arching over it may produce paraesthesiae along the ulnar border of the forearm and wasting of the small muscles of the hand (T1). Less commonly vascular changes, even gangrene, may be caused by pressure of the rib on the overlying subclavian artery. This results in post-stenotic dilatation of the vessel distal to the rib in which a thrombus forms from which emboli are thrown off.

The costal cartilages

These bars of hyaline cartilage serve to connect the upper seven ribs directly to the side of the sternum and the 8th, 9th and 10th ribs to the cartilage immediately above. The cartilages of the 11th and 12th ribs merely join the tapered extremities of these ribs and end in the abdominal musculature.

Clinical features

- 1 The cartilage adds considerable resilience to the thoracic cage and protects the sternum and ribs from more frequent fracture.
- 2 In old age (and sometimes also in young adults) the costal cartilages undergo progressive ossification; they then become radio-opaque and may give rise to some confusion when examining a chest radiograph of an elderly patient.

The sternum

This dagger-shaped bone, which forms the anterior part of the thoracic cage, consists of three parts. The *manubrium* is roughly triangular in outline and provides articulation for the clavicles and for the first and upper part of the 2nd costal cartilages on either side. It is situated opposite the 3rd and 4th thoracic vertebrae. Opposite the disc between T4 and T5 it articulates at an oblique angle at the manubriosternal joint (the angle of Louis), with the *body of the sternum* (placed opposite T5 to T8). This is composed of four parts or 'sternebrae' which fuse between puberty and 25 years of age. Its lateral border is notched to receive part of the 2nd and the 3rd to the 7th costal cartilage. The *xiphoid process* is the smallest part of the sternum and usually remains cartilaginous well into adult life. The cartilaginous manubriosternal joint and that between the xiphoid and the body of the sternum may also become ossified after the age of 30.

Clinical features

- 1 The attachment of the elastic costal cartilages largely protects the sternum from injury, but indirect violence accompanying fracture dislocation of the thoracic spine may be associated with a sternal fracture. Direct violence to the sternum may lead to displacement of the relatively mobile body of the sternum backwards from the relatively fixed manubrium.
- 2 In a sternal puncture a wide-bore needle is pushed through the thin layer of cortical bone covering the sternum into the highly vascular spongy bone beneath, and a specimen of bone marrow aspirated with a syringe.
- 3 In operations on the thymus gland, and occasionally for a retrosternal goitre, it is necessary to split the manubrium in the midline in order to gain access to the superior mediastinum. A complete vertical split of the whole sternum is one of the standard approaches to the heart and great vessels used in modern cardiac surgery.

The intercostal spaces

There are slight variations between the different intercostal spaces, but typically each space contains three muscles, comparable to those of the abdominal wall, and an associated neurovascular bundle (Fig. 8). The muscles are:

12 The Thorax

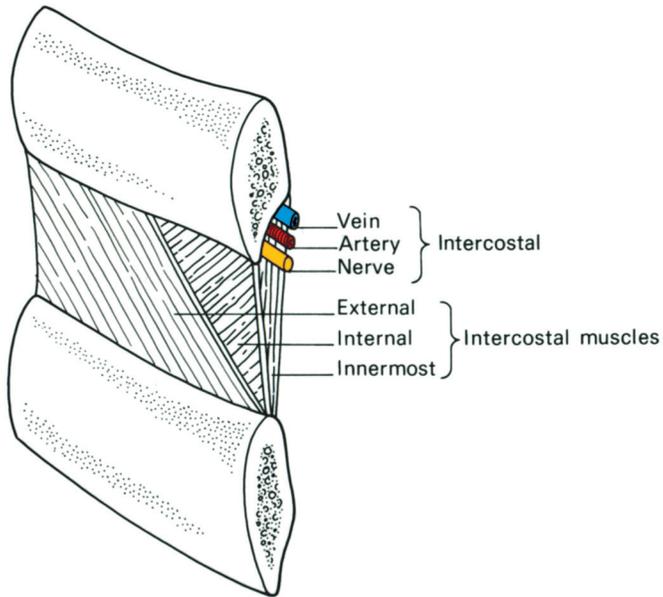


Fig. 8 The relationship of an intercostal space. (Note that a needle passed into the chest immediately *above* a rib will avoid the neurovascular bundle.)

- 1 the *external intercostal*, the fibres of which pass downwards and forwards from the rib above to the rib below and reach from the vertebrae behind to the costochondral junction in front, where muscle is replaced by the *anterior intercostal membrane*;
- 2 the *internal intercostal*, which runs downwards and backwards from the sternum to the angles of the ribs where it becomes the *posterior intercostal membrane*;
- 3 the *innermost intercostal*, which is only incompletely separated from the internal intercostal muscle by the neurovascular bundle.

The fibres of this sheet cross more than one intercostal space and it may be incomplete. Anteriorly it has a more distinct portion which is fan-like in shape, termed the *transversus thoracis* (or *sternocostalis*), which spreads upwards from the posterior aspect of the lower sternum to insert onto the inner surfaces of the second to the sixth costal cartilages.

Just as in the abdomen, the nerves and vessels of the thoracic wall lie between the middle and innermost layers of muscles. This neurovascular bundle consists, from above downwards, of vein, artery and nerve, the vein lying in a groove on the undersurface of the corresponding rib (remember—V,A,N).

The vessels comprise the posterior and anterior intercostals.

The *posterior intercostal arteries* of the lower nine spaces are branches of the thoracic aorta, while the first two are derived from the superior intercostal branch of the costocervical trunk, the only branch of the second part of the subclavian artery. Each runs forward in the subcostal groove to anastomose with the anterior intercostal artery. Each has a number of branches to adjacent muscles, to the skin and to the spinal cord. The corresponding veins are mostly tributaries of the azygos and hemiazygos veins. The first posterior intercostal vein drains into the brachiocephalic or vertebral vein.

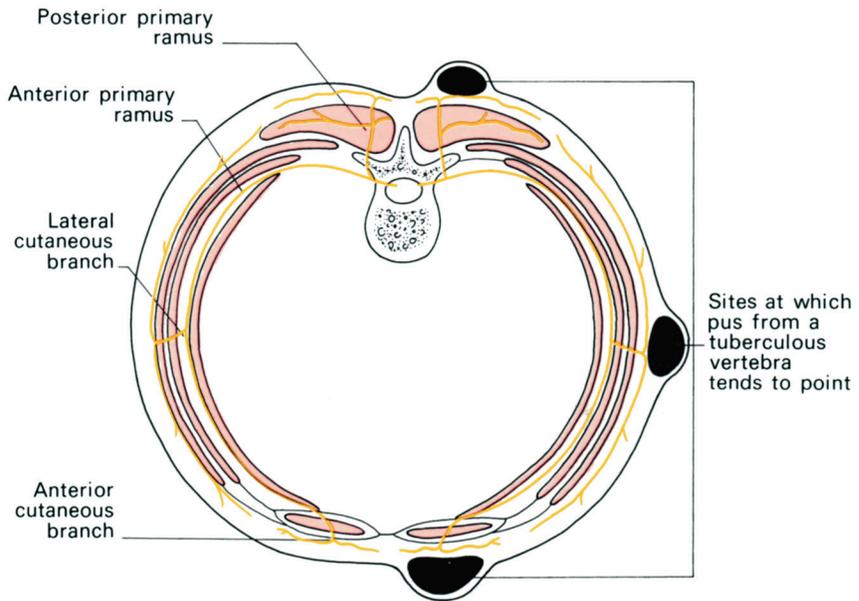


Fig. 9 Diagram of a typical spinal nerve and its body-wall relationships. On the left side the sites of eruption of a tuberculous cold abscess tracking forwards from a diseased vertebra are shown—these occur at the points of emergence of the cutaneous branches.

On the left, the 2nd and 3rd veins often join to form a superior intercostal vein, which crosses the aortic arch to drain into the left brachiocephalic vein.

The *anterior intercostal arteries* are branches of the internal thoracic artery (1st–6th space) or of its musculophrenic branch (7th–9th spaces). The lowest two spaces have only posterior arteries. Perforating branches pierce the upper five or six intercostal spaces; those of the 2nd–4th spaces are large in the female and supply the breast.

The *intercostal nerves* are the anterior primary rami of the thoracic nerves, each of which gives off a collateral muscular branch and lateral and anterior cutaneous branches for the innervation of the thoracic and abdominal walls (Fig. 9).

Clinical features

- 1 Local irritation of the intercostal nerves by such conditions as Pott's disease of the thoracic vertebrae (tuberculosis) may give rise to pain which is referred to the front of the chest or abdomen in the region of the peripheral termination of the nerves.
- 2 Local anaesthesia of an intercostal space is easily produced by infiltration around the intercostal nerve trunk and its collateral branch—a procedure known as *intercostal nerve block*.

14 The Thorax

- 3 In a conventional posterolateral *thoracotomy* (e.g. for a pulmonary lobectomy) an incision is made along the line of the 5th or 6th rib; the periosteum over a segment of the rib is elevated, thus protecting the neurovascular bundle, and the rib is excised. Access to the lung or mediastinum is then gained through the intercostal space, which can be opened out considerably owing to the elasticity of the thoracic cage.
- 4 Pus from the region of the vertebral column tends to track around the thorax along the course of the neurovascular bundle and to 'point' to the three sites of exit of the cutaneous branches of the intercostal nerves, which are lateral to erector spinae (sacrospinalis), in the midaxillary line and just lateral to the sternum (Fig. 9).

The diaphragm

The diaphragm is the dome-shaped septum dividing the thoracic from the abdominal cavity. It comprises two portions: a peripheral muscular part which arises from the margins of the thoracic outlet and a centrally placed aponeurosis (Fig. 10).

The muscular fibres are arranged in three parts.

- 1 A *vertebral part* from the crura and from the arcuate ligaments. The *right crus* arises from the front of the bodies of the upper three lumbar vertebrae and intervertebral discs; the *left crus* is only attached to the first two vertebrae. The *arcuate ligaments* are a series of fibrous arches, the *medial* being a thickening of the fascia covering psoas major and the *lateral* of fascia overlying quadratus lumborum. The fibrous medial borders of the two crura form a *median arcuate ligament* over the front of the aorta.
- 2 A *costal part* is attached to the inner aspect of the lower six ribs and costal cartilages.
- 3 A *sternal portion* consists of two small slips from the deep surface of the xiphisternum.

The central tendon, into which the muscular fibres are inserted, is trefoil in shape and is partially fused with the undersurface of the pericardium.

The diaphragm receives its entire motor supply from the phrenic nerve (C3, 4, 5) whose long course from the neck follows the embryological migration of the muscle of the diaphragm from the cervical region (see below). Injury or operative division of this nerve results in paralysis and elevation of the corresponding half of the diaphragm.

Radiographically, paralysis of the diaphragm is recognized by its elevation and paradoxical movement; instead of descending on inspiration it is forced upwards by pressure from the abdominal viscera.

The sensory nerve fibres from the central part of the diaphragm also run in the phrenic nerve, hence irritation of the diaphragmatic pleura (in pleurisy) or of the peritoneum on the undersurface of the diaphragm by subphrenic collections of pus or blood produces referred pain in the corresponding cutaneous area, the shoulder-tip.

The peripheral part of the diaphragm, including the crura, receives sensory fibres from the lower intercostal nerves.

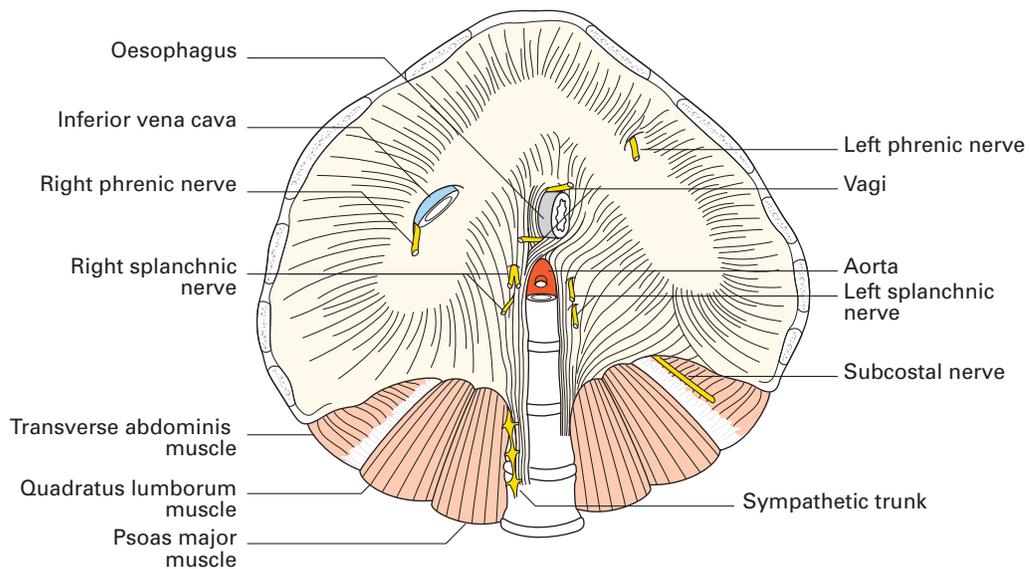


Fig. 10 The diaphragm—inferior aspect. The three major orifices, from above downwards, transmit the inferior vena cava, oesophagus and aorta.

Openings in the diaphragm

The three main openings in the diaphragm (Figs 10, 11) are:

- 1 the *aortic* (at the level of T12) which transmits the abdominal aorta, the thoracic duct and often the azygos vein;
- 2 the *oesophageal* (T10) which is situated between the muscular fibres of the right crus of the diaphragm and transmits, in addition to the oesophagus, branches of the left gastric artery and vein and the two vagi;
- 3 the *opening for the inferior vena cava* (T8) which is placed in the central tendon and also transmits the right phrenic nerve.

In addition to these structures, the greater and lesser splanchnic nerves (see page 49) pierce the crura and the sympathetic chain passes behind the diaphragm deep to the medial arcuate ligament.

The development of the diaphragm and the anatomy of diaphragmatic herniae

The diaphragm is formed (Fig. 12) by fusion in the embryo of:

- 1 the septum transversum (forming the central tendon);
- 2 the dorsal oesophageal mesentery;
- 3 a peripheral rim derived from the body wall;
- 4 the pleuroperitoneal membranes, which close the fetal communication between the pleural and peritoneal cavities.

The septum transversum is the mesoderm which, in early development, lies in front of the head end of the embryo. With the folding off of the head, this mesodermal mass is carried ventrally and caudally, to lie in its

16 The Thorax

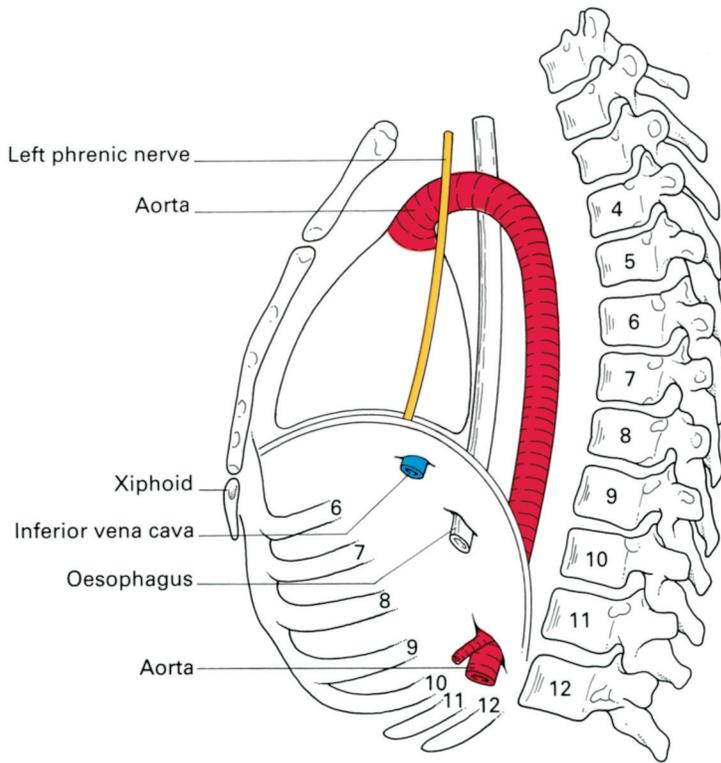


Fig. 11 Schematic lateral view of the diaphragm to show the levels at which it is pierced by major structures.

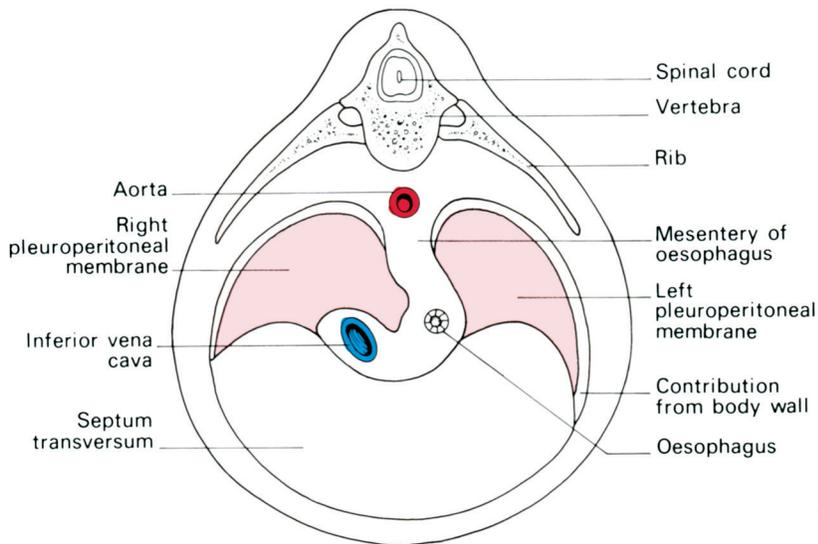


Fig. 12 The development of the diaphragm. This drawing shows the four elements contributing to the diaphragm—(1) the septum transversum, (2) the dorsal mesentery of the oesophagus, (3) the body wall and (4) the pleuroperitoneal membrane.

definitive position at the anterior part of the diaphragm. During this migration, the cervical myotomes and nerves contribute muscle and nerve supply respectively, thus accounting for the long course of the phrenic nerve (C3, 4 and 5) from the neck to the diaphragm.

With such a complex embryological story, one may be surprised to know that congenital abnormalities of the diaphragm are unusual.

However, a number of defects may occur, giving rise to a variety of congenital herniae through the diaphragm. These may be:

- 1 through the foramen of Morgagni; anteriorly between the xiphoid and costal origins;
- 2 through the foramen of Bochdalek—the pleuroperitoneal canal—lying posteriorly;
- 3 through a deficiency of the whole central tendon (occasionally such a hernia may be traumatic in origin);
- 4 through a congenitally large oesophageal hiatus.

Far more common are the *acquired* hiatus herniae (subdivided into sliding and rolling herniae). These are found in patients usually of middle age where weakening and widening of the oesophageal hiatus has occurred (Fig. 13).

In the *sliding hernia* the upper stomach and lower oesophagus slide upwards into the chest through the lax hiatus when the patient lies down or bends over; the competence of the cardia is often disturbed and peptic juice can therefore regurgitate into the gullet in lying down or bending over. This may be followed by oesophagitis with consequent heartburn, bleeding and, eventually, stricture formation.

In the *rolling hernia* (which is far less common) the cardia remains in its normal position and the cardio-oesophageal junction is intact, but the fundus of the stomach rolls up through the hiatus in front of the oesophagus, hence the alternative term of para-oesophageal hernia. In such a case

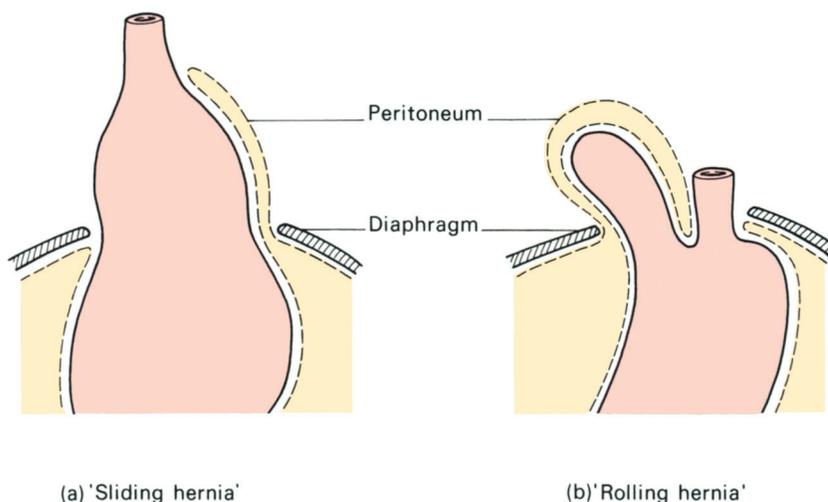


Fig. 13 (a) A sliding hiatus hernia. (b) A rolling hiatus hernia.

18 The Thorax

there may be epigastric discomfort, flatulence and even dysphagia, but *no* regurgitation because the cardiac mechanism is undisturbed.

The movements of respiration

During inspiration the movements of the chest wall and diaphragm result in an increase in all diameters of the thorax. This, in turn, brings about an increase in the negative intrapleural pressure and an expansion of the lung tissue. Conversely, in expiration the relaxation of the respiratory muscles and the elastic recoil of the lung reduce the thoracic capacity and force air out of the lungs.

In quiet *inspiration* the first rib remains relatively fixed, but contraction of the external and internal intercostals elevates and, at the same time, everts the succeeding ribs. In the case of the 2nd–7th ribs this principally increases the anteroposterior diameter of the thorax (by the forward thrust of the sternum), like a pump handle. The corresponding movement of the lower ribs raises the costal margin and leads mainly to an increase in the transverse diameter of the thorax, like a bucket handle. The depth of the thorax is increased by the contraction of the diaphragm which draws down its central tendon. Normal quiet *expiration*, brought about by elastic recoil of the elevated ribs, is aided by the tone of the abdominal musculature which, acting through the contained viscera, forces the diaphragm upwards.

In deep and in forced inspiration additional muscles attached to the chest wall are called into play (e.g. scalenus anterior, sternocleidomastoid, serratus anterior and pectoralis major) to increase further the capacity of the thorax. Similarly, in deep expiration, forced contraction of the abdominal muscles aids the normal expulsive factors described above.

The pleurae

The two pleural cavities are totally separate from each other (Fig. 2). Each *pleura* consists of two layers: a *visceral layer* intimately related to the surface of the lung, and a *parietal layer* lining the inner aspect of the chest wall, the upper surface of the diaphragm and the sides of the pericardium and mediastinum. The two layers are continuous in front and behind the root of the lung, but below this the pleura hangs down in a loose fold, the *pulmonary ligament*, which forms a 'dead-space' for distension of the pulmonary veins. The surface markings of the pleura and lungs have already been described in the section on surface anatomy.

Notice that the lungs do not occupy all the available space in the pleural cavity even in forced inspiration.

Clinical features

1 Normally the two pleural layers are in close apposition and the space between them is only a potential one. It may, however, fill with air (pneumothorax), blood (haemothorax) or pus (empyema).

2 Fluid can be drained from the pleural cavity by inserting a wide-bore needle through an intercostal space (usually the 7th posteriorly). The needle is passed along the superior border of the lower rib, thus avoiding the intercostal nerves and vessels (Fig. 8). Below the 7th intercostal space there is danger of penetrating the diaphragm.

3 For emergency chest drainage—for example traumatic haemothorax or haemopneumothorax—the site of election is the 5th intercostal space in the mid-axillary line. An incision is made through skin and fat and blunt dissection carried out over the upper border of the 6th rib. The pleura is opened, a finger inserted to clear any adhesions and ensure the safety of the adjacent diaphragm before inserting a tube into the pleural space and connecting it to an under-water drain.

4 Since the parietal pleura is segmentally innervated by the intercostal nerves, inflammation of the pleura results in pain referred to the cutaneous distribution of these nerves (i.e. to the thoracic wall or, in the case of the lower nerves, to the anterior abdominal wall, which may mimic an acute abdominal emergency).

The lower respiratory tract

The trachea (Figs 14, 15)

The trachea is about 4.5in (11.5cm) in length and nearly 1 in (2.5cm) in diameter. It commences at the lower border of the cricoid cartilage (C6) and terminates by bifurcating at the level of the sternal angle of Louis (T4/5) to form the right and left main bronchi. (In the living subject, the level of bifurcation varies slightly with the phase of respiration; in deep inspiration it descends to T6 and in expiration it rises to T4.)

Relations

Lying partly in the neck and partly in the thorax, its relations are:

Cervical

- anteriorly—the isthmus of thyroid gland, inferior thyroid veins, sternohyoid and sternothyroid muscles;
- laterally—the lobes of thyroid gland and the common carotid artery;
- posteriorly—the oesophagus with the recurrent laryngeal nerve lying in the groove between oesophagus and trachea (Fig. 16).

Thoracic

In the superior mediastinum its relations are:

- anteriorly—commencement of the brachiocephalic (innominate) artery

20 The Thorax

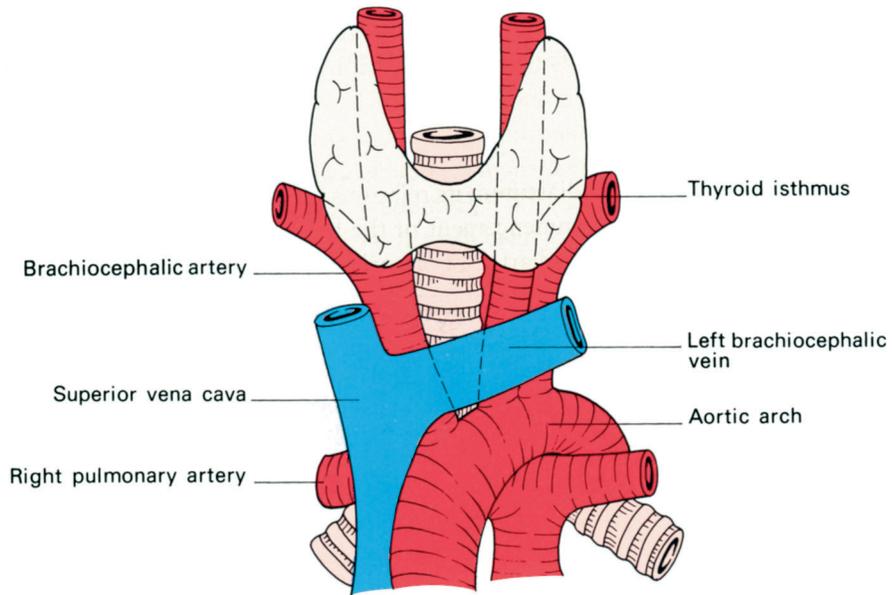


Fig. 14 The trachea and its anterior relationships.

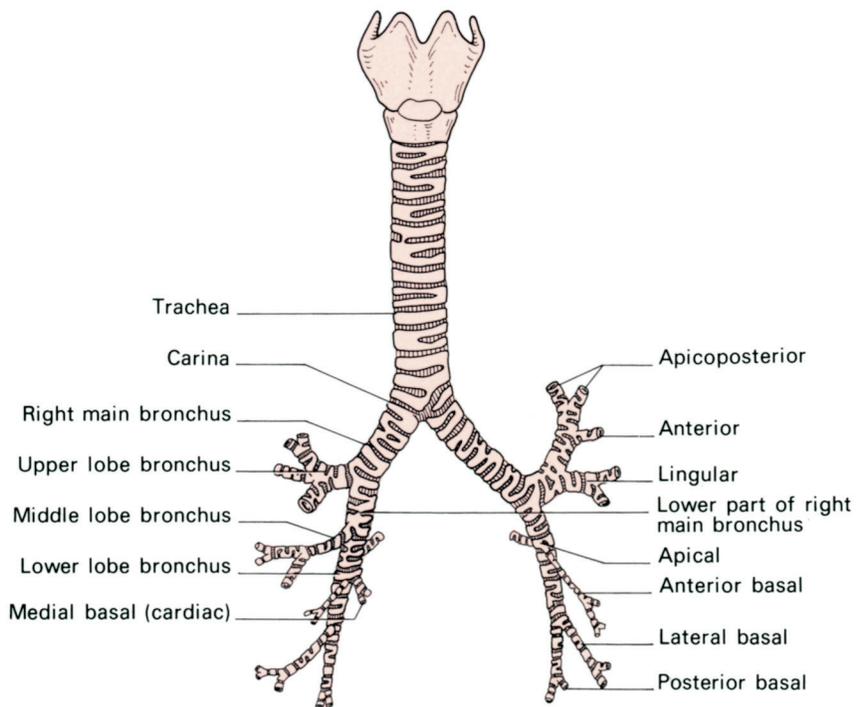


Fig. 15 The trachea and main bronchi viewed from the front.

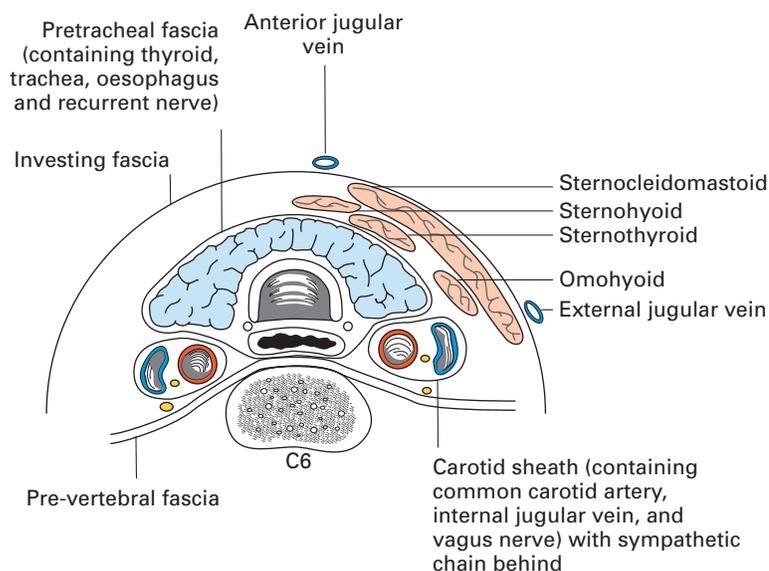


Fig. 16 The cervical part of the trachea and its environs in transverse section (through the 6th cervical vertebra).

and left carotid artery, both arising from the arch of the aorta, the left brachiocephalic (innominate) vein, and the thymus;

- posteriorly—oesophagus and left recurrent laryngeal nerve;
- to the left—arch of the aorta, left common carotid and left subclavian arteries, left recurrent laryngeal nerve and pleura;
- to the right—vagus, azygos vein and pleura (Fig. 17).

Structure

The patency of the trachea is maintained by a series of 15–20 U-shaped cartilages. Posteriorly, where the cartilage is deficient, the trachea is flattened and its wall completed by fibrous tissue and a sheet of smooth muscle (the trachealis). Within, it is lined by a ciliated columnar epithelium with many goblet cells.

Clinical features

Radiology

Since it contains air, the trachea is more radio-translucent than the neighbouring structures and is seen in posteroanterior and lateral radiographs as a dark area passing downwards, backwards and slightly to the right. In the elderly, calcification of the tracheal rings may be a source of radiological confusion.

Displacement

The trachea may be compressed or displaced by pathological enlargement

22 The Thorax

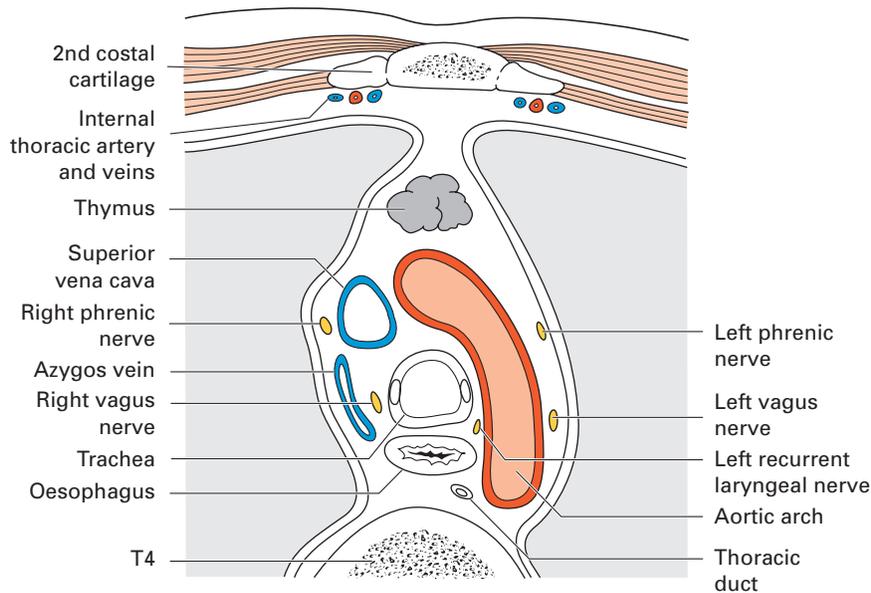


Fig. 17 The thoracic part of the trachea and its environs in transverse section (through the 4th thoracic vertebra).

of the neighbouring structures, particularly the thyroid gland and the arch of the aorta.

'Tracheal-tug'

The intimate relationship between the arch of the aorta and the trachea and left bronchus is responsible for the physical sign known as 'tracheal-tug', characteristic of aneurysms of the aortic arch.

Tracheostomy

Tracheostomy may be required for laryngeal obstruction (diphtheria, tumours, inhaled foreign bodies), for the evacuation of excessive secretions (severe postoperative chest infection in a patient who is too weak to cough adequately), and for long-continued artificial respiration (poliomyelitis, severe chest injuries). It is important to note that respiration is further assisted by considerable reduction of the dead-space air.

The neck is extended and the head held exactly in the midline by an assistant. A vertical incision is made downwards from the cricoid cartilage, passing between the anterior jugular veins. Alternatively, a more cosmetic transverse skin crease incision, placed halfway between the cricoid and suprasternal notch, is employed. A hook is thrust under the lower border of the cricoid to steady the trachea and pull it forward. The pretracheal fascia is split longitudinally, the isthmus of the thyroid either pushed upwards or divided between clamps and the cartilage of the trachea clearly exposed. A circular opening is then made into the trachea to admit the tracheostomy tube.

In children the neck is relatively short and the left brachiocephalic vein may come up above the suprasternal notch so that dissection is rather more difficult and dangerous. This difficulty is made greater because the child's trachea is softer and more mobile than the adult's and therefore not so readily identified and isolated. Its softness means that care must be taken, in incising the child's trachea, not to let the scalpel plunge through and damage the underlying oesophagus.

In contrast, the trachea may be ossified in the elderly and small bone shears required to open into it.

The golden rule of tracheostomy—based entirely on anatomical considerations—is '*stick exactly to the midline*'. If this is not done, major vessels are in jeopardy and it is possible, although the student may not credit it, to miss the trachea entirely.

The bronchi (Fig. 15)

The *right main bronchus* is wider, shorter and more vertical than the left. It is about 1 in (2.5cm) long and passes directly to the root of the lung at T5. Before joining the lung it gives off its *upper lobe branch*, and then passes below the pulmonary artery to enter the hilum of the lung. It has two important relations: the azygos vein, which arches over it from behind to reach the superior vena cava, and the pulmonary artery which lies first below and then anterior to it.

The *left main bronchus* is nearly 2 in (5cm) long and passes downwards and outwards below the arch of the aorta, in front of the oesophagus and descending aorta. Unlike the right, it gives off no branches until it enters the hilum of the lung, which it reaches opposite T6. The pulmonary artery spirals over the bronchus, lying first anteriorly and then above it.

Clinical features

- 1 The greater width and more vertical course of the right bronchus accounts for the greater tendency for foreign bodies and aspirated material to pass into the right bronchus (and thence especially into the middle and lower lobes of the right lung) rather than into the left.
- 2 The inner aspect of the whole of the trachea, the main and lobar bronchi and the commencement of the first segmental divisions can be seen at bronchoscopy.
- 3 Widening and distortion of the angle between the bronchi (the carina) as seen at bronchoscopy is a serious prognostic sign, since it usually indicates carcinomatous involvement of the tracheobronchial lymph nodes around the bifurcation of the trachea.

The lungs (Figs 18, 19)

Each lung is conical in shape, having a blunt apex which reaches above the sternal end of the 1st rib, a concave base overlying the diaphragm, an extensive costovertebral surface moulded to the form of the chest

24 The Thorax

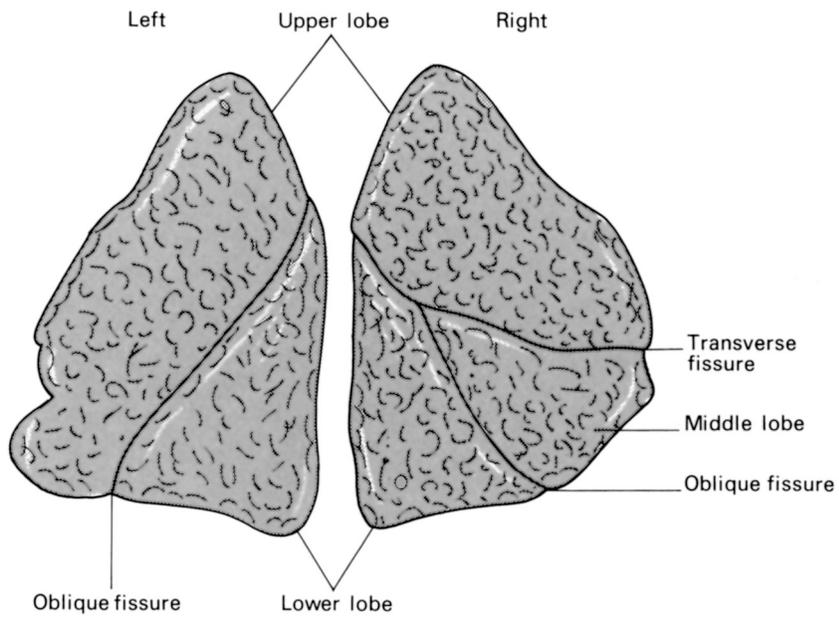


Fig. 18 The lungs, lateral aspects.

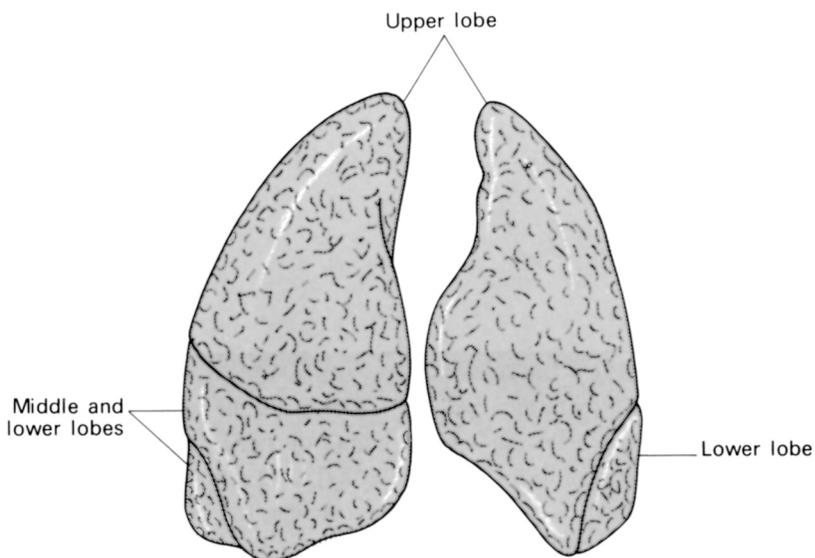


Fig. 19 The lungs, anterior aspects.

wall and a mediastinal surface which is concave to accommodate the pericardium.

The right lung is slightly larger than the left and is divided into three lobes—upper, middle and lower, by the oblique and horizontal fissures. The left lung has only an oblique fissure and hence only two lobes.

Blood supply

Mixed venous blood is returned to the lungs by the pulmonary arteries; the air passages are themselves supplied by the bronchial arteries, which are small branches of the descending aorta. The *bronchial arteries*, although small, are of great clinical importance. They maintain the blood supply to the lung parenchyma after pulmonary embolism, so that, if the patient recovers, lung function returns to normal.

The *superior* and *inferior pulmonary veins* return oxygenated blood to the left atrium, while the *bronchial veins* drain into the azygos system.

Lymphatic drainage

The lymphatics of the lung drain centripetally from the pleura towards the hilum. From the *bronchopulmonary lymph nodes* in the hilum, efferent lymph channels pass to the *tracheobronchial nodes* at the bifurcation of the trachea, thence to the *paratracheal nodes* and the mediastinal lymph trunks to drain usually directly into the brachiocephalic veins or, rarely, indirectly via the thoracic or right lymphatic duct.

Nerve supply

The pulmonary plexuses derive fibres from both the vagi and the sympathetic trunk. They supply efferents to the bronchial musculature (sympathetic bronchodilator fibres) and receive afferents from the mucous membrane of the bronchioles and from the alveoli.

The bronchopulmonary segments of the lungs

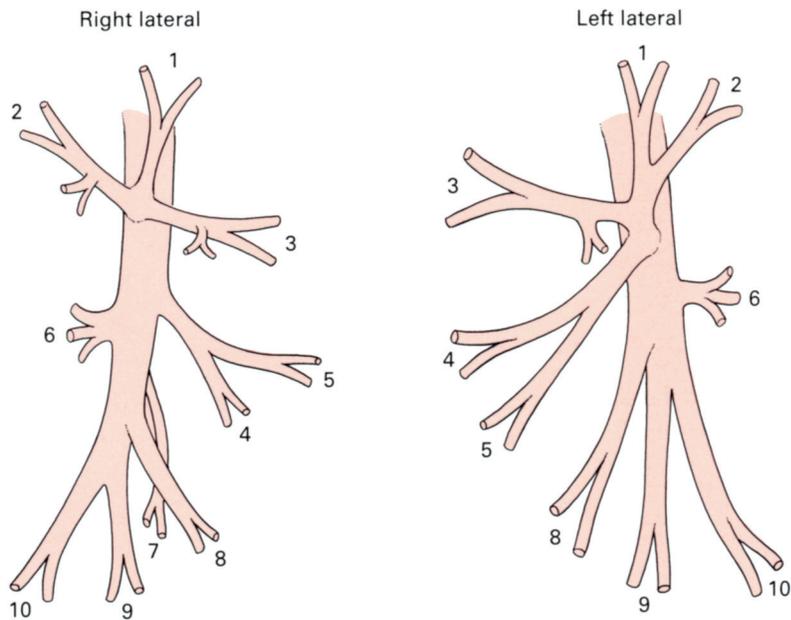
(Figs 20, 21)

A knowledge of the finer arrangement of the bronchial tree is an essential

Table 1 The named divisions of the main bronchi.

Right main bronchus	<ul style="list-style-type: none"> { Upper lobe bronchus { Middle lobe bronchus { Lower lobe bronchus 	<ul style="list-style-type: none"> { Apical { Posterior { Anterior { Lateral { Medial { Apical { Basal 	→	<ul style="list-style-type: none"> { Medial (cardiac) { Anterior { Lateral { Posterior 					
					Left main bronchus	<ul style="list-style-type: none"> { Upper lobe bronchus ↓ { Lingular bronchus { Lower lobe bronchus 	<ul style="list-style-type: none"> { Apicoposterior { Anterior { Superior { Inferior { Apical { Basal 	→	<ul style="list-style-type: none"> { Anterior { Lateral { Posterior

26 The Thorax



Right

Upper lobe

- 1 Apical bronchus
- 2 Posterior bronchus
- 3 Anterior bronchus

Middle lobe

- 4 Lateral bronchus
- 5 Medial bronchus

Lower lobe

- 6 Apical bronchus
- 7 Medial basal (cardiac) bronchus
- 8 Anterior basal bronchus
- 9 Lateral basal bronchus
- 10 Posterior basal bronchus

Left

Upper lobe

- 1 } Apicoposterior bronchus
- 2 } Apicoposterior bronchus
- 3 Anterior bronchus

Lingula

- 4 Superior bronchus
- 5 Inferior bronchus

Lower lobe

- 6 Apical bronchus
- 8 Anterior basal bronchus
- 9 Lateral basal bronchus
- 10 Posterior basal bronchus

Fig. 20 The named divisions of the main bronchi.

prerequisite to intelligent appreciation of lung radiology, to interpretation of bronchoscopy and to the surgical resection of lung segments. Each lobe of the lung is subdivided into a number of bronchopulmonary segments, each of which is supplied by a segmental bronchus, artery and vein. These segments are wedge-shaped with their apices at the hilum and bases at the lung surface; if excised accurately along their boundaries (which are marked by intersegmental veins), there is little bleeding or alveolar air leakage from the raw lung surface.

The names and arrangements of the bronchi are given in Table 1; each bronchopulmonary segment takes its title from that of its supplying segmental bronchus (listed in the right-hand column of the table).

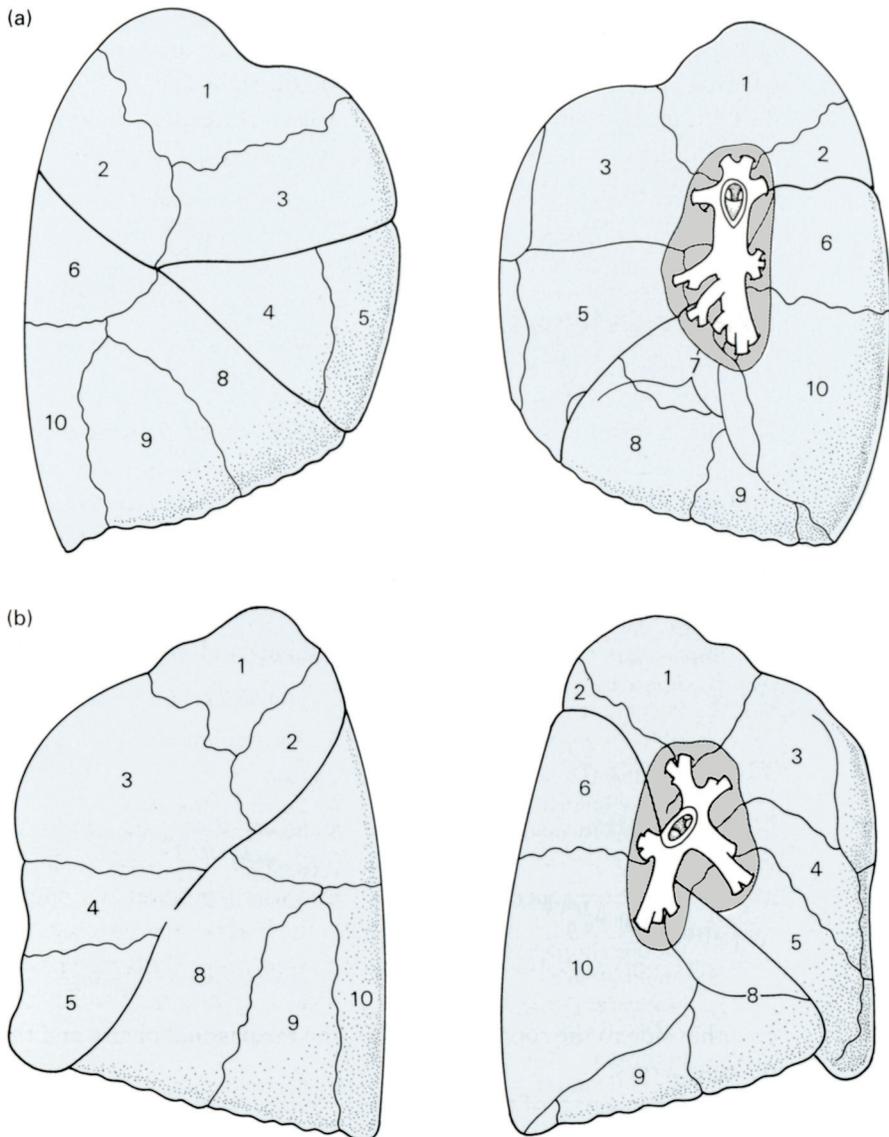


Fig. 21 (a) The segments of the right lung. (b) The segments of the left lung.

The left upper lobe has a *lingular segment*, supplied by the *lingular bronchus* from the main upper lobe bronchus. This lobe is equivalent to the *right middle lobe* whose bronchus arises as a branch from the main bronchus. Apart from this, differences between the two sides are very slight; on the left, the upper lobe bronchus gives off a combined apicoposterior segmental bronchus and an anterior branch, whereas all three branches are separate on the right side.

On the right also there is a small medial (or cardiac) lower lobe

28 The Thorax

bronchus which is absent on the left, the lower lobes being otherwise mirror images of each other.

The mediastinum

The mediastinum is defined as 'the space which is sandwiched between the two pleural sacs'. For descriptive purposes the mediastinum is divided by a line drawn horizontally from the sternal angle to the lower border of T4 (angle of Louis) into superior and inferior mediastinum. The inferior mediastinum is further subdivided into the anterior in front of the pericardium, a middle mediastinum containing the pericardium itself with the heart and great vessels, and posterior mediastinum between the pericardium and the lower eight thoracic vertebrae (Fig. 22).

The pericardium

The heart and the roots of the great vessels are contained within the conical *fibrous pericardium*, the apex of which is fused with the adventitia of the

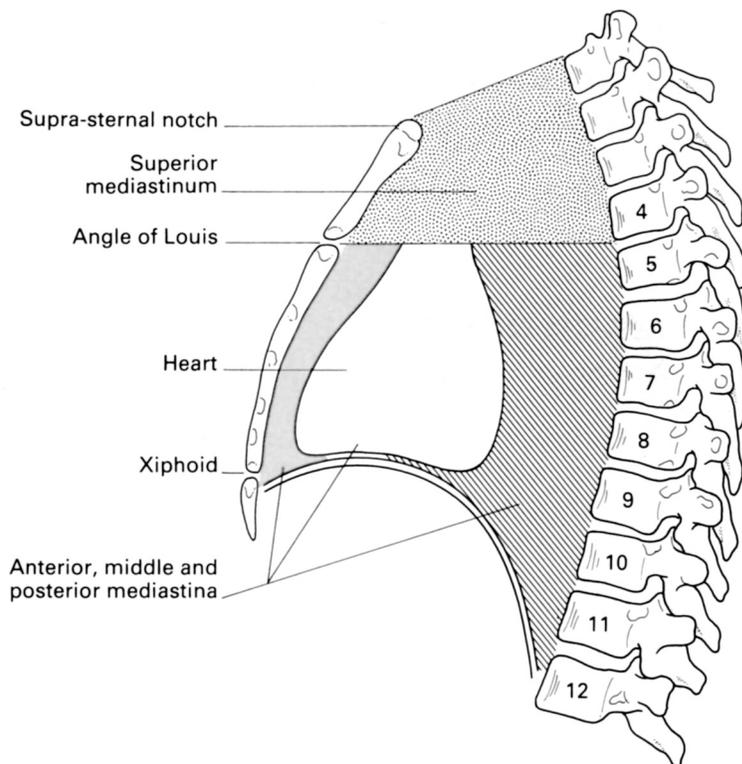


Fig. 22 The subdivisions of the mediastinum.

great vessels and the base with the central tendon of the diaphragm. Anteriorly it is related to the body of the sternum, to which it is attached by the sternopericardial ligament. The 3rd–6th costal cartilages and the anterior borders of the lungs; posteriorly, to the oesophagus, descending aorta, and vertebra T5–T8, and on either side to the roots of the lungs, the mediastinal pleura and the phrenic nerves.

The inner aspect of the fibrous pericardium is lined by the *parietal layer of serous pericardium*. This, in turn, is reflected around the roots of the great vessels to become continuous with the *visceral layer or epicardium*. The lines of pericardial reflexion are marked on the posterior surface of the heart (Fig. 23) by the *oblique sinus*, bounded by the inferior vena cava and the four pulmonary veins, which form a recess between the left atrium and the pericardium, and the *transverse sinus* between the superior vena cava and left atrium behind and the pulmonary trunk and aorta in front.

The heart (Fig. 24)

Its great importance means no excuse need be offered for dealing with the heart in considerable detail.

The heart is irregularly conical in shape, and it is placed obliquely in the middle mediastinum. Viewed from the front, portions of all the heart chambers can be seen. The right border is formed entirely by the right atrium, the left border partly by the auricular appendage of the left atrium but mainly by the left ventricle, and the inferior border chiefly by the right

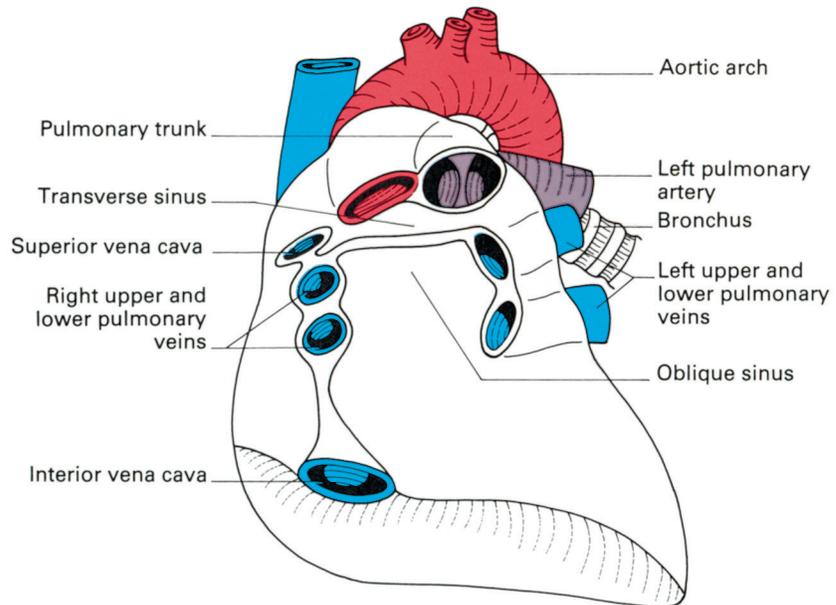


Fig. 23 The transverse and oblique sinuses of the pericardium. In this illustration the heart has been removed from the pericardial sac, which is seen in anterior view.

30 The Thorax

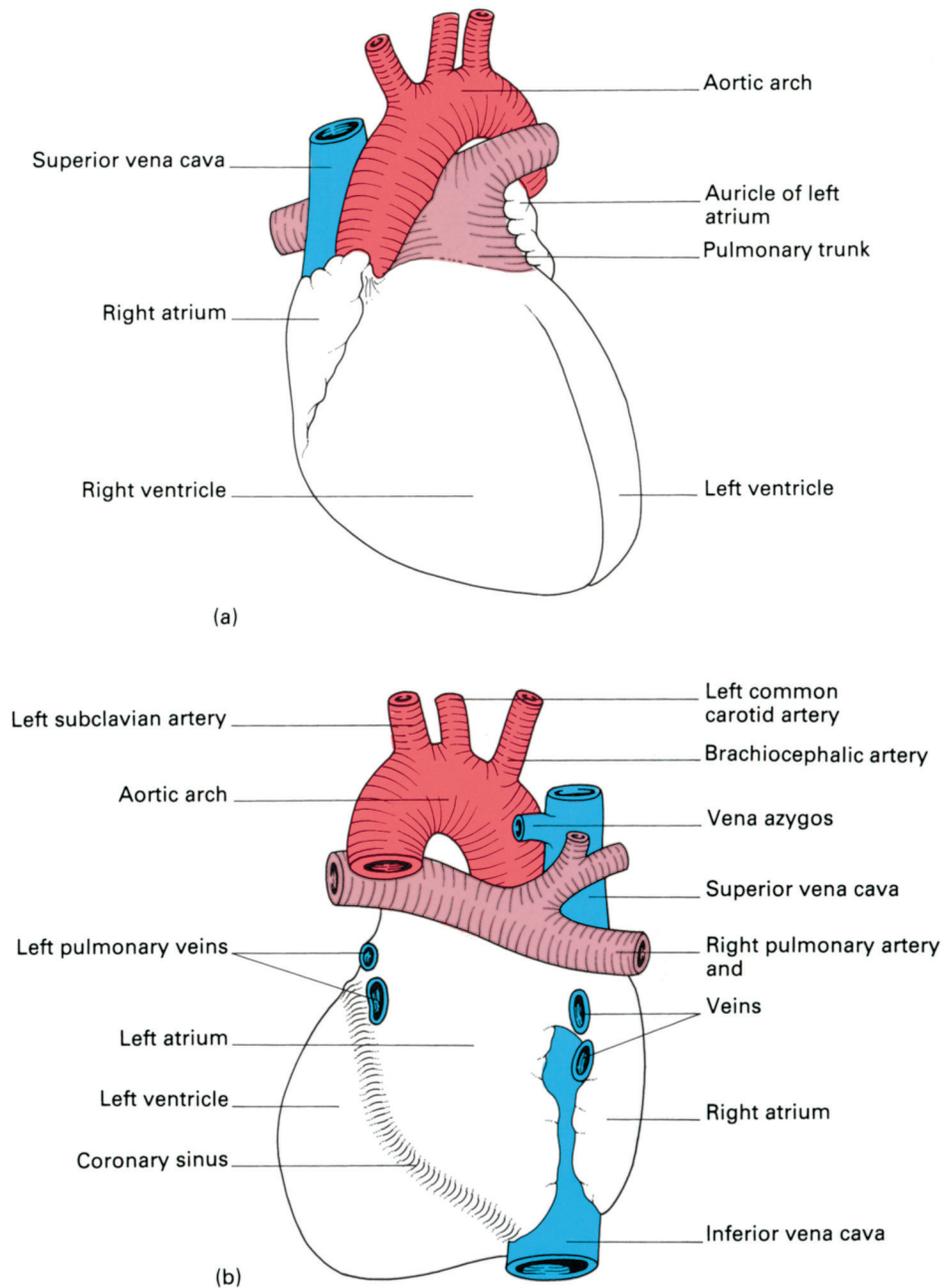


Fig. 24 The heart, (a) anterior and (b) posterior aspects.

ventricle but also by the lower part of the right atrium and the apex of the left ventricle.

The bulk of the anterior surface is formed by the right ventricle which is separated from the right atrium by the vertical atrioventricular groove, and from the left ventricle by the anterior interventricular groove.

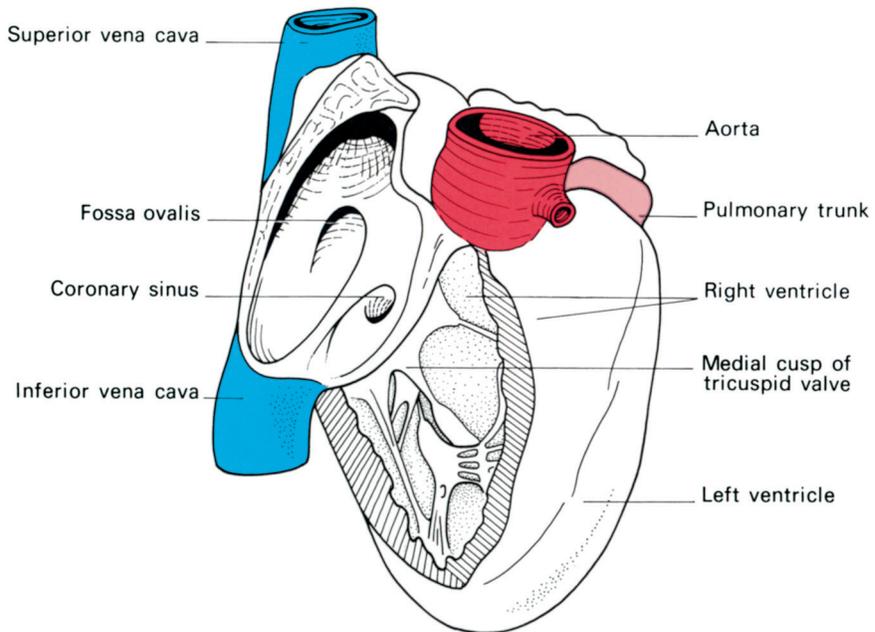


Fig. 25 The interior of the right atrium and ventricle.

The inferior or *diaphragmatic surface* consists of the right and left ventricles separated by the posterior interventricular groove and the portion of the right atrium which receives the inferior vena cava.

The base or *posterior surface* is quadrilateral in shape and is formed mainly by the left atrium with the openings of the pulmonary veins and, to a lesser extent, by the right atrium.

Chambers of the heart

Right atrium (Fig. 25)

The right atrium receives the superior vena cava in its upper and posterior part, the inferior vena cava and coronary sinus in its lower part, and the anterior cardiac vein (draining much of the front of the heart) anteriorly. Running more or less vertically downwards between the venae cavae is a distinct muscular ridge, the *crista terminalis* (indicated on the outer surface of the atrium by a shallow groove—the *sulcus terminalis*). This ridge separates the smooth-walled posterior part of the atrium, derived from the sinus venosus, from the rough-walled anterior portion which is prolonged into the *auricular appendage* and which is derived from the true fetal atrium.

The openings of the inferior vena cava and the coronary sinus are guarded by rudimentary valves; that of the inferior vena cava being continuous with the *annulus ovalis* around the shallow depression on the atrial septum, the *fossa ovalis*, which marks the site of the fetal *foramen ovale*.

32 The Thorax

Right ventricle (Fig. 25)

The right ventricle is joined to the right atrium by the way of the vertically disposed *tricuspid valve*, and with the pulmonary trunk through the pulmonary valve. A muscular ridge, the *infundibuloventricular crest*, between the atrioventricular and pulmonary orifices, separates the 'inflow' and 'outflow' tracts of the ventricle. The inner aspect of the inflow tract path is marked in the presence of a number of irregular muscular elevations (*trabeculae carneae*) from some of which the *papillary muscles* project into the lumen of the ventricle and find attachment to the free borders of the cusps of the tricuspid valve by way of the *chordae tendineae*. The *moderator band* is a muscular bundle crossing the ventricular cavity from the interventricular septum to the anterior wall and is of some importance since it conveys the right branch of the atrioventricular bundle to the ventricular muscle.

The outflow tract of the ventricle or *infundibulum* is smooth-walled and is directed upwards and to the right towards the pulmonary trunk. The pulmonary orifice is guarded by the *pulmonary valves*, comprising three semilunar cusps.

Left atrium

The left atrium is rather smaller than the right but has somewhat thicker walls. On the upper part of its posterior wall it presents the openings of the four pulmonary veins and on its septal surface there is a shallow depression corresponding to the fossa ovalis of the right atrium. As on the right side, the main part of the cavity is smooth-walled but the surface of the auricle is marked by a number of ridges due to the underlying pectinate muscles.

Left ventricle (Fig. 26)

The left ventricle communicates with the left atrium by way of the *mitral valve* (so-called because it vaguely resembles a bishop's mitre), which possesses a large anterior and a smaller posterior cusp attached to papillary muscles by chordae tendineae. With the exception of the fibrous *vestibule* immediately below the aortic orifice, the wall of the left ventricle is marked by thick trabeculae carneae.

The aortic orifice is guarded by the three semilunar cusps of the *aortic valve*, immediately above which are the dilated *aortic sinuses*. The mouths of the right and left coronary arteries are seen in the anterior and left posterior sinus respectively.

The conducting system of the heart

This consists of specialized cardiac muscle found in the sinoatrial node and in the atrioventricular node and bundle. The heart-beat is initiated in the *sinoatrial node* (the 'pacemaker of the heart'), situated in the upper part of the crista terminalis just to the right of the opening of the superior vena cava into the right atrium. From there the cardiac impulse spreads

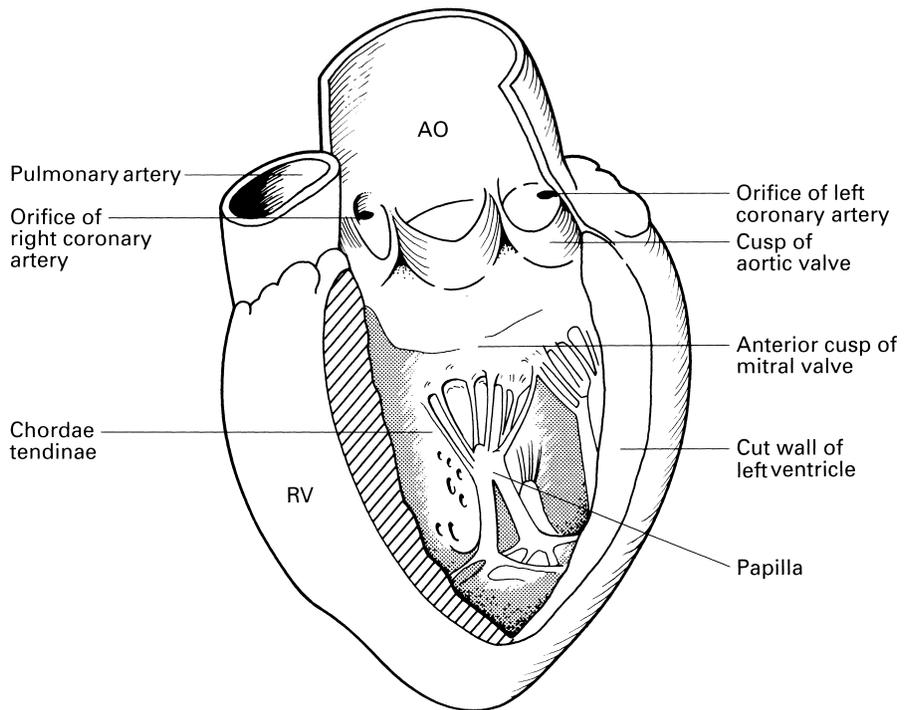


Fig. 26 The interior of the left ventricle.

throughout the atrial musculature to reach the *atrioventricular node* lying in the atrial septum immediately above the opening of the coronary sinus. The impulse is then conducted to the ventricles by way of the specialized tissue of the *atrioventricular bundle (of His)*. This bundle divides at the junction of the membranous and muscular parts of the interventricular septum into its right and left branches which run immediately beneath the endocardium to activate all parts of the ventricular musculature.

The blood supply to the heart (Fig. 27)

The heart's blood supply is derived from the right and left coronary arteries whose main branches lie in the interventricular and atrioventricular grooves.

The *right coronary artery* arises from the anterior aortic sinus and passes forwards between the pulmonary trunk and the right atrium to descend in the right part of the atrioventricular groove. At the inferior border of the heart it continues along the atrioventricular groove to anastomose with the left coronary at the posterior interventricular groove. It gives off a *marginal branch* along the lower border of the heart and the *posterior interventricular branch* which runs forward in the inferior interventricular groove and to anastomose near the apex of the heart with the corresponding branch of the left coronary artery.

34 The Thorax

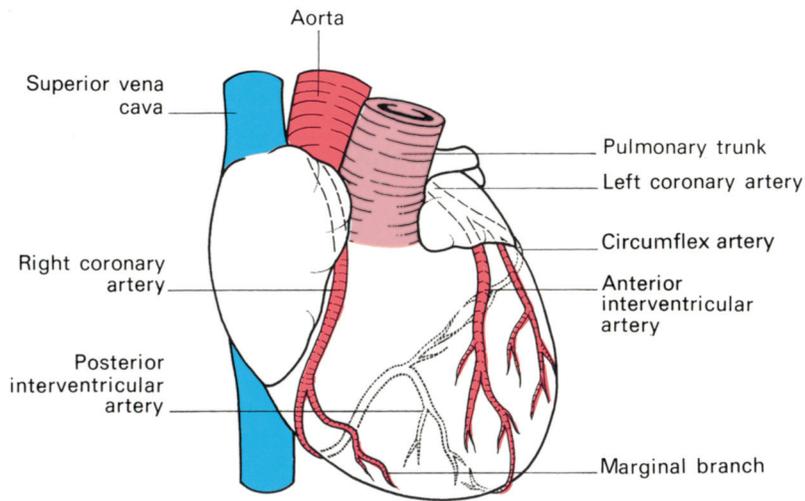


Fig. 27 The coronary arteries. (Dotted vessels lie posteriorly.)

The *left coronary artery*, which is larger than the right, rises from the left posterior aortic sinus. Passing first behind and then to the left of the pulmonary trunk, it reaches the left part of atrioventricular groove in which it runs laterally round the left border of the heart as the *circumflex artery* to reach the posterior interatrial groove. Its most important branch, given off about 2 cm from its origin, is the *anterior interventricular artery* which supplies the anterior aspect of both ventricles and passes around the apex of the heart to anastomose with the posterior interventricular branch of the right coronary. Note that the sinatrial node is usually supplied by the right coronary artery, although the left coronary artery takes over this duty in about one-third of subjects.

Although anastomoses occur between the terminations of the right and left coronary arteries, these are usually inefficient. Thrombosis in one or other of these vessels leads to death of the area of heart muscle supplied (a myocardial infarction).

The venous drainage of the heart (Fig. 28)

The bulk of the venous drainage of the heart is achieved by veins which accompany the coronary arteries and which open into the right atrium. The rest of the blood drains by means of small veins (*venae cordis minimae*) directly into the cardiac cavity.

The coronary sinus lies in the posterior atrioventricular groove and opens into the right atrium just to the left of the mouth of the inferior vena cava.

It receives:

- 1 the *great cardiac vein* in the anterior interventricular groove;
- 2 the *middle cardiac vein* the inferior interventricular groove;
- 3 the *small cardiac vein* — accompanying the marginal artery along the lower border of the heart;

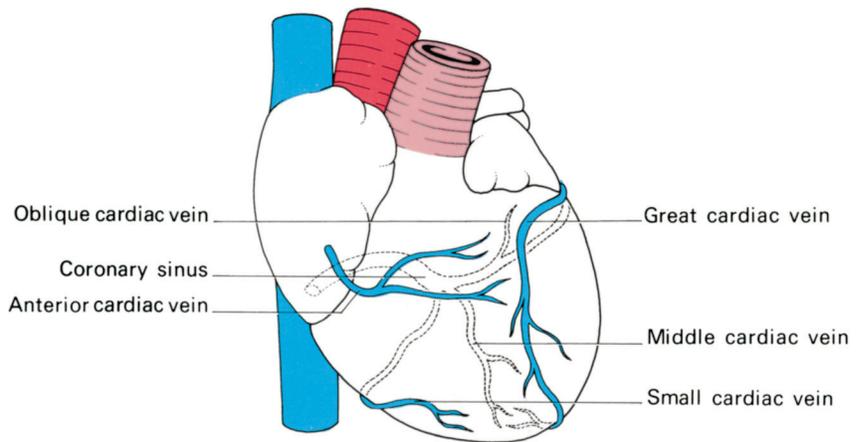


Fig. 28 The coronary veins. (Dotted vessels lie posteriorly.)

4 the *oblique vein*—descends obliquely on the posterior aspect of the left atrium.

The *anterior cardiac veins* (up to three or four in number) cross the anterior atrioventricular groove, drain much of the anterior surface of the heart and open directly into the right atrium.

Nerve supply

The nerve supply of the heart is derived from the vagus (cardio-inhibitor) and the cervical and upper 5 thoracic sympathetic ganglia (cardio-accelerator) by way of superficial and deep cardiac plexuses.

The development of the heart

The primitive heart is a single tube which soon shows grooves demarcating the *sinus venosus*, *atrium*, *ventricle* and *bulbus cordis* from behind forwards. As this tube enlarges it kinks so that its caudal end, receiving venous blood, comes to lie behind its cephalic end with its emerging arteries (Fig. 29).

The sinus venosus later absorbs into the atrium and the bulbus becomes incorporated into the ventricle so that, in the fully developed heart, the atria and great veins come to lie posterior to the ventricles and the roots of the great arteries.

The boundary tissue between the primitive single atrial cavity and single ventricle grows out as a *dorsal* and a *ventral endocardial cushion* which meet in the midline, thus dividing the common atrio-ventricular orifice into a right (tricuspid) and left (mitral) orifice.

The division of the primitive atrium into two is a complicated process but an important one in the understanding of congenital septal defects (Fig. 30). A partition, the *septum primum*, grows downwards from the posterior and superior walls of the primitive common atrium to fuse with the

36 The Thorax

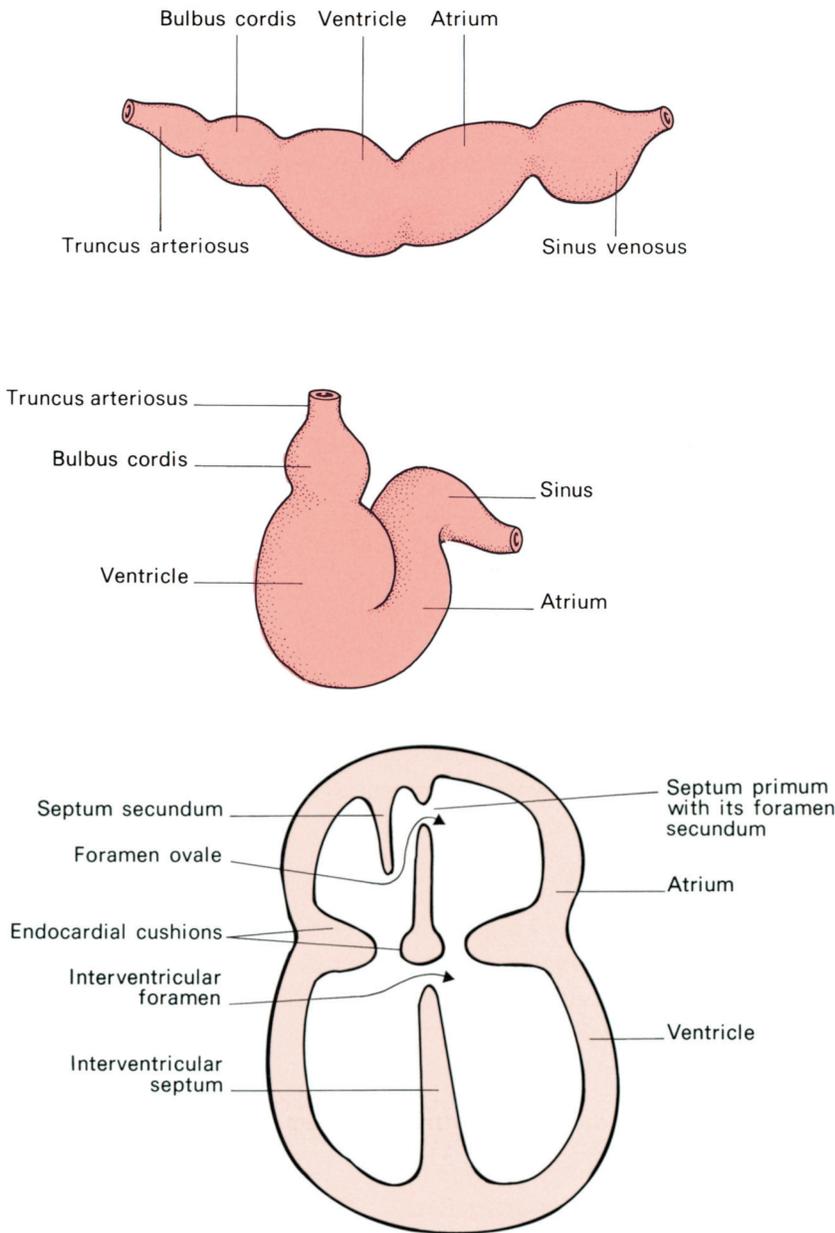


Fig. 29 The coiling of the primitive heart tube into its definitive form.

Fig. 30 The development of the chambers of the heart. (Note the septum primum and septum secundum which form the interatrial septum, leaving the foramen ovale as a valve-like opening passing between them.)

endocardial cushions. Before fusion is complete, however, a hole appears in the upper part of this septum which is termed *the foramen secundum in the septum primum*.

A second membrane, the *septum secundum*, then develops to the right of the primum but this is never complete; it has a free lower edge which does,

however, extend low enough for this new septum to overlap the foramen secundum in the septum primum and hence to close it.

The two overlapping defects in the septa form the valve-like *foramen ovale* which shunts blood from the right to left heart in the fetus (see 'fetal circulation' below). After birth, this foramen usually becomes completely fused leaving only the fossa ovalis on the septal wall of the right atrium as its memorial. In about 10% of adult subjects, however, a probe can still be insinuated through an anatomically patent, although functionally sealed foramen.

Division of the ventricle is commenced by the upgrowth of a fleshy septum from the apex of the heart towards the endocardial cushions. This stops short of dividing the ventricle completely and thus it has an upper free border, forming a temporary interventricular foramen. At the same time, the single truncus arteriosus is divided into aorta and pulmonary trunk by a spiral septum (hence the spiral relations of these two vessels), which grows downwards to the ventricle and fuses accurately with the upper free border of the ventricular septum. This contributes the small *pars membranacea septi*, which completes the separation of the ventricle in such a way that blood on the left of the septum flows into the aorta and on the right into the pulmonary trunk.

The primitive *sinus venosus* absorbs into the right atrium so that the venae cavae draining into the sinus come to open separately into this atrium. The smooth-walled part of the adult atrium represents the contribution of the sinus venosus, the pectinate part represents the portion derived from the primitive atrium.

Rather similarly, the adult left atrium has a double origin. The original single pulmonary venous trunk entering the left atrium becomes absorbed into it, and donates the smooth-walled part of this chamber with the pulmonary veins entering as four separate openings; the trabeculated part of the definitive left atrium is the remains of the original atrial wall.

The development of the aortic arches and their derivatives (Fig. 31)

Emerging from the bulbus cordis is a common arterial trunk termed the *truncus arteriosus*, from which arise six pairs of aortic arches, equivalent to the arteries supplying the gill clefts of the fish. These arteries curve dorsally around the pharynx on either side and join to form two longitudinally placed dorsal aortae which fuse distally into the descending aorta.

The 1st and 2nd arches disappear; the 3rd arches become the carotids. The 4th arch on the right becomes the brachiocephalic and right subclavian artery; on the left, it differentiates into the definitive aortic arch, gives off the left subclavian artery and links up distally with the descending aorta.

The 5th arch artery is rudimentary and disappears.

When the truncus arteriosus splits longitudinally to form the ascending aorta and pulmonary trunk, the 6th arch, unlike the others, remains linked with the latter and forms the right and left pulmonary arteries. On the left

38 The Thorax

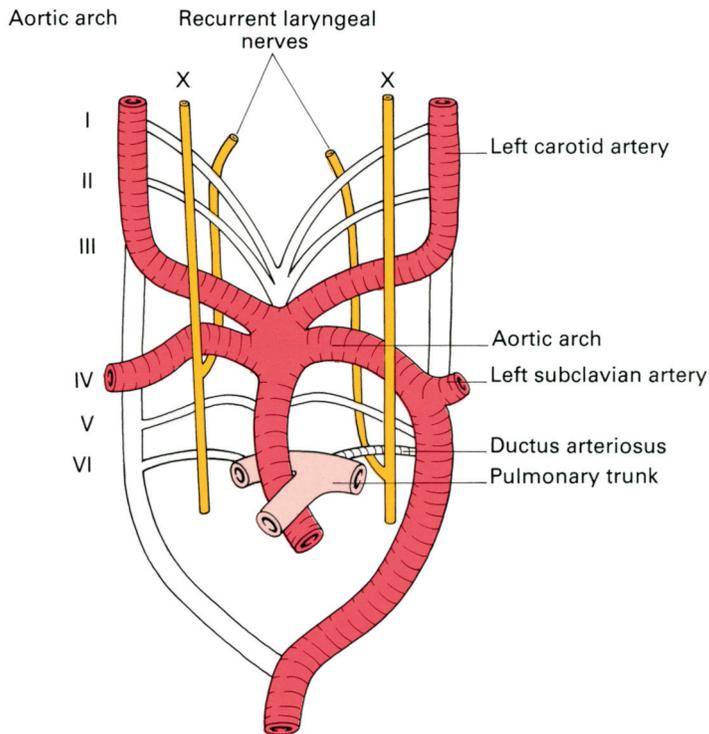


Fig. 31 The aortic arches and their derivatives. This diagram explains the relationship of the right recurrent laryngeal nerve to the right subclavian artery and the left nerve to the aortic arch and the ligamentum arteriosum (or to a patent ductus arteriosus).

side this arch retains its connection with the dorsal aorta to form the *ductus arteriosus* (the ligamentum arteriosum of adult anatomy).

This asymmetrical development of the aortic arches accounts for the different course taken by the recurrent laryngeal nerve on each side. In the early fetus the vagus nerve lies lateral to the primitive pharynx, separated from it by the aortic arches. What are to become the recurrent laryngeal nerves pass medially, caudal to the aortic arches, to supply the developing larynx. With elongation of the neck and caudal migration of the heart, the recurrent nerves are caught up and dragged down by the descending aortic arches. On the right side the 5th and distal part of the 6th arch absorb, leaving the nerve to hook round the 4th arch (i.e. the right subclavian artery). On the left side, the nerve remains looped around the persisting distal part the 6th arch (the ligamentum arteriosum) which is overlapped and dwarfed by the arch of the aorta.

The fetal circulation (Fig. 32)

The circulation of the blood in the embryo is a remarkable example of economy in nature and results in the shunting of well-oxygenated blood from the placenta to the brain and the heart, leaving relatively desaturated blood for less essential structures.

Blood is returned from the placenta by the umbilical vein to the inferior vena cava and thence the right atrium, most of it by-passing the liver in the

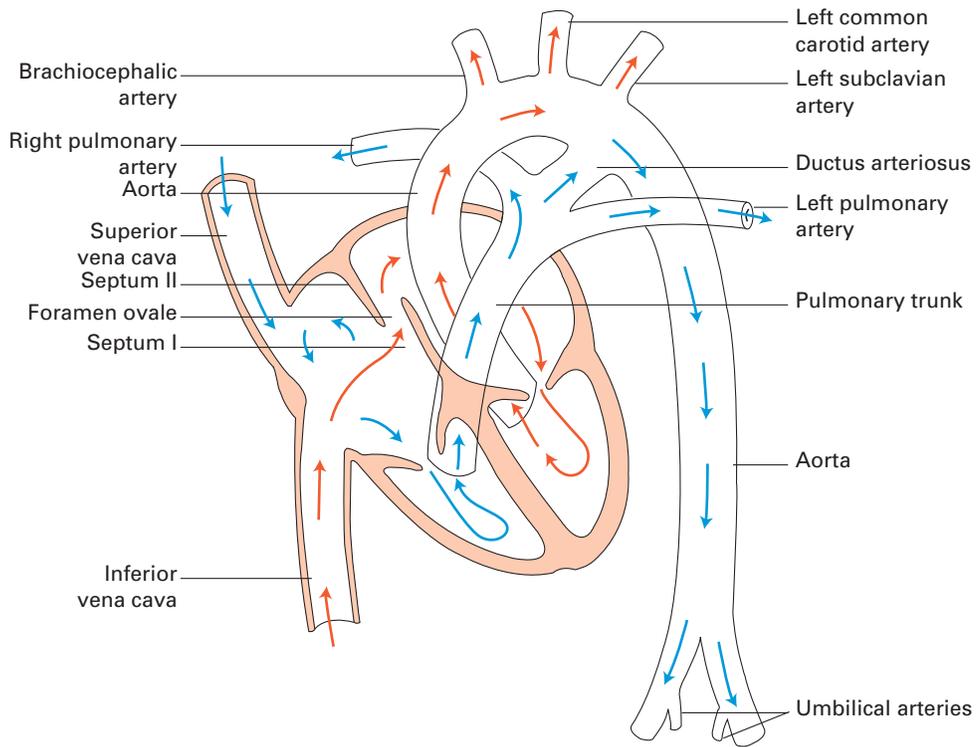


Fig. 32 The fetal circulation. The red arrows denote oxygenated blood.

ductus venosus (see page 95). Relatively little mixing of oxygenated and deoxygenated blood occurs in the right atrium since the valve overlying the orifice of the inferior vena cava serves to direct the flow of oxygenated blood from that vessel through the *foramen ovale* into the left atrium, while the deoxygenated stream from the superior vena cava is directed through the tricuspid valve into the right ventricle. From the left atrium the oxygenated blood (together with a small amount of deoxygenated blood from the lungs) passes into the left ventricle and hence into the ascending aorta for the supply of the brain and heart via the vertebral, carotid and coronary arteries.

As the lungs of the fetus are inactive, most of the deoxygenated blood from the right ventricle is short-circuited by way of the *ductus arteriosus* from the pulmonary trunk into the descending aorta. This blood supplies the abdominal viscera and the lower limbs and is shunted to the placenta, for oxygenation, along the *umbilical arteries* arising from the internal iliac arteries.

At birth, expansion of the lungs leads to an increased blood flow in the pulmonary arteries; the resulting pressure changes in the two atria bring the overlapping *septum primum* and *septum secundum* into apposition which effectively closes off the foramen ovale. At the same time active contraction of the muscular wall of the ductus arteriosus results in a functional closure

40 The Thorax

of this arterial shunt and, in the course of the next 2–3 months, its complete obliteration. Similarly, ligation of the umbilical cord is followed by thrombosis and obliteration of the umbilical vessels.

Congenital abnormalities of the heart and great vessels

The complex development of the heart and major arteries accounts for the multitude of congenital abnormalities which may affect these structures, either alone or in combination.

Dextro-rotation of the heart means that this organ and its emerging vessels lie as a mirror-image to the normal anatomy. It may be associated with reversal of all the intra-abdominal organs; I have seen a student correctly diagnose acute appendicitis as the cause of a patient's severe *left* iliac fossa pain because he found that the apex beat of the heart was on the right side!

Septal defects

At birth, the septum primum and septum secundum are forced together, closing the flap valve of the foramen ovale. Fusion usually takes place about 3 months after birth. In about 10% of subjects, this fusion may be incomplete. However, the two septa overlap and this patency of the foramen ovale is of no functional significance. If the septum secundum is too short to cover the foramen secundum in the septum primum, an *atrial septal defect* persists after the septum primum and septum secundum are pressed together at birth. This results in an *ostium secundum defect*, which allows shunting of blood from the left to the right atrium. This defect lies high up in the atrial wall and is relatively easy to close surgically. A more serious atrial septal defect results if the septum primum fails to fuse with the endocardial cushions. This *ostium primum defect* lies immediately above the atrioventricular boundary and may be associated with a defect of the pars membranacea septi of the ventricular septum. In such a case, the child is born with both an atrial and ventricular septal defect.

Occasionally the ventricular septal defect is so huge that the ventricles form a single cavity, giving a *trilocular heart*.

Congenital pulmonary stenosis may affect the trunk of the pulmonary artery, its valve or the infundibulum of the right ventricle. If stenosis occurs in conjunction with a septal defect, the compensatory hypertrophy of the right ventricle (developed to force blood through the pulmonary obstruction) develops a sufficiently high pressure to shunt blood through the defect into the left heart; this mixing of the deoxygenated right heart blood with the oxygenated left-sided blood results in the child being *cyanosed at birth*.

The commonest combination of congenital abnormalities causing cyanosis is *Fallot's tetralogy* (Fig. 33). This results from unequal division of the truncus arteriosus by the spiral septum, resulting in a stenosed pulmonary trunk and a wide aorta which overrides the orifices of both the ventricles. The displaced septum is unable to close the interventricular septum, which results in a ventricular septal defect. Right ventricular hypertrophy

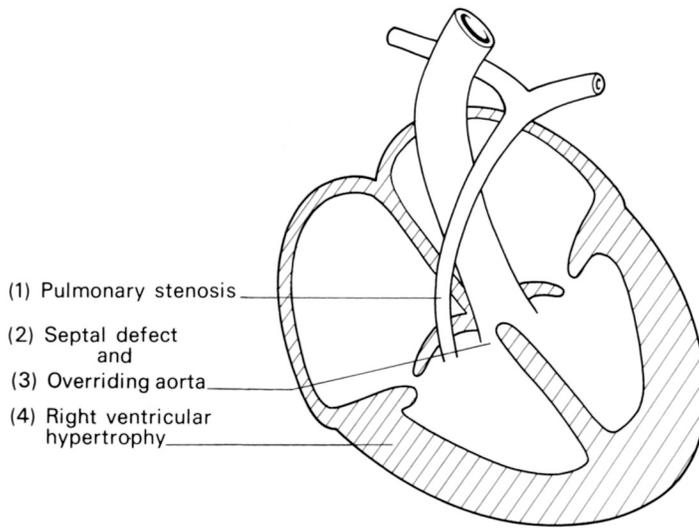


Fig. 33 The tetralogy of Fallot.

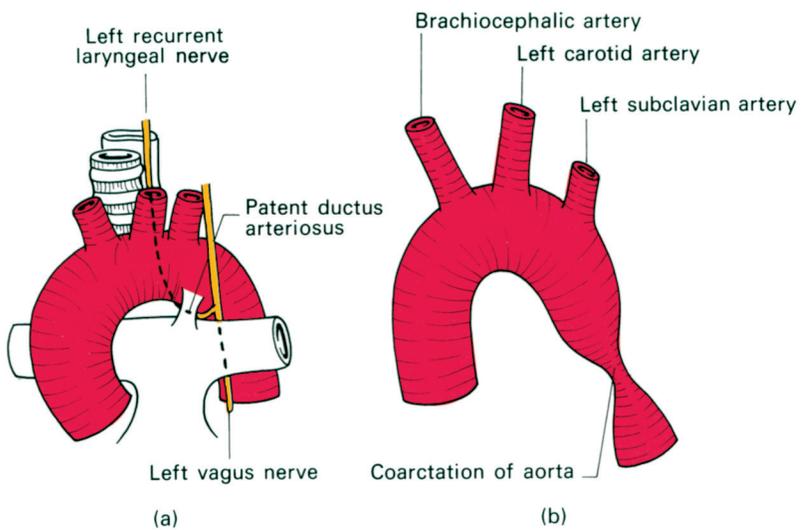


Fig. 34 (a) Persistent ductus arteriosus—showing its close relationship to the left recurrent laryngeal nerve. (b) Coarctation of the aorta.

develops as a consequence of the pulmonary stenosis. Cyanosis results from the shunting of large amounts of unsaturated blood from the right ventricle through the ventricular septal defect into the left ventricle and also directly into the aorta.

A persistent ductus arteriosus (Fig. 34a) is a relatively common congenital defect. If left uncorrected, it causes progressive work hypertrophy of the left heart and pulmonary hypertension.

Aortic coarctation (Fig. 34b) is thought to be due to an abnormality of the obliterative process which normally occludes the ductus arteriosus. There may be an extensive obstruction of the aorta from the left subclavian artery to the ductus, which is widely patent and maintains the circulation to the

42 The Thorax

lower parts of the body; often there are multiple other defects and frequently infants so afflicted die at an early age. More commonly there is a short segment involved in the region of the ligamentum arteriosum or still patent ductus. In these cases, circulation to the lower limb is maintained via collateral arteries around the scapula anastomosing with the intercostal arteries, and via the link-up between the internal thoracic and inferior epigastric arteries.

Clinically, this circulation may be manifest by enlarged vessels being palpable around the scapular margins; radiologically, dilatation of the engorged intercostal arteries results in notching of the inferior borders of the ribs.

Abnormal development of the primitive aortic arches may result in the aortic arch being on the right or actually being double. An abnormal right subclavian artery may arise from the dorsal aorta and pass behind the oesophagus—a rare cause of difficulty in swallowing (dysphagia lusoria).

Rarely, the division of the truncus into aorta and pulmonary artery is incomplete, leaving an *aorta–pulmonary window*, the most unusual congenital fistula between the two sides of the heart.

The superior mediastinum

This is bounded in front by the manubrium sterni and behind the first four thoracic vertebrae (Fig. 22). Above, it is in direct continuity with the root of the neck and below it is continuous with the three compartments of the inferior mediastinum. Its principal contents are: the great vessels, trachea, oesophagus, thymus—mainly replaced by fatty tissue in the adult, thoracic duct, vagi, left recurrent laryngeal nerve and the phrenic nerves (Fig. 17).

The *arch of the aorta* is directed anteroposteriorly, its three great branches, the *brachiocephalic*, *left carotid* and *left subclavian arteries*, ascend to the thoracic inlet, the first two forming a V around the trachea. The *brachiocephalic veins* lie in front of the arteries, the left running almost horizontally across the superior mediastinum and the right vertically downwards; the two unite to form the *superior vena cava*. Posteriorly lies the trachea with the oesophagus immediately behind it lying against the vertebral column.

The oesophagus

The oesophagus, which is 10 in (25 cm) long, extends from the level of the lower border of the cricoid cartilage at the level of the 6th cervical vertebra to the cardiac orifice of the stomach (Fig. 35).

Course and relations

Cervical

In the neck it commences in the median plane and deviates slightly to the left as it approaches the thoracic inlet. The trachea and the thyroid gland are its immediate anterior relations, the 6th and 7th cervical vertebrae and pre-

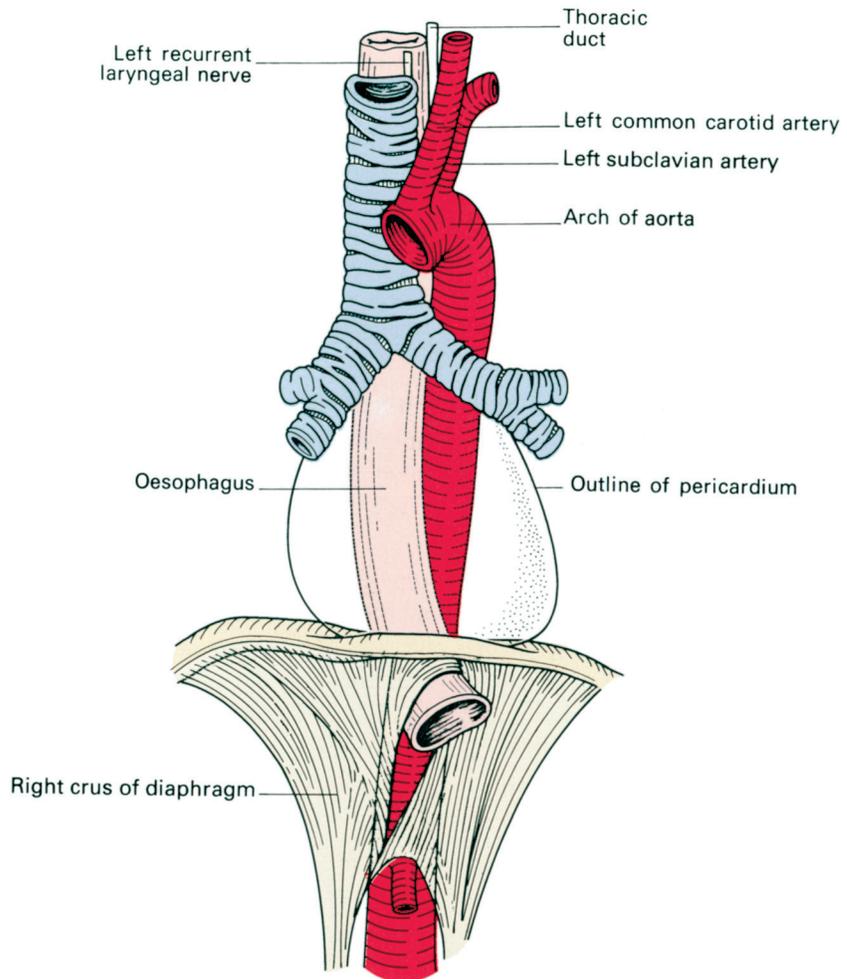


Fig. 35 The oesophagus and its relations.

vertebral fascia are behind it and on either side it is related to the common carotid arteries and the recurrent laryngeal nerves. On the left side it is also related to the subclavian artery and the terminal part of the thoracic duct (Fig. 16).

Thoracic

The thoracic part traverses first the superior and then the posterior mediastinum. From being somewhat over to the left, it returns to the midline at T5 then passes downwards, forwards and to the left to reach the oesophageal opening in the diaphragm (T10). For convenience, the relations of this part are given in sequence from above downwards.

Anteriorly, it is crossed by the trachea, the left bronchus (which

44 The Thorax

constricts it), the pericardium (separating it from the left atrium) and the diaphragm.

Posteriorly lie the thoracic vertebrae, the thoracic duct, the azygos vein and its tributaries and, near the diaphragm, the descending aorta.

On the left side it is related to the left subclavian artery, the terminal part of the aortic arch, the left recurrent laryngeal nerve, the thoracic duct and the left pleura. In the posterior mediastinum it relates to the descending thoracic aorta before this passes posteriorly to the oesophagus above the diaphragm.

On the right side there is the pleura and the azygos vein.

Below the root of the lung the vagi form a plexus on the oesophagus, the left vagus lying anteriorly, the right posteriorly.

In the abdomen, passing forwards through the opening in the right crus of the diaphragm, the oesophagus comes to lie in the oesophageal groove on the posterior surface of the left lobe of the liver, covered by peritoneum on its anterior and left aspects. Behind it is the left crus of the diaphragm.

Structure

The oesophagus is made of:

- 1 an outer connective tissue sheath of areolar tissue;
- 2 a muscular layer of external longitudinal and internal circular fibres which are striated in the upper two-thirds and smooth in the lower one-third;
- 3 a submucous layer containing mucous glands;
- 4 a mucosa of stratified epithelium passing abruptly into the columnar epithelium of the stomach.

Blood supply is from the inferior thyroid artery, branches of the descending thoracic aorta and the left gastric artery. The veins from the cervical part drain into the inferior thyroid veins, from the thoracic portion into the azygos vein and from the abdominal portion partly into the azygos and partly into the left gastric veins.

The *lymphatic drainage* is from a peri-oesophageal lymph plexus into the posterior mediastinal nodes, which drain both into the supraclavicular nodes and into nodes around the left gastric vessels. It is not uncommon to be able to palpate hard, fixed supraclavicular nodes in patients with advanced oesophageal cancer.

Radiographically, the oesophagus is studied by X-rays taken after a barium swallow, in which it is seen lying in the retrocardiac space just in front of the vertebral column. Anteriorly, the normal oesophagus is indented from above downwards by the three most important structures that cross it, the arch of the aorta, the left bronchus and the left atrium.

Clinical features

- 1 For oesophagoscopy, measurements are made from the upper incisor

teeth; the three important levels 7in (17cm), 11in (28cm) and 17in (43cm) corresponding to the commencement of the oesophagus, the point at which it is crossed by the left bronchus and its termination respectively.

2 These three points also indicate the narrowest parts of the oesophagus: the sites at which, as might be expected, swallowed foreign bodies are most likely to become impacted and strictures to occur after swallowing corrosive fluids.

3 The anastomosis between the azygos (systemic) and left gastric (portal) venous tributaries in the oesophageal veins is of great importance. In portal hypertension these veins distend into large collateral channels, *oesophageal varices*, which may then rupture with severe haemorrhage (probably as a result of peptic ulceration of the overlying mucosa).

4 Use is made of the close relationship between the oesophagus and the left atrium in determining the degree of left atrial enlargement in mitral stenosis; a barium swallow may show marked backward displacement of the oesophagus caused by the dilated atrium.

5 The oesophagus is crossed solely by the vena azygos on the right side. This is therefore the side of election to approach the oesophagus surgically.

Development of the oesophagus

The oesophagus develops from the distal part of the primitive fore-gut. From the floor of the fore-gut also differentiate the larynx and trachea, first as a groove (the laryngotracheal groove) which then converts into a tube, a bud on each side of which develops and ramifies into the lung.

This close relationship between the origins of the oesophagus and trachea accounts for the relatively common malformation in which the upper part of the oesophagus ends blindly while the lower part opens into the lower trachea at the level of T4 (*oesophageal atresia with tracheo-oesophageal fistula*). Less commonly, the upper part of the oesophagus opens into the trachea, or oesophageal atresia occurs without concomitant fistula into the trachea. Rarely, there is a tracheo-oesophageal fistula without atresia (Fig. 36).

The thoracic duct (Figs 37, 213)

The *cisterna chyli* lies between the abdominal aorta and right crus of the diaphragm. It drains lymphatics from the abdomen and the lower limbs, then passes upwards through the aortic opening to become the *thoracic duct*. This ascends behind the oesophagus, inclines to the left of the oesophagus at the level of T5, then runs upwards behind the carotid sheath, descends over the subclavian artery and drains into the commencement of the left brachiocephalic vein (see Fig. 213).

The left *jugular*, *subclavian* and *mediastinal lymph trunks*, draining the left side of the head and neck, upper limb and thorax respectively, usually join the thoracic duct, although they may open directly into the adjacent large veins at the root of the neck.

46 The Thorax

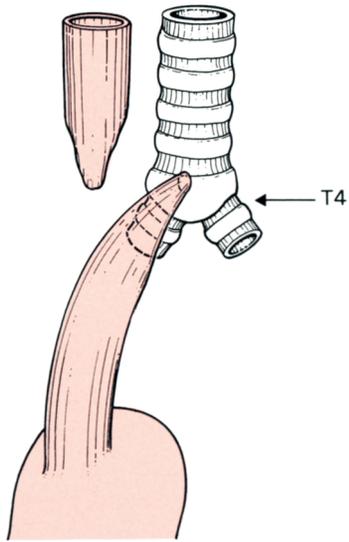


Fig. 36 The usual form of oesophageal stenosis. The upper oesophagus ends blindly; the lower oesophagus communicates with the trachea at the level of the 4th thoracic vertebra.

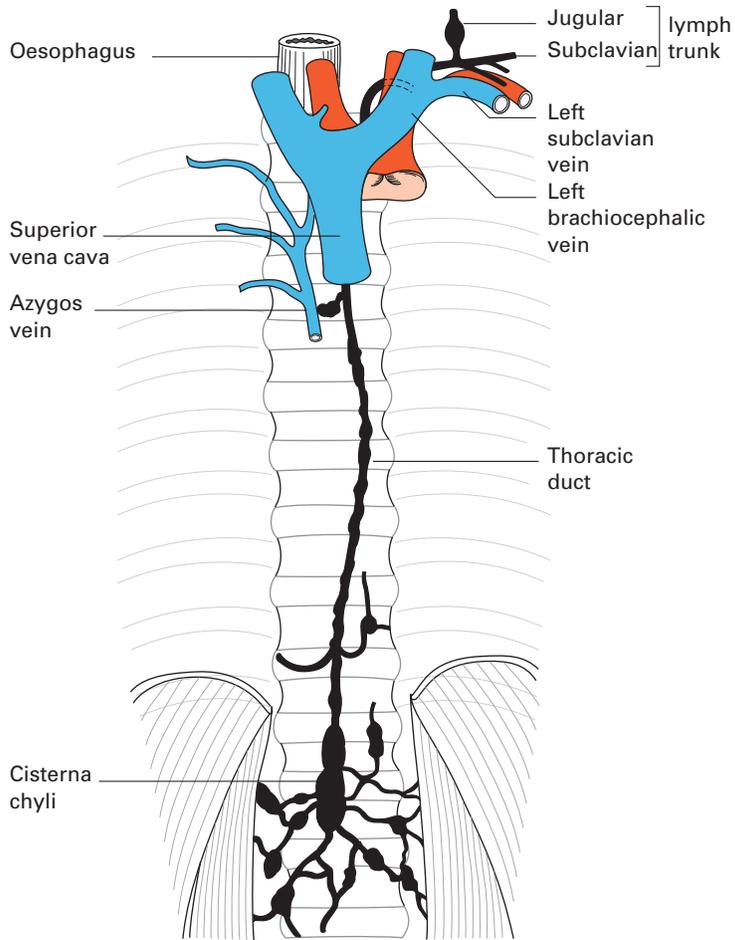


Fig. 37 The course of the thoracic duct.

The thoracic duct thus usually drains the whole lymphatic field below the diaphragm and the left half of the lymphatics above it.

On the right side, the right subclavian, jugular and mediastinal trunks may open independently into the great veins. Usually the subclavian and jugular trunks first join into a *right lymphatic duct* and this may be joined by the mediastinal trunk so that all three then have a common opening into the origin of the right brachiocephalic vein.

Clinical features

- 1 The lymphatics may become blocked by infection and fibrosis due to the *Microfilaria bancrofti*. This usually results in lymphoedema of the legs and scrotum but occasional involvement of the main channels of the trunk and thorax is followed by chylous ascites, chyluria and chylous pleural effusion.
- 2 The thoracic duct may be damaged during block dissection of the neck. If noticed at operation, the injured duct should be ligated; lymph then finds its way into the venous system by anastomosing channels. If the accident is missed, there follows an unpleasant chylous fistula in the neck.
- 3 Tears of the thoracic duct have also been reported as a complication of fractures of the thoracic vertebrae to which, in its lower part, the duct is closely related. Such injuries are followed by a chylothorax.

The thoracic sympathetic trunk (Fig. 38)

The sympathetic chain lies immediately lateral to the mediastinum behind the parietal pleura.

Descending from the cervical chain, it crosses:

- the neck of the first rib;
- the heads of the 2nd to 10th ribs;
- the bodies of the 11th and 12th thoracic vertebrae.

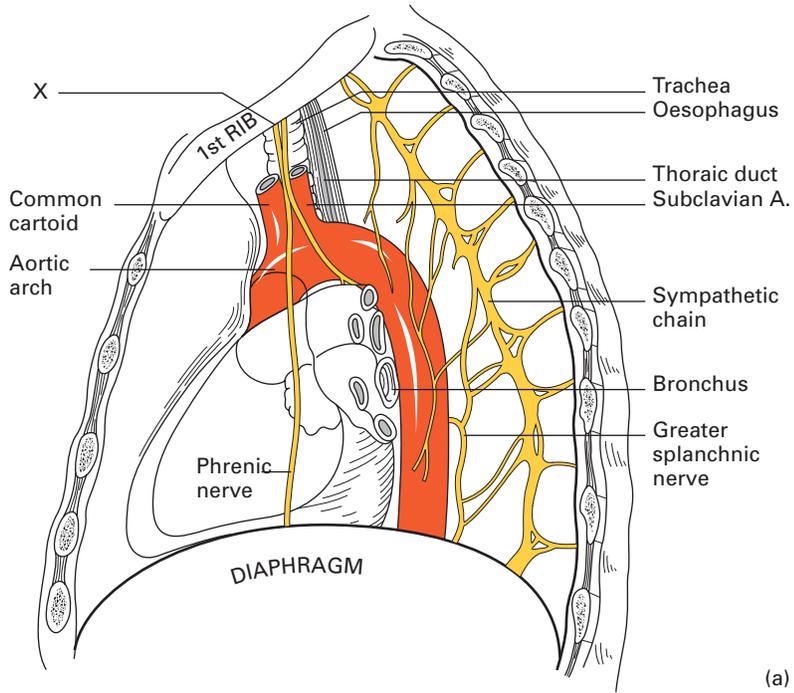
It then passes behind the medial arcuate ligament of the diaphragm to continue as the lumbar sympathetic trunk.

The thoracic chain bears a ganglion for each spinal nerve; the first frequently joins the inferior cervical ganglion to form the *stellate ganglion*. Each ganglion receives a white ramus communicans containing preganglionic fibres from its corresponding spinal nerve and donates back a grey ramus, bearing postganglionic fibres.

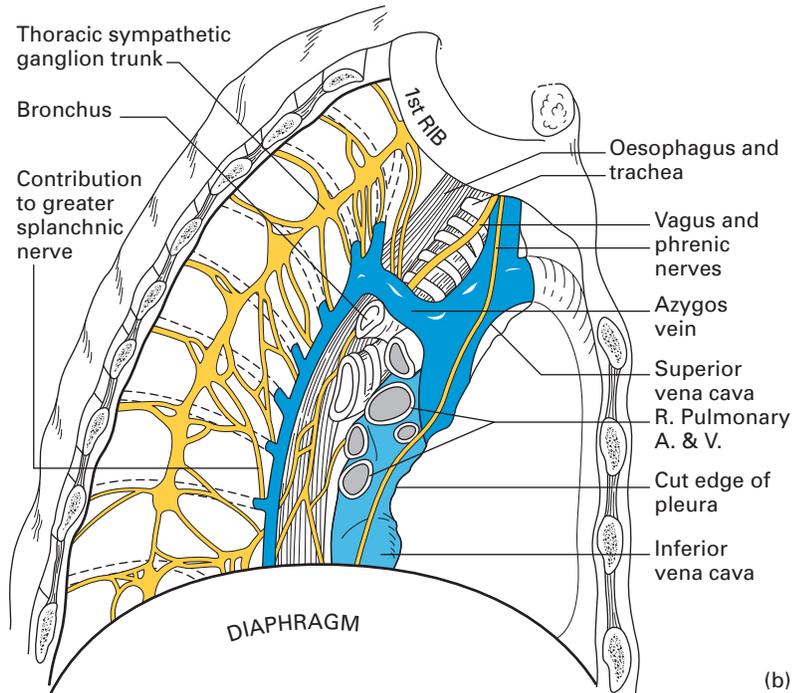
Branches

- 1 Sympathetic fibres are distributed to the skin with each of the thoracic spinal nerves.
- 2 Postganglionic fibres from T1–5 are distributed to the thoracic viscera—the heart and great vessels, the lungs and the oesophagus.
- 3 Mainly preganglionic fibres from T5–12 form the *splanchnic nerves*, which pierce the crura of the diaphragm and pass to the coeliac, superior

48 The Thorax



(a)



(b)

Fig. 38 (a) The left thoracic sympathetic trunk with a display of the left mediastinum. (b) The right mediastinum.

mesenteric, inferior mesenteric and renal ganglia from which they are relayed as postganglionic fibres to the abdominal viscera. These splanchnic nerves are the:

- *greater splanchnic* (T5–10);
- *lesser splanchnic* (T10–11);
- *least splanchnic* (T12).

They lie medial to the sympathetic trunk on the bodies of the thoracic vertebra and are quite easily visible through the parietal pleura (For their distribution see pages 429 and 430).

Clinical features

A high spinal anaesthetic will produce temporary hypotension by paralysing the sympathetic (vasoconstrictor) preganglionic outflow from spinal segment T5 downwards, passing to the abdominal viscera.

On the examination of a chest radiograph

The following features should be examined in every radiograph of the chest.

Centering and density of film

The sternal ends of the two clavicles should be equidistant from the shadow of the vertebral spines. The assessment of the density of the film can only be learned by experience, but in a 'normal' film the bony cage should be clearly outlined and the larger vessels in the lung fields clearly visible.

General shape

Any abnormalities in the general form of the thorax (scoliosis, kyphosis and the barrel chest of emphysema, for example) should always be noted before other abnormalities are described.

Bony cage

The thoracic vertebrae should be examined first, then each of the ribs in turn (counting conveniently from their posterior ends and comparing each one with its fellow of the opposite side), and finally clavicles and scapulae. Unless this procedure is carried out systematically, important diagnostic clues (e.g. the presence of a cervical rib, or notching of the ribs by enlarged anastomotic vessels) are liable to be missed.

50 The Thorax

The domes of the diaphragm

These should be examined for height and symmetry and the nature of the cardiophrenic and costophrenic angles observed.

The mediastinum

The outline of the mediastinum should be traced systematically. Special note should be made of the size of the heart, of mediastinal shift and of the vessels and nodes at the hilum of the lung.

Lung fields

Again, systematic examination of the lung fields visible in each intercostal space is necessary if slight differences between the two sides are not to be overlooked.

Abnormalities

When this scheme has been carefully followed, any abnormalities in the bony cage, the mediastinum or lung fields should now be apparent. They should then be defined anatomically as accurately as possible and checked, where necessary, by reference to a film taken from a different angle.

Radiographic appearance of the heart

For the appearance of the heart as seen at fluoroscopy, reference should be made to a standard work in radiology or cardiology. In the present account, only the more important features of the heart and great vessels which can be seen in standard posteroanterior and oblique lateral radiographs of the chest will be described.

The heart and great vessels in anteroposterior radiographs (Fig. 39)

The greater part of the 'mediastinal shadow' in an anteroposterior film of the chest is formed by the heart and great vessels. These should be examined as follows.

Size and shape of the heart

Normally the transverse diameter should not exceed half the total width of the chest, but since it varies widely with bodily build and the position of the heart, these factors must also be assessed. The *shape* of the cardiac shadow also varies a good deal with the position of the heart, being long and narrow in a vertically disposed heart and broad and rounded in the so-called horizontal heart.

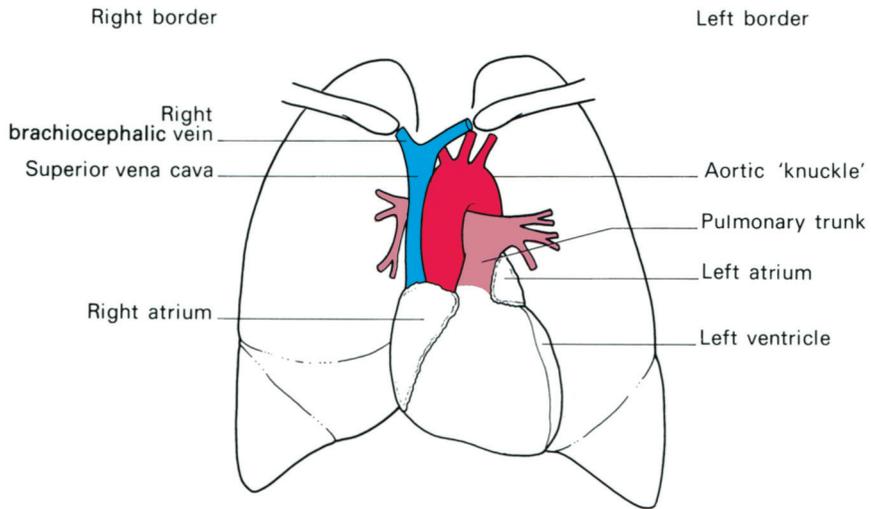


Fig. 39 A tracing of a chest radiograph to show the composition of the right and left borders of the mediastinal shadow.

The cardiac outline

Each 'border' of the cardiac shadow should be examined in turn. The *right border* of the mediastinal shadow is formed from above downwards by the right brachiocephalic vein, the superior vena cava and the right atrium. Immediately above the heart, the *left border* of the mediastinal shadow presents a well-marked projection, the *aortic knuckle*, which represents the arch of the aorta seen 'end-on'. Beneath this there are, successively, the shadows due to the pulmonary trunk (or the infundibulum of the right ventricle), the auricle of the left atrium, and the left ventricle. The shadow of the inferior border of the heart blends centrally with that of the diaphragm, but on either side the two shadows are separated by the well-defined cardio-phrenic angles.

The heart and great vessels in anterior oblique radiographs

The left oblique view (Fig. 40)

The greater part of the mediastinal shadow in this view is formed by the right and left ventricles, above which the relation of the arch of the aorta and the pulmonary trunk to the translucent trachea can be seen.

The right oblique view (Fig. 41)

Almost all of the cardiac shadow in this view is due to the right ventricle. It is particularly useful for the assessment of the size of the left atrium since its

52 The Thorax

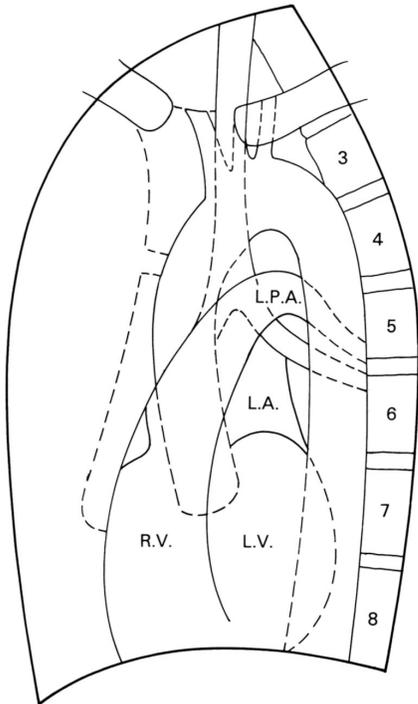


Fig. 40 Tracing of a left oblique radiograph of the chest.

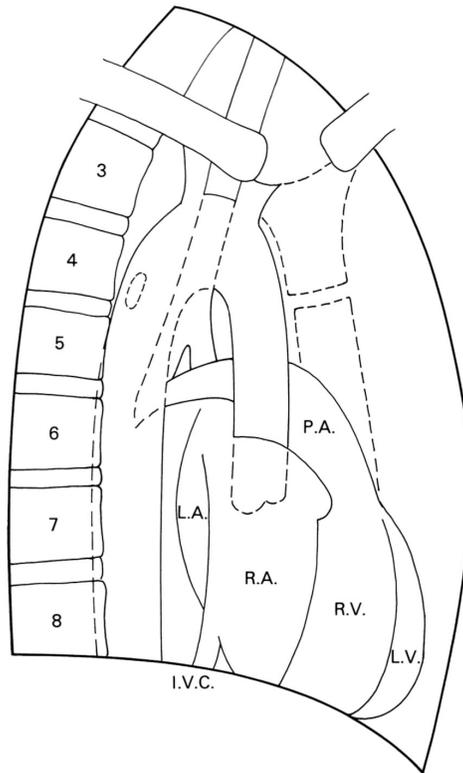


Fig. 41 Tracing of a right oblique radiograph of the chest.

posterior wall forms the upper half of the posterior border of the cardiac shadow. This border can be defined more accurately by giving the patient barium paste to swallow; the outlined oesophagus is indented by an enlarged left atrium.