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.

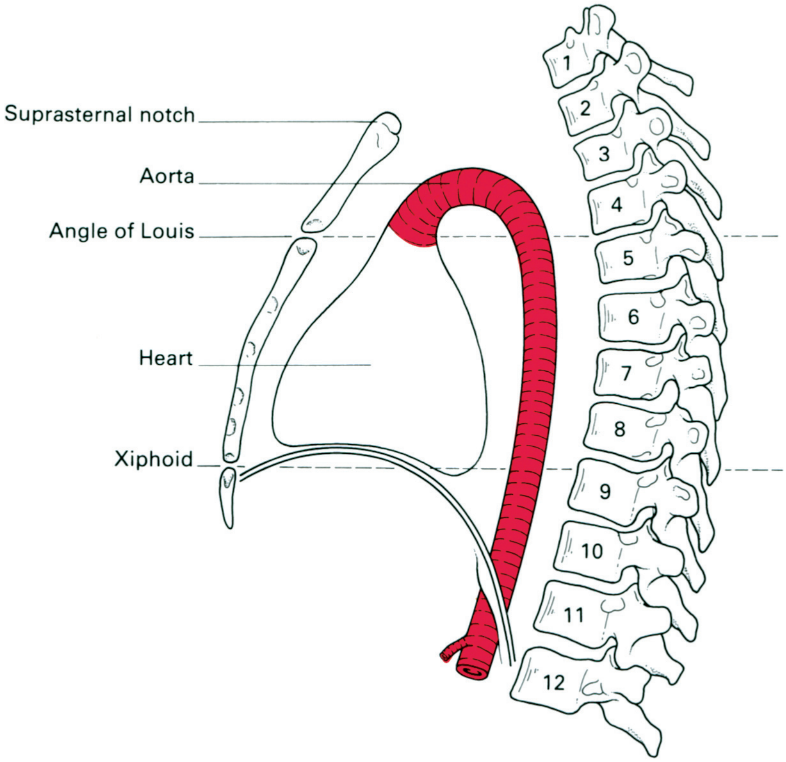

Fig. 1 Lateral view of the thorax—its surface markings and vertebral levels. (Note that the angle of Louis (T4/5) demarcates the superior mediastinum, the upper margin of the heart and the beginning and end of the aortic arch.)

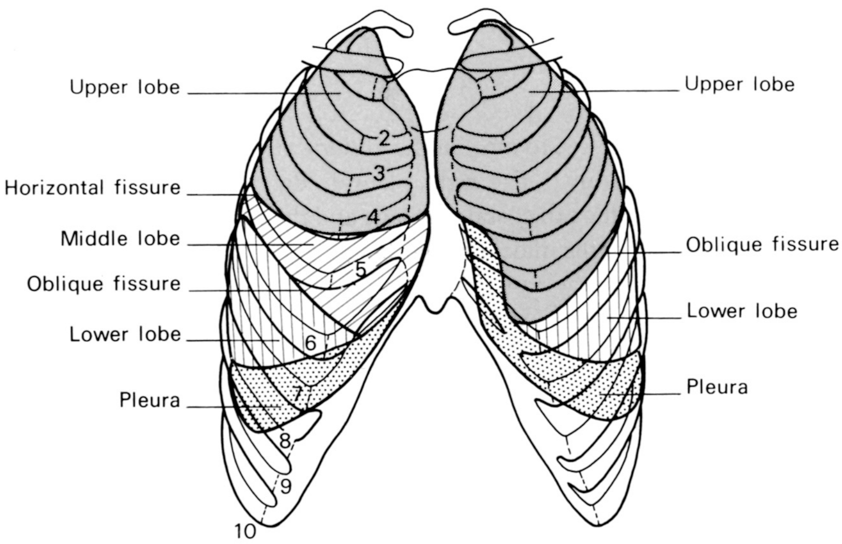

Fig. 2 The surface markings of the lungs and pleura—anterior view.

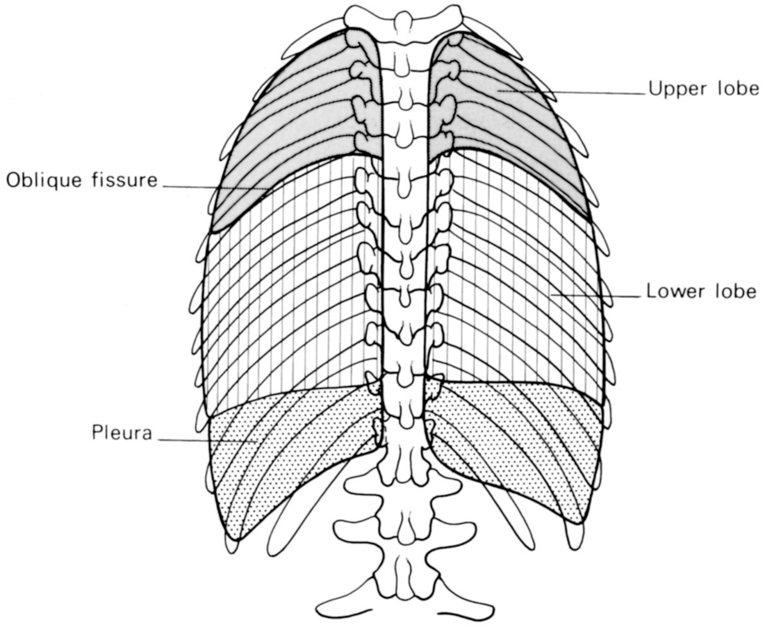

Fig. 3 The surface markings of the lungs and pleura—posterior view.

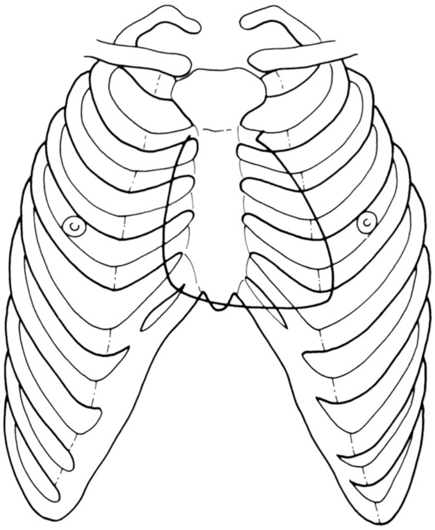

Fig. 4 The surface markings of the heart (see text).

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 (2.5 cm) 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 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

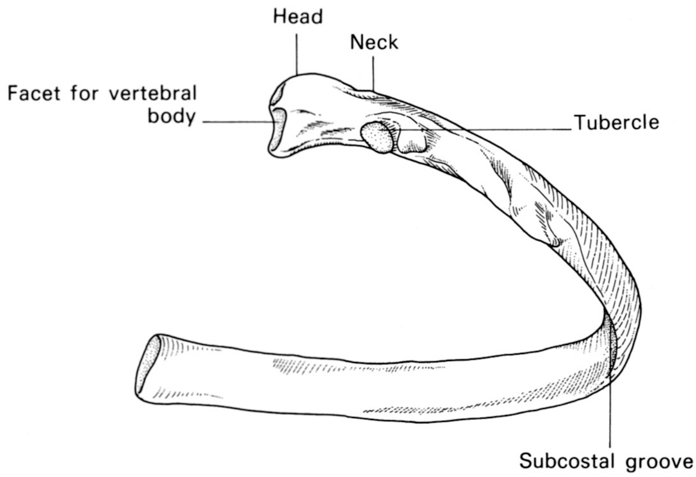

Fig. 5 A typical rib.

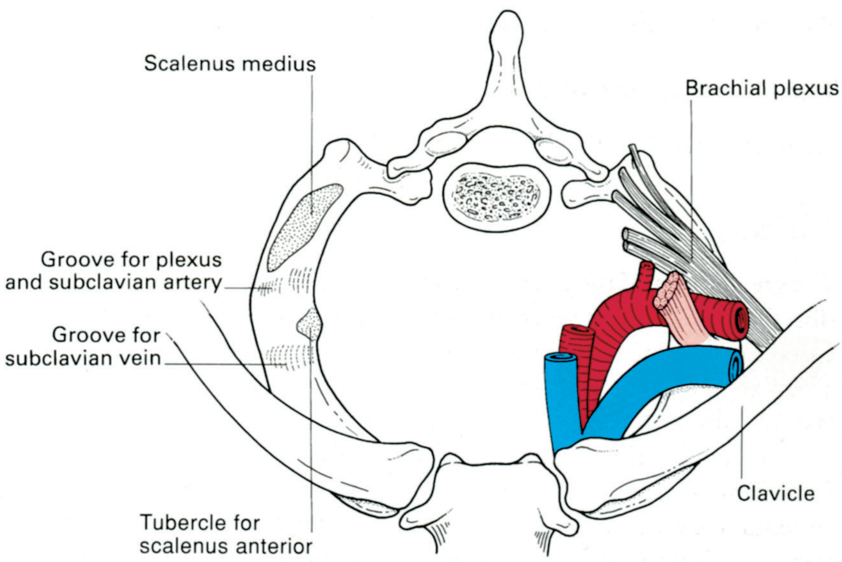

Fig. 6 Structures crossing the first rib.

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.

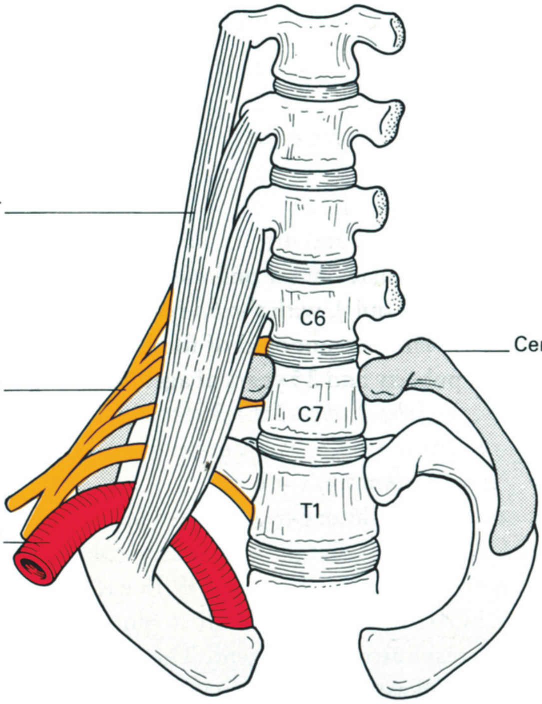

Fig. 7 Bilateral cervical ribs. On the right side the brachial plexus is shown arching over the rib and stretching its lowest trunk.

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:

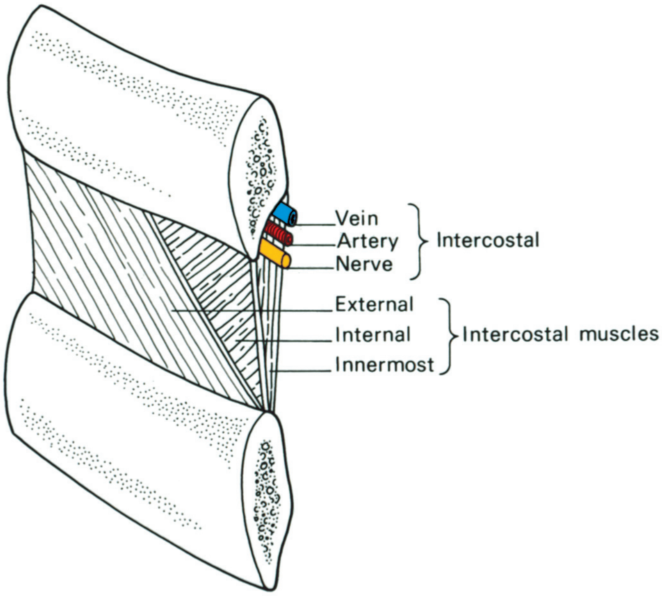

Fig. 8 The relationship of an intercostal space. (Note that a needle passed into the chest immediately *above* a rib will avoid the neurovascular bundle.)

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.

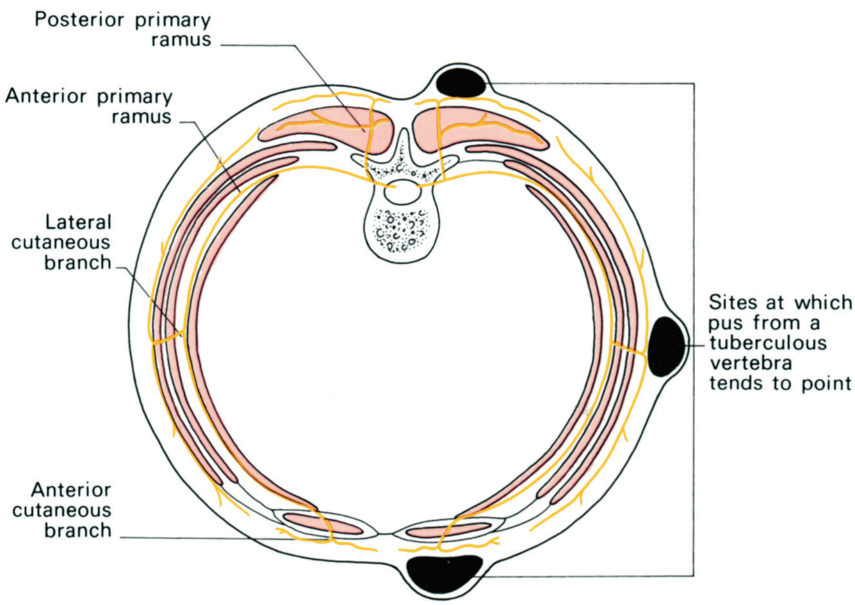

Fig. 9 Diagram of a typical spinal nerve and its body-wall relationships. On the left side the sites of eruption of a tuberculous cold abscess tracking forwards from a diseased vertebra are shown—these occur at the points of emergence of the cutaneous branches.

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*.

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 though 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.

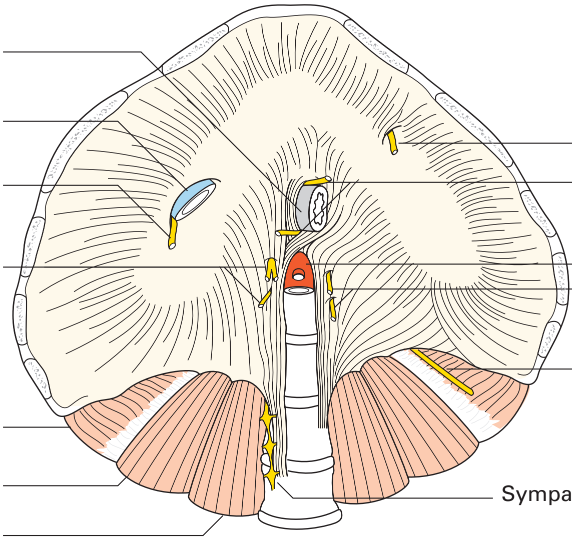

Fig. 10 The diaphragm—inferior aspect. The three major orifices, from above downwards, transmit the inferior vena cava, oesophagus and aorta.

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

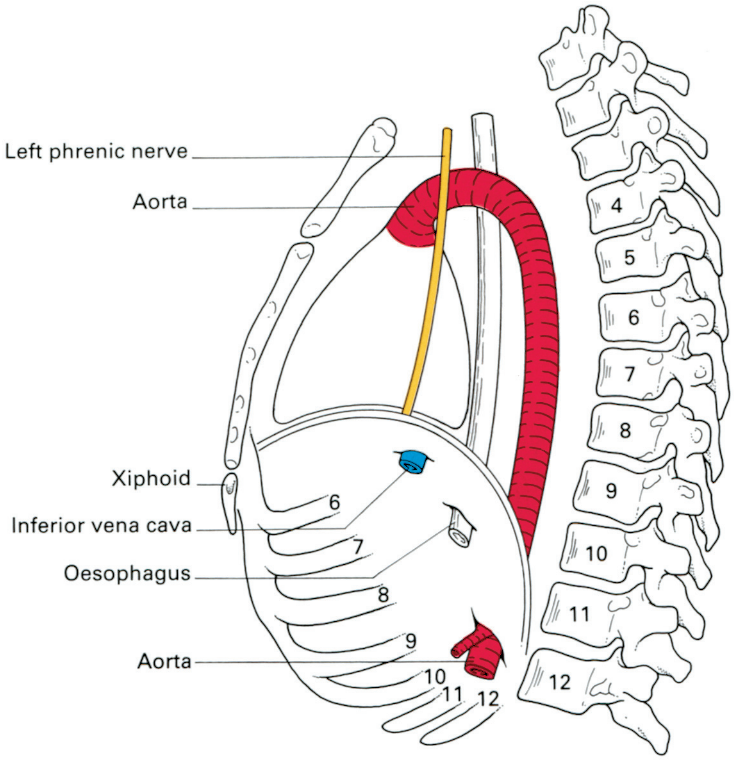

Fig. 11 Schematic lateral view of the diaphragm to show the levels at which it is pierced by major structures.

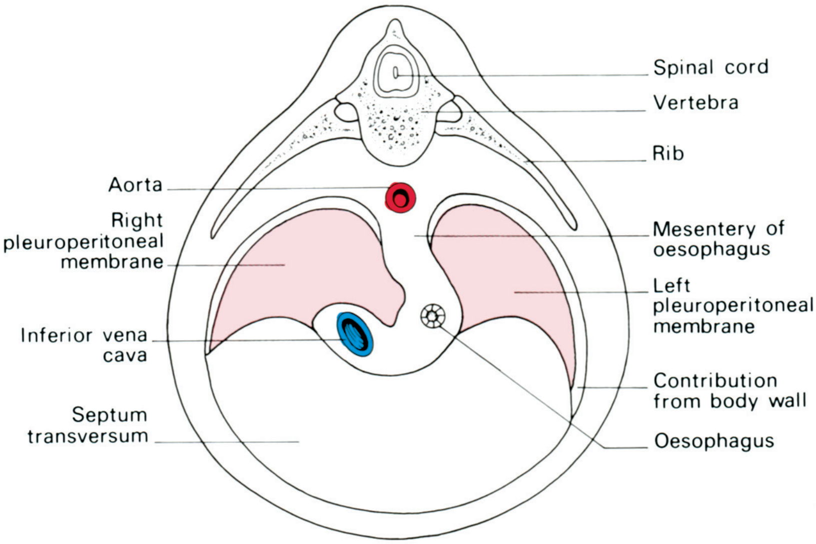

Fig. 12 The development of the diaphragm. This drawing shows the four elements contributing to the diaphragm—(1) the septum transversum, (2) the dorsal mesentery of the oesophagus, (3) the body wall and (4) the pleuroperitoneal membrane.

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

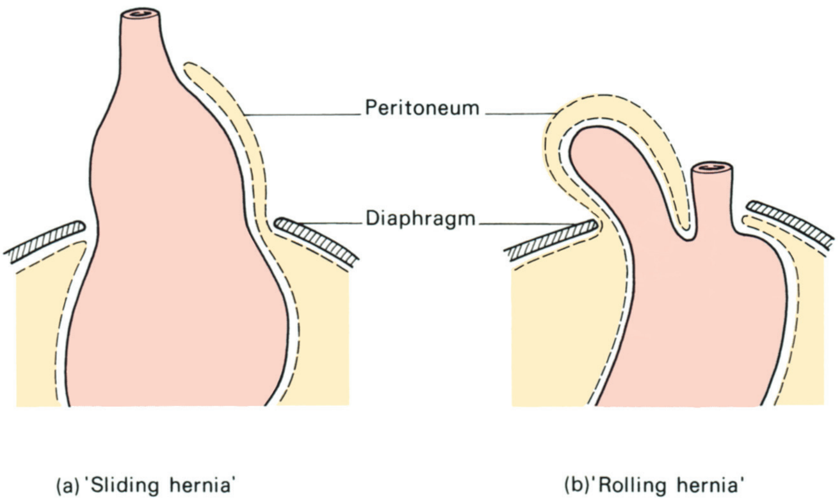

Fig. 13 (a) A sliding hiatus hernia. (b) A rolling hiatus hernia.

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).