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3 Thorax
Conceptual overview

GENERAL DESCRIPTION

The thorax is an irregularly shaped cylinder with a narrow opening (superior thoracic aperture) superiorly and a relatively large opening (inferior thoracic aperture) inferiorly (Fig. 3.1). The superior thoracic aperture is open, allowing continuity with the neck; the inferior thoracic aperture is closed by the diaphragm.

The musculoskeletal wall of the thorax is flexible and consists of segmentally arranged vertebrae, ribs, muscles, and the sternum.

The thoracic cavity enclosed by the thoracic wall and the diaphragm is subdivided into three major compartments:

Fig. 3.1 Thoracic wall and cavity.
a left and a right pleural cavity, each surrounding a lung;
the mediastinum.

The mediastinum is a thick, flexible soft tissue partition oriented longitudinally in a median sagittal position. It contains the heart, esophagus, trachea, major nerves, and major systemic blood vessels.

The pleural cavities are completely separated from each other by the mediastinum. Therefore, abnormal events in one pleural cavity do not necessarily affect the other cavity. This also means that the mediastinum can be entered surgically without opening the pleural cavities.

Another important feature of the pleural cavities is that they extend above the level of rib I. The apex of each lung actually extends into the root of the neck. As a consequence, abnormal events in the root of the neck can involve the adjacent pleura and lung, and events in the adjacent pleura and lung can involve the root of the neck.

FUNCTIONS

Breathing

One of the most important functions of the thorax is breathing. The thorax not only contains the lungs but also provides the machinery necessary—the diaphragm, thoracic wall, and the ribs—for effectively moving air into and out of the lungs.

Up and down movements of the diaphragm and changes in the lateral and anterior dimensions of the thoracic wall, caused by movements of the ribs, alter the volume of the thoracic cavity and are key elements in breathing.

Protection of vital organs

The thorax houses and protects the heart, lungs, and great vessels. Because of the domed shape of the diaphragm, the thoracic wall also offers protection to some important abdominal viscera.

Much of the liver lies under the right dome of the diaphragm, and the stomach and spleen lie under the left. The posterior aspects of the superior poles of the kidneys lie on the diaphragm and are anterior to rib XII, on the right, and to ribs XI and XII, on the left.

Conduit

The mediastinum acts as a conduit for structures that pass completely through the thorax from one body region to another and for structures that connect organs in the thorax to other body regions.

The esophagus, vagus nerves, and thoracic duct pass through the mediastinum as they course between the abdomen and neck.

The phrenic nerves, which originate in the neck, also pass through the mediastinum to penetrate and supply the diaphragm.

Other structures such as the trachea, thoracic aorta, and superior vena cava course within the mediastinum en route to and from major visceral organs in the thorax.

COMPONENT PARTS

Thoracic wall

The thoracic wall consists of skeletal elements and muscles (Fig. 3.1):

posteriorly, it is made up of twelve thoracic vertebrae and their intervening intervertebral discs;

laterally, the wall is formed by ribs (twelve on each side) and three layers of flat muscles, which span the intercostal spaces between adjacent ribs, move the ribs and provide support for the intercostal spaces;

anteriorly, the wall is made up of the sternum, which consists of the manubrium of sternum, body of sternum, and xiphoid process.

The manubrium of sternum, angled posteriorly on the body of sternum at the manubriosternal joint, forms the sternal angle, which is a major surface landmark used by clinicians in performing physical examinations of the thorax.

The anterior (distal) end of each rib is composed of costal cartilage, which contributes to the mobility and elasticity of the wall.

All ribs articulate with thoracic vertebrae posteriorly. Most ribs (from rib II to IX) have three articulations with the vertebral column. The head of each rib articulates with the body of its own vertebra and with the body of the vertebra above (Fig. 3.2). As these ribs curve posteriorly, each also articulates with the transverse process of its vertebra.

Anteriorly, the costal cartilages of ribs I to VII articulate with the sternum.

The costal cartilages of ribs VIII to X articulate with the inferior margins of the costal cartilages above them. Ribs XI and XII are called floating ribs because they do not articulate with other ribs, costal cartilages, or the sternum. Their costal cartilages are small, only covering their tips.

The skeletal framework of the thoracic wall provides extensive attachment sites for muscles of the neck, abdomen, back, and upper limbs.
A number of these muscles attach to ribs and function as accessory respiratory muscles; some of them also stabilize the position of the first and last ribs.

**Superior thoracic aperture**

Completely surrounded by skeletal elements, the **superior thoracic aperture** consists of the body of vertebra T1 posteriorly, the medial margin of rib I on each side, and the manubrium anteriorly.

The superior margin of the manubrium is in approximately the same horizontal plane as the intervertebral disc between vertebrae TII and TIII.

The first ribs slope inferiorly from their posterior articulation with vertebra T1 to their anterior attachment to the manubrium. Consequently, the plane of the superior thoracic aperture is at an oblique angle, facing somewhat anteriorly.

At the superior thoracic aperture, the superior aspects of the pleural cavities, which surround the lungs, lie on either side of the entrance to the mediastinum (Fig. 3.3).

Structures that pass between the upper limb and thorax pass over rib I and the superior part of the pleural cavity as they enter and leave the mediastinum. Structures that pass between the neck and head and the thorax pass more vertically through the superior thoracic aperture.

**Inferior thoracic aperture**

The **inferior thoracic aperture** is large and expandable. Bone, cartilage, and ligaments form its margin (Fig. 3.4A).

The inferior thoracic aperture is closed by the diaphragm, and structures passing between the abdomen and thorax pierce or pass posteriorly to the diaphragm.

Skeletal elements of the inferior thoracic aperture are:

- the body of vertebra TXII posteriorly;
- rib XII and the distal end of rib XI posterolaterally;
- the distal cartilaginous ends of ribs VII to X, which unite to form the costal margin anterolaterally; and
- the xiphoid process anteriorly.

The joint between the costal margin and sternum lies roughly in the same horizontal plane as the intervertebral disc between vertebrae TIX and TX. In other words, the posterior margin of the inferior thoracic aperture is inferior to the anterior margin.

When viewed anteriorly, the inferior thoracic aperture is tilted superiorly.
Diaphragm

The muscolotendinous diaphragm seals the inferior thoracic aperture (Fig. 3.4B).

Generally, muscle fibers of the diaphragm arise radially, from the margins of the inferior thoracic aperture, and converge into a large central tendon.

Because of the oblique angle of the inferior thoracic aperture, the posterior attachment of the diaphragm is inferior to the anterior attachment.

The diaphragm is not flat; rather, it “balloons” superiorly, on both the right and left sides, to form domes. The right dome is higher than the left, reaching as far as rib V.
As the diaphragm contracts, the height of the domes decreases and the volume of the thorax increases. The esophagus and inferior vena cava penetrate the diaphragm; the aorta passes posterior to the diaphragm.

**Mediastinum**

The *mediastinum* is a thick midline partition that extends from the sternum anteriorly to the thoracic vertebrae posteriorly, and from the superior thoracic aperture to the inferior thoracic aperture.

A horizontal plane passing through the sternal angle and the intervertebral disc between vertebrae TIV and TV separates the mediastinum into superior and inferior parts (Fig. 3.5). The inferior part is further subdivided by the pericardium, which encloses the pericardial cavity surrounding the heart. The pericardium and heart constitute the middle mediastinum.

The anterior mediastinum lies between the sternum and the pericardium; the posterior mediastinum lies between the pericardium and thoracic vertebrae.

**Pleural cavities**

The two pleural cavities are situated on either side of the mediastinum (Fig. 3.6).

Each *pleural cavity* is completely lined by a mesothelial membrane called the pleura. During development, the lungs grow out of the mediastinum, becoming surrounded by the pleural cavities. As a result, the outer surface of each organ is covered by pleura.

Each lung remains attached to the mediastinum by a root formed by the airway, pulmonary blood vessels, lymphatic tissues, and nerves.

The pleura lining the walls of the cavity is the parietal pleura, whereas that reflected from the mediastinum at the roots and onto the surfaces of the lungs is the visceral pleura. Only a potential space normally exists between the visceral pleura covering lung and the parietal pleura lining the wall of the thoracic cavity.

The lung does not completely fill the potential space of the pleural cavity, resulting in recesses, which do not contain lung and are important for accommodating changes in lung volume during breathing. The costodiaphragmatic recess, which is the largest and clinically most important recess, lies inferiorly between the thoracic wall and diaphragm.
RELATIONSHIP TO OTHER REGIONS

Neck

The superior thoracic aperture opens directly into the root of the neck (Fig. 3.7).

The superior aspect of each pleural cavity extends approximately 2–3 cm above rib I and the costal cartilage into the neck. Between these pleural extensions, major visceral structures pass between the neck and superior mediastinum. In the midline, the trachea lies immediately anterior to the esophagus. Major blood vessels and nerves pass in and out of the thorax at the superior thoracic aperture anteriorly and laterally to these structures.
**Thorax**

### Upper limb

An **axillary inlet**, or gateway to the upper limb, lies on each side of the superior thoracic aperture. These two axillary inlets and the superior thoracic aperture communicate superiorly with the root of the neck (Fig. 3.7).

Each axillary inlet is formed by:

- the superior margin of the scapula posteriorly;
- the clavicle anteriorly; and
- the lateral margin of rib I medially.

The apex of each triangular inlet is directed laterally and is formed by the medial margin of the coracoid process, which extends anteriorly from the superior margin of the scapula.

The base of the axillary inlet’s triangular opening is the lateral margin of rib I.

Large blood vessels passing between the axillary inlet and superior thoracic aperture do so by passing over rib I.

Proximal parts of the brachial plexus also pass between the neck and upper limb by passing through the axillary inlet.

### Abdomen

The diaphragm separates the thorax from the abdomen. Structures that pass between the thorax and abdomen either penetrate the diaphragm or pass posteriorly to it (Fig. 3.8):

- the inferior vena cava pierces the **central tendon of the diaphragm** to enter the right side of the mediastinum near vertebral level T VIII;
- the esophagus penetrates the muscular part of the diaphragm to leave the mediastinum and enter the abdomen just to the left of the midline at vertebral level T X;
- the aorta passes posteriorly to the diaphragm at the midline at vertebral level T XII;
- numerous other structures that pass between the thorax and abdomen pass through or posterior to the diaphragm.

### Breast

The breasts, consisting of secretory glands, superficial fascia, and overlying skin, are in the **pectoral region** on each side of the anterior thoracic wall (Fig. 3.9).

Branches from the internal thoracic arteries and veins perforate the anterior chest wall on each side of the sternum to supply anterior aspects of the thoracic wall. Those branches associated mainly with the second to fourth intercostal spaces also supply the anteromedial parts of each breast.

Lymphatic vessels from the medial part of the breast accompany the perforating arteries and drain into the parasternal nodes on the deep surface of the thoracic wall:

- vessels and lymphatics associated with lateral parts of the breast emerge from or drain into the **axillary region** of the upper limb;
- lateral and anterior branches of the fourth to sixth intercostal nerves carry general sensation from the skin of the breast.

### KEY FEATURES

**Vertebral level TIV/V**

When working with patients, physicians use vertebral levels to determine the position of important anatomical structures within body regions.
The horizontal plane passing through the disc that separates thoracic vertebrae TIV and TV is one of the most significant planes in the body (Fig. 3.10) because it:

- passes through the sternal angle anteriorly, marking the position of the anterior articulation of the costal cartilage of rib II with the sternum. The sternal angle is used to find the position of rib II as a reference for counting ribs (because of the overlying clavicle, rib I is not palpable);
- separates the superior mediastinum from the inferior mediastinum and marks the position of the superior limit of the pericardium;
- marks where the arch of the aorta begins and ends;
- passes through the site where the superior vena cava penetrates the pericardium to enter the heart;
- is the level at which the trachea bifurcates into right and left main bronchi; and
- marks the superior limit of the pulmonary trunk.
Venous shunts from left to right

The right atrium is the chamber of the heart that receives deoxygenated blood returning from the body. It lies on the right side of the midline, and the two major veins, the superior and inferior venae cavae, that drain into it are also located on the right side of the body. This means that, to get to the right side of the body, all blood coming from the left side has to cross the midline. This left-to-right shunting is carried out by a number of important and, in some cases, very large, veins, several of which are in the thorax (Fig. 3.11).

In adults, the left brachiocephalic vein crosses the midline immediately posterior to the manubrium and delivers blood from the left side of the head and neck, the left upper limb, and part of the left thoracic wall into the superior vena cava.

The hemiazygos and accessory hemiazygos veins drain posterior and lateral parts of the left thoracic wall, pass immediately anterior to the bodies of thoracic vertebrae, and flow into the azygos vein on the right side, which ultimately connects with the superior vena cava.

Segmental neurovascular supply of thoracic wall

The arrangement of vessels and nerves that supply the thoracic wall reflects the segmental organization of the wall. Arteries to the wall arise from two sources:
- the thoracic aorta, which is in the posterior mediastinum; and
- a pair of vessels, the internal thoracic arteries, which run along the deep aspect of the anterior thoracic wall on either side of the sternum.

Posterior and anterior intercostal vessels branch segmentally from these arteries and pass laterally around the wall, mainly along the inferior margin of each rib (Fig. 3.12A). Running with these vessels are intercostal nerves (the anterior rami of thoracic spinal nerves), which innervate the wall, related parietal pleura, and associated skin. The position of these nerves and vessels relative to the ribs must be considered when passing objects, such as chest tubes, through the thoracic wall.

Dermatomes of the thorax generally reflect the segmental organization of the thoracic spinal nerves (Fig. 3.12B). The exception occurs, anteriorly and superiorly, with the first thoracic dermatome, which is located mostly in the upper limb, and not on the trunk.

![Figure 3.12 A. Segmental neurovascular supply of thoracic wall.](image)
The anterosuperior region of the trunk receives branches from the anterior ramus of C4 via supraclavicular branches of the cervical plexus.

The highest thoracic dermatome on the anterior chest wall is T2, which also extends into the upper limb. In the midline, skin over the xiphoid process is innervated by T6.

Dermatomes of T7 to T12 follow the contour of the ribs onto the anterior abdominal wall (Fig. 3.12C).

**Sympathetic system**

All preganglionic nerve fibers of the sympathetic system are carried out of the spinal cord in spinal nerves T1 to L2 (Fig. 3.13). This means that sympathetic fibers found anywhere in the body ultimately emerge from the spinal cord as components of these spinal nerves. Preganglionic sympathetic fibers destined for the head are carried out of the spinal cord in spinal nerve T1.

**Flexible wall and inferior thoracic aperture**

The thoracic wall is expandable because most ribs articulate with other components of the wall by true joints that allow movement, and because of the shape and orientation of the ribs (Fig. 3.14).

A rib’s posterior attachment is superior to its anterior attachment. Therefore, when a rib is elevated, it moves the anterior thoracic wall forward relative to the posterior wall, which is fixed. In addition, the middle part of each rib is inferior to its two ends, so that when this region of the rib is elevated, it expands the thoracic wall laterally. Finally, because the diaphragm is muscular, it changes the volume of the thorax in the vertical direction.

Changes in the anterior, lateral, and vertical dimensions of the thoracic cavity are important for breathing.

**Innervation of the diaphragm**

The diaphragm is innervated by two phrenic nerves that originate, one on each side, as branches of the cervical plexus in the neck (Fig. 3.15). They arise from the anterior rami of cervical nerves C3, C4, and C5, with the major contribution coming from C4.

The phrenic nerves pass vertically through the neck, the superior thoracic aperture, and the mediastinum to supply motor innervation to the entire diaphragm.
including the crura (muscular extensions that attach the diaphragm to the upper lumbar vertebrae). In the mediastinum, the phrenic nerves pass anteriorly to the roots of the lungs.

The tissues that initially give rise to the diaphragm are in an anterior position on the embryological disc before the head fold develops, which explains the cervical origin of the nerves that innervate the diaphragm. In other words, the tissue that gives rise to the diaphragm originates superior to the ultimate location of the diaphragm.

Spinal cord injuries below the level of the origin of the phrenic nerve do not affect movement of the diaphragm.
Fig. 3.15 Innervation of the diaphragm.
Regional anatomy

The cylindrical thorax consists of:

- a wall;
- two pleural cavities;
- the lungs; and
- the mediastinum.

The thorax houses the heart and lungs, acts as a conduit for structures passing between the neck and the abdomen, and plays a principal role in breathing. In addition, the thoracic wall protects the heart and lungs and provides support for the upper limbs. Muscles anchored to the anterior thoracic wall provide some of this support, and together with their associated connective tissues, nerves, and vessels, and the overlying skin and superficial fascia, define the pectoral region.

PECTORAL REGION

The pectoral region is external to the anterior thoracic wall and anchors the upper limb to the trunk. It consists of:

- a superficial compartment containing skin, superficial fascia, and breasts; and
- a deep compartment containing muscles and associated structures.

Nerves, vessels, and lymphatics in the superficial compartment emerge from the thoracic wall, the axilla, and the neck.

Breast

The breasts consist of mammary glands and associated skin and connective tissues. The mammary glands are modified sweat glands in the superficial fascia anterior to the pectoral muscles and the anterior thoracic wall (Fig. 3.16).

The mammary glands consist of a series of ducts and associated secretory lobules. These converge to form 15 to 20 lactiferous ducts, which open independently onto the nipple. The nipple is surrounded by a circular pigmented area of skin termed the areola.

A well-developed, connective tissue stroma surrounds the ducts and lobules of the mammary gland. In certain regions, this condenses to form well-defined ligaments, the suspensory ligaments of breast, which are continuous with the dermis of the skin and support the breast. Carcinoma of the breast creates tension on these ligaments, causing pitting of the skin.

In nonlactating women, the predominant component of the breasts is fat, while glandular tissue is more abundant in lactating women.

The breast lies on deep fascia related to the pectoralis major muscle and other surrounding muscles. A layer of loose connective tissue (the retromammary space) separates the breast from the deep fascia and provides some degree of movement over underlying structures.

The base, or attached surface, of each breast extends vertically from ribs II to VI, and transversely from the sternum to as far laterally as the midaxillary line.

It is important for clinicians to remember when evaluating the breast for pathology that the upper lateral region of the breast can project around the lateral margin of the pectoralis major muscle and into the axilla. This axillary process (axillary tail) may perforate deep fascia and extend as far superiorly as the apex of the axilla.

Arterial supply

The breast is related to the thoracic wall and to structures associated with the upper limb; therefore, vascular supply and drainage can occur by multiple routes (Fig. 3.16):

- laterally, vessels from the axillary artery—superior thoracic, thoraco-acromial, lateral thoracic, and subscapular arteries;
- medially, branches from the internal thoracic artery;
- the second to fourth intercostal arteries via branches that perforate the thoracic wall and overlying muscle.

Venous drainage

Veins draining the breast parallel the arteries and ultimately drain into the axillary, internal thoracic, and intercostal veins.

Innervation

Innervation of the breast is via anterior and lateral cutaneous branches of the second to sixth intercostal nerves. The nipple is innervated by the fourth intercostal nerve.
Lymphatic drainage

Lymphatic drainage of the breast is as follows:

- approximately 75% is via lymphatic vessels that drain laterally and superiorly into axillary nodes (Fig. 3.16);
- most of the remaining drainage is into parasternal nodes deep to the anterior thoracic wall and associated with the internal thoracic artery; and
- some drainage may occur via lymphatic vessels that follow the lateral branches of posterior intercostal arteries and connect with intercostal nodes situated near the heads and necks of ribs.

Breast in men

The breast in men is rudimentary and consists only of small ducts, often composed of cords of cells, that normally do not extend beyond the areola. Breast cancer can occur in men.
Breast cancer
Breast cancer is one of the most common malignancies in women. In the early stages, curative treatment may include surgery, radiotherapy, and chemotherapy.

Breast cancer develops in the cells of the acini, lactiferous ducts, and lobules of the breast. Tumor growth and spread depends on the exact cellular site of origin of the cancer. These factors affect the response to surgery, chemotherapy, and radiotherapy. Breast tumors spread via the lymphatics and veins, or by direct invasion.

When a patient has a lump in the breast, a diagnosis of breast cancer is confirmed by a biopsy and histological evaluation. Once confirmed, the clinician must attempt to stage the tumor.

**Staging the tumor** means defining the:
- size of the primary tumor;
- exact site of the primary tumor;
- number and sites of lymph node spread; and
- organs to which the tumor may have spread.

Computed tomography (CT) scanning of the body may be carried out to look for any spread to the lungs (pulmonary metastases), liver (hepatic metastases), or bone (bony metastases).

Further imaging may include bone scanning using radioactive isotopes, which are avidly taken up by the tumor metastases in bone.

Lymph drainage of the breast is complex. Lymph vessels pass to axillary, supraclavicular, parasternal, and abdominal lymph nodes, as well as the opposite breast. Containment of nodal metastatic breast cancer is therefore potentially difficult because it can spread through many lymph node groups.

Subcutaneous lymphatic obstruction and tumor growth pull on connective tissue ligaments in the breast resulting in the appearance of an orange peel texture (*peau d’orange*) on the surface of the breast. Further subcutaneous spread can induce a rare manifestation of breast cancer that produces a hard, woody texture to the skin (*cancer en cuirasse*).

A mastectomy (surgical removal of the breast) involves excision of the breast tissue to the pectoralis major muscle and fascia. Within the axilla the breast tissue must be removed from the medial axillary wall. Closely applied to the medial axillary wall is the long thoracic nerve. Damage to this nerve can result in paralysis of the serratus anterior muscle producing a characteristic “winged” scapula. It is also possible to damage the nerve to the latissimus dorsi muscle, and this may affect extension, medial rotation, and adduction of the humerus.

Muscles of the pectoral region

Each pectoral region contains the pectoralis major, pectoralis minor, and subclavius muscles (Fig. 3.17 and Table 3.1). All originate from the anterior thoracic wall and insert into bones of the upper limb.

**Pectoralis major**

The **pectoralis major** muscle is the largest and most superficial of the pectoral region muscles. It directly underlies the breast and is separated from it by deep fascia and the loose connective tissue of the retromammary space.

Pectoralis major has a broad origin that includes the anterior surfaces of the medial half of the clavicle, the sternum, and related costal cartilages. The muscle fibers converge to form a flat tendon, which inserts into the lateral lip of the intertubercular sulcus of the humerus.

Pectoralis major adducts, flexes, and medially rotates the arm.

**Subclavius and pectoralis minor**

The **subclavius** and **pectoralis minor muscles** underlie pectoralis major:

- subclavius is small and passes laterally from the anterior and medial part of rib I to the inferior surface of the clavicle;
- pectoralis minor passes from the anterior surfaces of ribs III to V to the coracoid process of the scapula.

Both subclavius and pectoralis minor pull the tip of the shoulder inferiorly.

A continuous layer of deep fascia, **clavipectoral fascia**, encloses subclavius and pectoralis minor and attaches to the clavicle above and to the floor of the axilla below.
The muscles of the pectoral region form the anterior wall of the axilla, a region between the upper limb and the neck through which all major structures pass. Nerves, vessels, and lymphatics that pass between the pectoral region and the axilla pass through the clavipectoral fascia between subclavius and pectoralis minor or pass under the inferior margins of pectoralis major and minor.
THORACIC WALL

The thoracic wall is segmental in design and composed of skeletal elements and muscles. It extends between:

- the superior thoracic aperture bordered by vertebra T1, rib I, and the manubrium of sternum; and
- the inferior thoracic aperture bordered by vertebra TXII, rib XII, the end of rib XI, the costal margin, and the xiphoid process of sternum.

Skeletal framework

The skeletal elements of the thoracic wall consist of thoracic vertebrae, intervertebral discs, ribs, and sternum.

Thoracic vertebrae

There are twelve thoracic vertebrae, each of which is characterized by articulations with ribs.

A typical thoracic vertebra

A typical thoracic vertebra has a heart-shaped vertebral body, with roughly equal dimensions in the transverse and anteroposterior directions, and a long spinous process (Fig. 3.18). The vertebral foramen is generally circular and the laminae are broad and overlap with those of the vertebra below. The superior articular processes are flat, with their articular surfaces facing almost directly posteriorly, while the inferior articular processes project from the laminae and their articular facets face anteriorly. The transverse processes are club shaped and project posterolaterally.

Articulation with ribs

A typical thoracic vertebra has three sites on each side for articulation with ribs.

- Two demifacets (i.e., partial facets) are located on the superior and inferior aspects of the body for articulation with corresponding sites on the heads of adjacent ribs. The superior costal facet articulates with part of the head of its own rib, and the inferior costal facet articulates with part of the head of the rib below.
- An oval facet (transverse costal facet) at the end of the transverse process articulates with the tubercle of its own rib.
Not all vertebrae articulate with ribs in the same fashion (Fig. 3.19):

- the superior costal facets on the body of vertebra TI are complete and articulate with a single facet on the head of its own rib—in other words, the head of rib I does not articulate with vertebra CVII;
- similarly, vertebra TX (and often TIX) articulates only with its own ribs and therefore lacks inferior demifacets on the body;
- vertebrae TXI and TXII articulate only with the heads of their own ribs— they lack transverse costal facets and have only a single complete facet on each side of their bodies.

**Ribs**

There are twelve pairs of ribs, each terminating anteriorly in a costal cartilage (Fig. 3.20).

Although all ribs articulate with the vertebral column, only the costal cartilages of the upper seven ribs, known as true ribs, articulate directly with the sternum. The remaining five pairs of ribs are false ribs:

- the costal cartilages of ribs VIII to X articulate anteriorly with the costal cartilages of the ribs above;
- ribs XI and XII have no anterior connection with other ribs or with the sternum and are often called floating ribs.

**Fig. 3.19** Typical thoracic vertebrae.

**Fig. 3.20** Ribs.
A typical rib consists of a curved shaft with anterior and posterior ends (Fig. 3.21). The anterior end is continuous with its costal cartilage. The posterior end articulates with the vertebral column and is characterized by a head, neck, and tubercle.

The **head** is somewhat expanded and typically presents two articular surfaces separated by a **crest**. The smaller superior surface articulates with the inferior costal facet on the body of the vertebra above, whereas the larger inferior facet articulates with the superior costal facet of its own vertebra.

The **neck** is a short flat region of bone that separates the head from the tubercle.

The **tubercle** projects posteriorly from the junction of the neck with the shaft and consists of two regions, an articular part and a nonarticular part:

- the articular part is medial and has an oval facet for articulation with a corresponding facet on the transverse process of the associated vertebra;
- the raised nonarticular part is roughened by ligament attachments.

The shaft is generally thin and flat with internal and external surfaces.

The superior margin is smooth and rounded, whereas the inferior margin is sharp. The shaft bends forward just laterally to the tubercle at a site termed the **angle**. It also has a gentle twist around its longitudinal axis so that the internal surface of the anterior part of the shaft faces somewhat superiorly relative to the posterior part. The inferior margin of the internal surface is marked by a distinct **costal groove**.

**Distinct features of upper and lower ribs**

The upper and lower ribs have distinct features (Fig. 3.22).

**Rib I**

**Rib I** is flat in the horizontal plane and has broad superior and inferior surfaces. From its articulation with vertebra T1, it slopes inferiorly to its attachment to the manubrium of sternum. The head articulates only with the body of
Thorax

Vertebra T1 and therefore has only one articular surface. Like other ribs, the tubercle has a facet for articulation with the transverse process. The superior surface of the rib is characterized by a distinct tubercle, the *scalen e tubercle*, which separates two smooth grooves that cross the rib approximately midway along the shaft. The anterior groove is caused by the subclavian vein, and the posterior groove is caused by the subclavian artery. Anterior and posterior to these grooves, the shaft is roughened by muscle and ligament attachments.

**Rib II**

Rib II, like rib I, is flat but twice as long. It articulates with the vertebral column in a way typical of most ribs.

**Rib X**

The head of rib X has a single facet for articulation with its own vertebra.

**Ribs XI and XII**

Ribs XI and XII articulate only with the bodies of their own vertebrae and have no tubercles or necks. Both ribs are short, have little curve, and are pointed anteriorly.

**Sternum**

The adult sternum consists of three major elements: the broad and superiorly positioned manubrium of sternum, the narrow and longitudinally oriented body of sternum, and the small and inferiorly positioned xiphoid process (Fig. 3.23).

**Manubrium of sternum**

The manubrium of sternum forms part of the bony framework of the neck and the thorax.

The superior surface of the manubrium is expanded laterally and bears a distinct and palpable notch, the *jugular notch (suprasternal notch)*, in the midline. On either side of this notch is a large oval fossa for articulation with the clavicle. Immediately inferior to this fossa, on each lateral surface of the manubrium, is a facet for the attachment of the first costal cartilage. At the lower end of the lateral border is a demifacet for articulation with the upper half of the anterior end of the second costal cartilage.

**Body of the sternum**

The body of the sternum is flat.

The anterior surface of the body of the sternum is often marked by transverse ridges that represent lines of fusion between the segmental elements called sternebrae, from which this part of the sternum arises embryologically.

The lateral margins of the body of the sternum have articular facets for costal cartilages. Superiorly, each lateral margin has a demifacet for articulation with the inferior aspect of the second costal cartilage. Inferior to this demifacet are four facets for articulation with the costal cartilages of ribs III to VI.

At the inferior end of the body of the sternum is a demifacet for articulation with the upper demifacet on the seventh costal cartilage. The inferior end of the body of the sternum is attached to the xiphoid process.

**Xiphoid process**

The xiphoid process is the smallest part of the sternum. Its shape is variable: it may be wide, thin, pointed, bifid, curved, or perforated. It begins as a cartilaginous structure, which becomes ossified in the adult. On each side of its upper lateral margin is a demifacet for articulation with the inferior end of the seventh costal cartilage.
Joints
Costovertebral joints
A typical rib articulates with:
- the bodies of adjacent vertebrae, forming a joint with the head of the rib; and
- the transverse process of its related vertebra, forming a costotransverse joint (Fig. 3.24).

Together, the costovertebral joints and related ligaments allow the necks of the ribs either to rotate around their longitudinal axes, which occurs mainly in the upper ribs, or to ascend and descend relative to the vertebral column, which occurs mainly in the lower ribs. The combined movements of all of the ribs on the vertebral column are essential for altering the volume of the thoracic cavity during breathing.

Joint with head of rib
The two facets on the head of the rib articulate with the superior facet on the body of its own vertebra and with the inferior facet on the body of the vertebra above. This joint is divided into two synovial compartments by an intra-articular ligament, which attaches the crest to the adjacent intervertebral disc and separates the two articular surfaces on the head of the rib. The two synovial compartments and the intervening ligament are surrounded by a single joint capsule attached to the outer margins of the combined articular surfaces of the head and vertebral column.

Costotransverse joints
Costotransverse joints are synovial joints between the tubercle of a rib and the transverse process of the related vertebra (Fig. 3.24). The capsule surrounding each joint is thin. The joint is stabilized by two strong extracapsular ligaments that span the space between the transverse process and the rib on the medial and lateral sides of the joint:
- the costotransverse ligament is medial to the joint and attaches the neck of the rib to the transverse process;
- the lateral costotransverse ligament is lateral to the joint and attaches the tip of the transverse process to the roughened nonarticular part of the tubercle of the rib.

A third ligament, the superior costotransverse ligament, attaches the superior surface of the neck of the rib to the transverse process of the vertebra above.
Slight gliding movements occur at the costotransverse joints.

**Sternocostal joints**
The sternocostal joints are joints between the upper seven costal cartilages and the sternum (Fig. 3.25).
The joint between rib I and the manubrium is not synovial and consists of a fibrocartilaginous connection between the manubrium and the costal cartilage. The second to seventh joints are synovial and have thin capsules reinforced by surrounding sternocostal ligaments.
The joint between the second costal cartilage and the sternum is divided into two compartments by an intrarticular ligament. This ligament attaches the second costal cartilage to the junction of the manubrium and the body of the sternum.

**Interchondral joints**
Interchondral joints occur between the costal cartilages of adjacent ribs (Fig. 3.25), mainly between the costal cartilages of ribs VII to X, but may also involve the costal cartilages of ribs V and VI.

Interchondral joints provide indirect anchorage to the sternum and contribute to the formation of a smooth inferior costal margin. They are usually synovial, and the thin fibrous capsules are reinforced by interchondral ligaments.

**Manubriosternal and xiphisternal joints**
The joints between the manubrium and body of sternum and between the body of sternum and the xiphoid process are usually symphyses (Fig. 3.25). Only slight angular
movements occur between the manubrium and body of sternum during respiration. The joint between the body of sternum and the xiphoid process often becomes ossified with age.

A clinically useful feature of the manubriosternal joint is that it can be palpated easily. This is because the manubrium normally angles posteriorly on the body of sternum, forming a raised feature referred to as the sternal angle. This elevation marks the site of articulation of rib II with the sternum. Rib I is not palpable because it lies inferior to the clavicle and is embedded in tissues at the base of the neck. Therefore, rib II is used as a reference for counting ribs and can be felt immediately lateral to the sternal angle.

In addition, the sternal angle lies on a horizontal plane that passes through the intervertebral disc between vertebrae TIV and TV (see Fig. 3.10). This plane separates the superior mediastinum from the inferior mediastinum and marks the superior border of the pericardium. The plane also passes through the end of the ascending aorta and the beginning of the arch of the aorta, the end of the arch of the aorta and the beginning of the thoracic aorta, the bifurcation of the trachea, and just superior to the pulmonary trunk (see Figs. 3.78 and 3.85).

**Intercostal spaces**

Intercostal spaces lie between adjacent ribs and are filled by intercostal muscles (Fig. 3.26).

Intercostal nerves and associated major arteries and veins lie in the costal groove along the inferior margin of the superior rib and pass in the plane between the inner two layers of muscles.

In each space, the vein is the most superior structure and is therefore highest in the costal groove. The artery is inferior to the vein, and the nerve is inferior to the artery and often not protected by the groove. Therefore, the nerve is the structure most at risk when objects perforate the upper aspect of an intercostal space. Small collateral branches of the major intercostal nerves and vessels are often present superior to the inferior rib below.

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**In the clinic**

**Cervical ribs**

Cervical ribs are present in approximately 1% of the population.

A cervical rib is an accessory rib articulating with vertebra CVII; the anterior end attaches to the superior border of the anterior aspect of rib I. Plain radiographs may demonstrate cervical ribs as small horn-like structures.

It is often not appreciated by clinicians that a fibrous band commonly extends from the anterior tip of the small cervical ribs to rib I, producing a “cervical band” that is not visualized on radiography. In patients with cervical ribs and cervical bands, structures that normally pass over rib I are elevated by, and pass over, the cervical rib and band (see Fig. 3.7).

Clinically, thoracic outlet syndrome is used to describe symptoms resulting from abnormal compression of the brachial plexus of nerves as it passes over the first rib and through the axillary inlet into the upper limb. The anterior ramus of T1 passes superiority out of the superior thoracic aperture to join and become part of the brachial plexus. The cervical band from a cervical rib is one cause of thoracic outlet syndrome by putting upward stresses on the lower parts of the brachial plexus as they pass over the first rib.

---

**Collection of sternal bone marrow**

The subcutaneous position of the sternum makes it possible to place a needle through the hard outer cortex into the internal (or medullary) cavity containing bone marrow. Once the needle is in this position, bone marrow can be aspirated. Evaluation of this material under the microscope helps clinicians diagnose certain blood diseases such as leukemia.

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**Rib fractures**

Single rib fractures are of little consequence, though extremely painful.

After severe trauma, ribs may be broken in two or more places. If enough ribs are broken, a loose segment of chest wall, a flail segment (flail chest), is produced. When the patient takes a deep inspiration, the flail segment moves in the opposite direction to the chest wall, preventing full lung expansion and creating a paradoxically moving segment. If a large enough segment of chest wall is affected, ventilation may be impaired and assisted ventilation may be required until the ribs have healed.
Deep to the intercostal spaces and ribs, and separating these structures from the underlying pleura, is a layer of loose connective tissue, called *endothoracic fascia*, which contains variable amounts of fat.

Superficial to the spaces are deep fascia, superficial fascia, and skin. Muscles associated with the upper limbs and back overlie the spaces.

**Muscles**

Muscles of the thoracic wall include those that fill and support the intercostal spaces, those that pass between the sternum and the ribs, and those that cross several ribs between costal attachments (Table 3.2).

The muscles of the thoracic wall, together with muscles between the vertebrae and ribs posteriorly (i.e., the *leva-...
Intercostal muscles

The intercostal muscles are three flat muscles found in each intercostal space that pass between adjacent ribs (Fig. 3.26, cont’d). Individual muscles in this group are named according to their positions:

- the external intercostal muscles are the most superficial;
- the internal intercostal muscles are sandwiched between the external and innermost muscles.

<table>
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<tr>
<th>Table 3.2 Muscles of the thoracic wall</th>
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<td><strong>Muscle</strong></td>
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<td>External intercostal</td>
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<td>Internal intercostal</td>
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<td>Innermost intercostal</td>
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<td>Subcostales</td>
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<td>Transversus thoracis</td>
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The intercostal muscles are innervated by the related intercostal nerves. As a group, the intercostal muscles provide structural support for the intercostal spaces during breathing. They can also move the ribs.

**External intercostal muscles**

The eleven pairs of *external intercostal muscles* extend from the inferior margins (lateral edges of costal grooves) of the ribs above to the superior margins of the ribs below. When the thoracic wall is viewed from a lateral position, the muscle fibers pass obliquely anteroinferiorly (Fig. 3.27). The muscles extend around the thoracic wall from the regions of the tubercles of the ribs to the costal cartilages, where each layer continues as a thin connective tissue aponeurosis termed the *external intercostal membrane*. The external intercostal muscles are most active in inspiration.

**Internal intercostal muscles**

The eleven pairs of *internal intercostal muscles* pass between the most inferior lateral edge of the costal grooves of the ribs above, to the superior margins of the ribs below. They extend from parasternal regions, where the muscles course between adjacent costal cartilages, to the angle of the ribs posteriorly (Fig. 3.27). This layer continues medially toward the vertebral column, in each intercostal space, as the *internal intercostal membrane*. The muscle fibers pass in the opposite direction to those of the external intercostal muscles. When the thoracic wall is viewed from a lateral position, the muscle fibers pass obliquely postero-
inferiorly. The internal intercostal muscles are most active during expiration.

**Innermost intercostal muscles**

The *innermost intercostal muscles* are the least distinct of the intercostal muscles, and the fibers have the same orientation as the internal intercostals (Fig. 3.27). These muscles are most evident in the lateral thoracic wall. They extend between the inner surfaces of adjacent ribs from the medial edge of the costal groove to the deep surface of the rib below. Importantly, the neurovascular bundles associated with the intercostal spaces pass around the thoracic wall in the costal grooves in a plane between the innermost and internal intercostal muscles.

**Subcostales**

The *subcostales* are in the same plane as the innermost intercostals, span multiple ribs, and are more numerous in lower regions of the posterior thoracic wall (Fig. 3.28A). They extend from the internal surfaces of one rib to the internal surface of the second or third rib below. Their fibers parallel the course of the internal intercostal muscles and extend from the angle of the ribs to more medial positions on the ribs below.

**Transversus thoracis muscles**

The *transversus thoracis muscles* are found on the deep surface of the anterior thoracic wall (Fig. 3.28B) and in the same plane as the innermost intercostals.

The transversus thoracis muscles originate from the posterior aspect of the xiphoid process, the inferior part of the body of the sternum, and the adjacent costal cartilages of the lower true ribs. They pass superiorly and laterally to insert into the lower borders of the costal cartilages of ribs III to VI. They most likely pull these latter elements inferiorly.

The transversus thoracis muscles lie deep to the internal thoracic vessels and secure these vessels to the wall.

**Arterial supply**

Vessels that supply the thoracic wall consist mainly of posterior and anterior intercostal arteries, which pass around the wall between adjacent ribs in intercostal spaces (Fig. 3.29). These arteries originate from the aorta and internal thoracic arteries, which in turn arise from the subclavian arteries in the root of the neck. Together, the intercostal arteries form a basket-like pattern of vascular supply around the thoracic wall.

**Posterior intercostal arteries**

*Posterior intercostal arteries* originate from vessels associated with the posterior thoracic wall. The upper two posterior intercostal arteries on each side are derived from the *supreme intercostal artery*, which descends into the thorax as a branch of the costocervical trunk in the neck. The *costocervical trunk* is a posterior branch of the subclavian artery (Fig. 3.29).

The remaining nine pairs of posterior intercostal arteries arise from the posterior surface of the thoracic aorta.
Because the aorta is on the left side of the vertebral column, those posterior intercostal vessels passing to the right side of the thoracic wall cross the midline anterior to the bodies of the vertebrae and therefore are longer than the corresponding vessels on the left.

In addition to having numerous branches that supply various components of the wall, the posterior intercostal arteries have branches that accompany lateral cutaneous branches of the intercostal nerves to superficial regions.

**Anterior intercostal arteries**

The anterior intercostal arteries originate directly or indirectly as lateral branches from the internal thoracic arteries (Fig. 3.29).

Each internal thoracic artery arises as a major branch of the subclavian artery in the neck. It passes anteriorly over the cervical dome of pleura and descends vertically through the superior thoracic aperture and along the deep aspect of the anterior thoracic wall. On each side, the internal thoracic artery lies posterior to the costal cartilages of the upper six ribs and about 1 cm lateral to the sternum. At approximately the level of the sixth intercostal space, it divides into two terminal branches:

- the **superior epigastric artery**, which continues inferiorly into the anterior abdominal wall (Fig. 3.29);
- the **musculophrenic artery**, which passes along the costal margin, goes through the diaphragm, and ends near the last intercostal space.
Anterior intercostal arteries that supply the upper six intercostal spaces arise as lateral branches from the internal thoracic artery, whereas those supplying the lower spaces arise from the musculophrenic artery.

In each intercostal space, the anterior intercostal arteries usually have two branches:

- one passes below the margin of the upper rib;
- the other passes above the margin of the lower rib and meets a collateral branch of the posterior intercostal artery.

The distributions of the anterior and posterior intercostal vessels overlap and can develop anastomotic connections. The anterior intercostal arteries are generally smaller than the posterior vessels.

In addition to anterior intercostal arteries and a number of other branches, the internal thoracic arteries give rise to perforating branches that pass directly forward between the costal cartilages to supply structures external to the thoracic wall. These vessels travel with the anterior cutaneous branches of intercostal nerves.

**Venous drainage**

Venous drainage from the thoracic wall generally parallels the pattern of arterial supply (Fig. 3.30). Centrally, the intercostal veins ultimately drain into the azygos system of veins or into internal thoracic veins, which connect with the brachiocephalic veins in the neck.

Often the upper posterior intercostal veins on the left side come together and form the left superior intercostal vein, which empties into the left brachiocephalic vein.

Similarly, the upper posterior intercostal veins on the right side may come together and form the right superior intercostal vein, which empties into the azygos vein.
Lymphatic drainage
Lymphatic vessels of the thoracic wall drain mainly into lymph nodes associated with the internal thoracic arteries (parasternal nodes), with the heads and necks of ribs (intercostal nodes), and with the diaphragm (diaphragmatic nodes) (Fig. 3.31). Diaphragmatic nodes are posterior to the xiphoid and at sites where the phrenic nerves penetrate the diaphragm. They also occur in regions where the diaphragm is attached to the vertebral column.

Parasternal nodes drain into bronchomediastinal trunks. Intercostal nodes in the upper thorax also drain into bronchomediastinal trunks, whereas intercostal nodes in the lower thorax drain into the thoracic duct.

Nodes associated with the diaphragm interconnect with parasternal, prevertebral, juxta-esophageal nodes, brachiocephalic (anterior to the brachiocephalic veins in the superior mediastinum), and lateral aortic/lumbar nodes (in the abdomen).

Superficial regions of the thoracic wall drain mainly into axillary lymph nodes in the axilla or parasternal nodes.

Innervation
Intercostal nerves
Innervation of the thoracic wall is mainly by the intercostal nerves, which are the anterior rami of spinal nerves T1 to T11 and lie in the intercostal spaces between adja-
cent ribs. The anterior ramus of spinal nerve T12 (the subcostal nerve) is inferior to rib XII (Fig. 3.32).

A typical intercostal nerve passes laterally around the thoracic wall in an intercostal space. The largest of the branches is the lateral cutaneous branch, which pierces the lateral thoracic wall and divides into an anterior branch and a posterior branch that innervate the overlying skin.

The intercostal nerves end as anterior cutaneous branches, which emerge either parasternally, between adjacent costal cartilages, or laterally to the midline, on the anterior abdominal wall, to supply the skin.

In addition to these major branches, small collateral branches can be found in the intercostal space running along the superior border of the lower rib.

In the thorax, the intercostal nerves carry:

- somatic motor innervation to the muscles of the thoracic wall (intercostal, subcostal, and transversus thoracis muscles);
- somatic sensory innervation from the skin and parietal pleura; and
- postganglionic sympathetic fibers to the periphery.

Sensory innervation from the skin overlying the upper thoracic wall is supplied by cutaneous branches (supraclavicular nerves), which descend from the cervical plexus in the neck.

In addition to innervating the thoracic wall, intercostal nerves innervate other regions:

- the anterior ramus of T1 contributes to the brachial plexus;
- the lateral cutaneous branch of the second intercostal nerve (the intercostobrachial nerve) contributes to cutaneous innervation of the medial surface of the upper arm;
- the lower intercostal nerves supply muscles, skin, and peritoneum of the abdominal wall.

![Fig. 3.32 Intercostal nerves.](image-url)
Thorax

In the clinic

Surgical access to the chest
A surgical access is potentially more challenging in the chest given the rigid nature of the thoracic cage. Moreover, access is also dependent upon the organ which is operated upon and its relationships to subdiaphragmatic structures and structures in the neck. Minimally invasive thoracic surgery (video-assisted thoracic surgery [VATS]) involves making small (1 cm) incisions in the intercostal spaces, placing a small camera on a telescope, and manipulating other instruments through additional small incisions. A number of procedures can be performed in this manner, including lobectomy, lung biopsy, and esophagectomy. A standard incision site would include a medium sternotomy to obtain access to the heart, including the coronary arteries and the cardiac valves.

A left lateral thoracotomy or a right lateral thoracotomy is an incision through an intercostal space to access the lungs and the medial sternum structures.

In the clinic

Chest drain (tube) insertion
Insertion of a chest drain (tube) is commonly performed procedure and is indicated in the presence of pneumothorax, malignant pleural effusion, empyema, hemopneumothorax and postoperatively after thoracic surgery.

The position of the chest drain (tube) is determined by the “safe triangle.” This triangle is formed by the anterior border of the latissimus dorsi, the lateral border of the pectoralis major muscle, aligned superior to the horizontal level of the nipple, and the apex below the axilla. The position of the ribs in this region should be clearly marked. Anesthetic should be applied to the superior border of the rib and the inferior aspect of the intercostal space. The neurovascular bundle runs in the neurovascular plane, which lies in the superior aspect of the intercostal space, hence the reason for positioning of the tube on the superior border of a rib (i.e., at the lowest position in the intercostal space).

DIAPHRAGM

The diaphragm is a thin musculotendinous structure that fills the inferior thoracic aperture and separates the thoracic cavity from the abdominal cavity (Fig. 3.33 and see Chapter 4). It is attached peripherally to the:

- xiphoid process of the sternum;
- costal margin of the thoracic wall;
- ends of ribs XI and XII;
- ligaments that span across structures of the posterior abdominal wall; and
- vertebrae of the lumbar region.

From these peripheral attachments, muscle fibers converge to join the central tendon. The pericardium is attached to the middle part of the central tendon.

In the median sagittal plane, the diaphragm slopes inferiorly from its anterior attachment to the xiphoid, approximately at vertebral level TVIII/IX, to its posterior attachment to the median arcuate ligament, crossing anteriorly to the aorta at approximately vertebral level TXII.

Structures traveling between the thorax and abdomen pass through the diaphragm or between the diaphragm and its peripheral attachments.
the inferior vena cava passes through the central tendon at approximately vertebral level TVIII;
the esophagus passes through the muscular part of the diaphragm, just to the left of midline, approximately at vertebral level TX;
the vagus nerves pass through the diaphragm with the esophagus;
the aorta passes behind the posterior attachment of the diaphragm at vertebral level TXII;
the thoracic duct passes behind the diaphragm with the aorta;
the azygos and hemi-azygos veins may also pass through the aortic hiatus or through the crura of the diaphragm.

Other structures outside the posterior attachments of the diaphragm lateral to the aortic hiatus include the sympathetic trunks and the least splanchnic nerves. The greater and lesser splanchnic nerves penetrate the crura.

**Arterial supply**

The arterial supply to the diaphragm is from vessels that arise superiorly and inferiorly to it. From above, pericardiophrenic and musculophrenic arteries supply the diaphragm. These vessels are branches of the internal thoracic arteries. **Superior phrenic arteries**, which arise directly from lower parts of the thoracic aorta, and small branches...
from intercostal arteries contribute to the supply. The largest arteries supplying the diaphragm arise from below it. These arteries are the **inferior phrenic arteries**, which branch directly from the abdominal aorta.

**Venous drainage**
Venous drainage of the diaphragm is by veins that generally parallel the arteries. The veins drain into:

- the brachiocephalic veins in the neck;
- the **azygos system of veins**; or
- abdominal veins (left suprarenal vein and inferior vena cava).

**Innervation**
The diaphragm is innervated by the **phrenic nerves** (C3 to C5), which penetrate the diaphragm and innervate it from its abdominal surface.

Contraction of the domes of the diaphragm flattens the diaphragm, so increasing thoracic volume. Movements of the diaphragm are essential for normal breathing.

**MOVEMENTS OF THE THORACIC WALL AND DIAPHRAGM DURING BREATHING**

One of the principal functions of the thoracic wall and the diaphragm is to alter the volume of the thorax and thereby move air in and out of the lungs.

During breathing, the dimensions of the thorax change in the vertical, lateral, and anteroposterior directions. Elevation and depression of the diaphragm significantly alter the vertical dimensions of the thorax. Depression results when the muscle fibers of the diaphragm contract. Elevation occurs when the diaphragm relaxes.

Changes in the anteroposterior and lateral dimensions result from elevation and depression of the ribs (Fig. 3.34). The posterior ends of the ribs articulate with the vertebral column, whereas the anterior ends of most ribs articulate with the sternum or adjacent ribs.

Because the anterior ends of the ribs are inferior to the posterior ends, when the ribs are elevated, they move the sternum upward and forward. Also, the angle between the body of the sternum and the manubrium may become slightly less acute. When the ribs are depressed, the sternum moves downward and backward. This “pump handle” movement changes the dimensions of the thorax in the anteroposterior direction (Fig. 3.34A).

As well as the anterior ends of the ribs being lower than the posterior ends, the middles of the shafts tend to be lower than the two ends. When the shafts are elevated, the
middles of the shafts move laterally. This “bucket handle” movement increases the lateral dimensions of the thorax (Fig. 3.34B).

Any muscles attaching to the ribs can potentially move one rib relative to another and therefore act as accessory respiratory muscles. Muscles in the neck and the abdomen can fix or alter the positions of upper and lower ribs.

**PLEURAL CAVITIES**

Two **pleural cavities**, one on either side of the mediastinum, surround the lungs (Fig. 3.35):

- superiorly, they extend above rib I into the root of the neck;
- inferiorly, they extend to a level just above the costal margin;
- the medial wall of each pleural cavity is the mediastinum (see p. 000).

**Pleura**

Each pleural cavity is lined by a single layer of flat cells, mesothelium, and an associated layer of supporting connective tissue; together, they form the pleura.

The **pleura** is divided into two major types, based on location:

- pleura associated with the walls of a pleural cavity is **parietal pleura**;
- pleura that reflects from the medial wall and onto the surface of the lung is **visceral pleura** (Fig. 3.35), which adheres to and covers the lung.

Each pleural cavity is the potential space enclosed between the visceral and parietal pleurae. They normally contain only a very thin layer of serous fluid. As a result, the surface of the lung, which is covered by visceral pleura, directly opposes and freely slides over the parietal pleura attached to the wall.

**Parietal pleura**

The names given to the parietal pleura correspond to the parts of the wall with which they are associated (Fig. 3.36):

- pleura related to the ribs and intercostal spaces is termed the **costal part**;
- pleura covering the diaphragm is the **diaphragmatic part**;
- pleura covering the mediastinum is the **mediastinal part**;
- the dome-shaped layer of parietal pleura lining the cervical extension of the pleural cavity is **cervical pleura** (dome of pleura or pleural cupola).

Covering the superior surface of the cervical pleura is a distinct dome-like layer of fascia, the **suprapleural membrane** (Fig. 3.36). This connective tissue membrane is attached laterally to the medial margin of the first rib and behind to the transverse process of vertebra CVII. Superiorly, the membrane receives muscle fibers from some of the deep muscles in the neck (scalene muscles) that function to keep the membrane taught. The suprapleural membrane provides apical support for the pleural cavity in the root of the neck.

In the region of vertebrae TV to TVII, the mediastinal pleura reflects off the mediastinum as a tubular, sleeve-like
covering for structures (i.e., airway, vessels, nerves, lymphatics) that pass between the lung and mediastinum. This sleeve-like covering, and the structures it contains, forms the **root of the lung**. The root joins the medial surface of the lung at an area referred to as the **hilum of lung**. Here, the mediastinal pleura is continuous with the visceral pleura.

The parietal pleural is innervated by somatic afferent fibers. The costal pleura is innervated by branches from the intercostal nerves and pain would be felt in relation to the thoracic wall. The diaphragmatic pleura and the mediastinal pleura are innervated mainly by the phrenic nerves (originating at spinal cord levels C3, C4 and C5). Pain from these areas would refer to the C3, C4 and C5 dermatomes (lateral neck and the supraclavicular region of the shoulder).

**Peripheral reflections**

The peripheral reflections of parietal pleura mark the extent of the pleural cavities (Fig. 3.37).
Superiorly, the pleural cavity can project as much as 3–4 cm above the first costal cartilage, but does not extend above the neck of rib I. This limitation is caused by the inferior slope of rib I to its articulation with the manubrium.

Anteriorly, the pleural cavities approach each other posterior to the upper part of the sternum. However, posterior to the lower part of the sternum, the parietal pleura does not come as close to the midline on the left side as it does on the right because the middle mediastinum, containing the pericardium and heart, bulges to the left.

Inferiorly, the costal pleura reflects onto the diaphragm above the costal margin. In the midclavicular line, the pleural cavity extends inferiorly to approximately rib VIII. In the midaxillary line, it extends to rib X. From this point, the inferior margin courses somewhat horizontally, crossing ribs XI and XII to reach vertebra TXII. From the midclavicular line to the vertebral column, the inferior boundary of the pleura can be approximated by a line that runs between the rib VIII, rib X, and vertebra TXII.

**Visceral pleura**

Visceral pleura is continuous with parietal pleura at the hilum of each lung where structures enter and leave the organ. The visceral pleura is firmly attached to the surface of the lung, including both opposed surfaces of the fissures that divide the lungs into lobes.

Although the visceral pleura is innervated by visceral afferent nerves that accompany bronchial vessels, pain is generally no elicited from this tissue.
Pleural recesses
The lungs do not completely fill the anterior or posterior inferior regions of the pleural cavities (Fig. 3.38). This results in recesses in which two layers of parietal pleura become opposed. Expansion of the lungs into these spaces usually occurs only during forced inspiration; the recesses also provide potential spaces in which fluids can collect and from which fluids can be aspirated.

Costomediastinal recesses
Anteriorly, a costomediastinal recess occurs on each side where costal pleura is opposed to mediastinal pleura. The largest is on the left side in the region overlying the heart.

Costodiaphragmatic recesses
The largest and clinically most important recesses are the costodiaphragmatic recesses, which occur in each pleural cavity between the costal pleura and diaphragmatic pleura (Fig. 3.38). The costodiaphragmatic recesses are the regions between the inferior margin of the lungs and inferior margin of the pleural cavities. They are deepest after forced expiration and shallowest after forced inspiration.

During quiet respiration, the inferior margin of the lung crosses rib VI in the midclavicular line, rib VIII in the midaxillary line, and then courses somewhat horizontally to reach the vertebral column at vertebral level TX. From the midclavicular line and around the thoracic wall to the vertebral column, the inferior margin of the lung can be approximated by a line running between rib VI, rib VIII, and vertebra TX. The inferior margin of the pleural cavity at the same points is rib VIII, rib X, and vertebra TXII. The costodiaphragmatic recess is the region between the two margins.

During expiration, the inferior margin of the lung rises and the costodiaphragmatic recess becomes larger.
Lungs

The two lungs are organs of respiration and lie on either side of the mediastinum surrounded by the right and left pleural cavities. Air enters and leaves the lungs via main bronchi, which are branches of the trachea.

The pulmonary arteries deliver deoxygenated blood to the lungs from the right ventricle of the heart. Oxygenated blood returns to the left atrium via the pulmonary veins.

The right lung is normally a little larger than the left lung because the middle mediastinum, containing the heart, bulges more to the left than to the right.

Each lung has a half-cone shape, with a base, apex, two surfaces, and three borders (Fig. 3.39).

- The base sits on the diaphragm.
- The apex projects above rib I and into the root of the neck.
- The two surfaces—the costal surface lies immediately adjacent to the ribs and intercostal spaces of the thoracic wall. The mediastinal surface lies against the mediastinum anteriorly and the vertebral column posteriorly and contains the comma-shaped hilum of the lung through which structures enter and leave.
- The three borders—the inferior border of the lung is sharp and separates the base from the costal surface. The anterior and posterior borders separate the costal surface from the medial surface. Unlike the anterior and inferior borders, which are sharp, the posterior border is smooth and rounded.

The lungs lie directly adjacent to, and are indented by, structures contained in the overlying area. The heart and major vessels form bulges in the mediastinum that indent the medial surfaces of the lung; the ribs indent the costal surfaces. Pathology, such as tumors, or abnormalities in one structure can affect the related structure.

Root and hilum

The root of each lung is a short tubular collection of structures that together attach the lung to structures in the mediastinum (Fig. 3.40). It is covered by a sleeve of medi-
astinal pleura that reflects onto the surface of the lung as visceral pleura. The region outlined by this pleural reflection on the medial surface of the lung is the hilum, where structures enter and leave.

A thin blade-like fold of pleura projects inferiorly from the root of the lung and extends from the hilum to the mediastinum. This structure is the pulmonary ligament. It may stabilize the position of the inferior lobe and may also accommodate the down-and-up translocation of structures in the root during breathing.

In the mediastinum, the vagus nerves pass immediately posterior to the roots of the lungs, while the phrenic nerves pass immediately anterior to them.

Within each root and located in the hilum are:

- a pulmonary artery;
- two pulmonary veins;
- a main bronchus;
- bronchial vessels;
- nerves; and
- lymphatics.

Generally, the pulmonary artery is superior at the hilum, the pulmonary veins are inferior, and the bronchi are somewhat posterior in position.

On the right side, the lobar bronchus to the superior lobe branches from the main bronchus in the root, unlike on the left where it branches within the lung itself, and is superior to the pulmonary artery.

**Right lung**

The right lung has three lobes and two fissures (Fig. 3.41A). Normally, the lobes are freely movable against each other because they are separated, almost to the hilum, by invaginations of visceral pleura. These invaginations form the fissures:

- the oblique fissure separates the inferior lobe (lower lobe) from the superior lobe and the middle lobe of the right lung;
- the horizontal fissure separates the superior lobe (upper lobe) from the middle lobe.
Fig. 3.41 A. Right lung. B. Major structures related to the right lung.
The approximate position of the oblique fissure on a patient, in quiet respiration, can be marked by a curved line on the thoracic wall that begins roughly at the spinous process of vertebra TIV level of the spine, crosses the fifth interspace laterally, and then follows the contour of rib VI anteriorly (see p. 000).

The horizontal fissure follows the fourth intercostal space from the sternum until it meets the oblique fissure as it crosses rib V.

The orientations of the oblique and horizontal fissures determine where clinicians should listen for lung sounds from each lobe.

The largest surface of the superior lobe is in contact with the upper part of the anterolateral wall and the apex of this lobe projects into the root of the neck. The surface of the middle lobe lies mainly adjacent to the lower anterior and lateral wall. The costal surface of the inferior lobe is in contact with the posterior and inferior walls.

When listening to lung sounds from each of the lobes, it is important to position the stethoscope on those areas of the thoracic wall related to the underlying positions of the lobes (see p. 000).

The medial surface of the right lung lies adjacent to a number of important structures in the mediastinum and the root of the neck (Fig. 3.41B). These include the:

- heart,
- inferior vena cava,
- superior vena cava,
- azygos vein, and
- esophagus.

The right subclavian artery and vein arch over and are related to the superior lobe of the right lung as they pass over the dome of cervical pleura and into the axilla.

**Left lung**

The left lung is smaller than the right lung and has two lobes separated by an oblique fissure (Fig. 3.42A). The oblique fissure of the left lung is slightly more oblique than the corresponding fissure of the right lung.

During quiet respiration, the approximate position of the left oblique fissure can be marked by a curved line on the thoracic wall that begins between the spinous processes of vertebrae TIII and TIV, crosses the fifth interspace laterally, and follows the contour of rib VI anteriorly (see p. 000).

As with the right lung, the orientation of the oblique fissure determines where to listen for lung sounds from each lobe.

The largest surface of the superior lobe is in contact with the upper part of the anterolateral wall, and the apex of this lobe projects into the root of the neck. The costal surface of the inferior lobe is in contact with the posterior and inferior walls.

When listening to lung sounds from each of the lobes, the stethoscope should be placed on those areas of the thoracic wall related to the underlying positions of the lobes (see p. 000).

The inferior portion of the medial surface of the left lung, unlike the right lung, is notched because of the heart’s projection into the left pleural cavity from the middle mediastinum.

From the anterior border of the lower part of the superior lobe a tongue-like extension (the **lingula of left lung**) projects over the heart bulge.

The medial surface of the left lung lies adjacent to a number of important structures in the mediastinum and root of the neck (Fig. 3.42B). These include the:

- heart,
- aortic arch,
- thoracic aorta, and
- esophagus.

The left subclavian artery and vein arch over and are related to the superior lobe of the left lung as they pass over the dome of cervical pleura and into the axilla.
Fig. 3.42  A. Left lung. B. Major structures related to the left lung.
Bronchial tree

The **trachea** is a flexible tube that extends from vertebral level CVI in the lower neck to vertebral level TIV/V in the mediastinum where it bifurcates into a right and a left main bronchus (Fig. 3.43). The trachea is held open by C-shaped transverse cartilage rings embedded in its wall—the open part of the C facing posteriorly. The lowest tracheal ring has a hook-shaped structure, the carina, that projects...
backwards in the midline between the origins of the two main bronchi. The posterior wall of the trachea is composed mainly of smooth muscle.

Each main bronchus enters the root of a lung and passes through the hilum into the lung itself. The right main bronchus is wider and takes a more vertical course through the root and hilum than the left main bronchus (Fig. 3.43A). Therefore, inhaled foreign bodies tend to lodge more frequently on the right side than on the left.

The main bronchus divides within the lung into lobar bronchi (secondary bronchi), each of which supplies a lobe. On the right side, the lobar bronchi to the superior lobe originates within the root of the lung. The lobar bronchi further divide into segmental bronchi (tertiary bronchi), which supply bronchopulmonary segments (Fig. 3.43B).

Within each bronchopulmonary segment, the segmental bronchi give rise to multiple generations of divisions and, ultimately, to bronchioles, which further subdivide and supply the respiratory surfaces. The walls of the bronchi are held open by discontinuous elongated plates of cartilage, but these are not present in bronchioles.

**Bronchopulmonary segments**

A bronchopulmonary segment is the area of lung supplied by a segmental bronchus and its accompanying pulmonary artery branch.

Tributaries of the pulmonary vein tend to pass intersegmentally between and around the margins of segments.

Each bronchopulmonary segment is shaped like an irregular cone with the apex at the origin of the segmental bronchus and the base projected peripherally onto the surface of the lung.

A bronchopulmonary segment is the smallest, functionally independent region of a lung and the smallest area of lung that can be isolated and removed without affecting adjacent regions.

There are ten bronchopulmonary segments in each lung (Fig. 3.44); some of them fuse in the left lung.

**Pulmonary arteries**

The right and left pulmonary arteries originate from the pulmonary trunk and carry deoxygenated blood to the lungs from the right ventricle of the heart (Fig. 3.45).

The bifurcation of the pulmonary trunk occurs to the left of the midline just inferior to vertebral level TIV/V, and anteroinferiorly to the left of the bifurcation of the trachea.

**Right pulmonary artery**

The right pulmonary artery is longer than the left and passes horizontally across the mediastinum (Fig. 3.45). It passes:

- anteriorly and slightly inferiorly to the tracheal bifurcation and anteriorly to the right main bronchus; and
- posteriorly to the ascending aorta, superior vena cava, and upper right pulmonary vein.

The right pulmonary artery enters the root of the lung and gives off a large branch to the superior lobe of the lung. The main vessel continues through the hilum of the lung, gives off a second (recurrent) branch to the superior lobe, and then divides to supply the middle and inferior lobes.

**Left pulmonary artery**

The left pulmonary artery is shorter than the right and lies anterior to the descending aorta and posterior to the superior pulmonary vein (Fig. 3.45). It passes through the root and hilum and branches within the lung.

**Pulmonary veins**

On each side a superior pulmonary vein and an inferior pulmonary vein carry oxygenated blood from the lungs back to the heart (Fig. 3.45). The veins begin at the hilum of the lung, pass through the root of the lung, and immediately drain into the left atrium.

**Bronchial arteries and veins**

The bronchial arteries (Fig. 3.45) and veins constitute the “nutritive” vascular system of the pulmonary tissues (bronchial walls and glands, walls of large vessels, and visceral pleura). They interconnect within the lung with branches of the pulmonary arteries and veins.

The bronchial arteries originate from the thoracic aorta or one of its branches:

- a single right bronchial artery normally arises from the third posterior intercostal artery (but occasionally, it originates from the upper left bronchial artery);
- two left bronchial arteries arise directly from the anterior surface of the thoracic aorta—the superior left bronchial artery arises at vertebral level TV, and the inferior one inferior to the left bronchus.

The bronchial arteries run on the posterior surfaces of the bronchi and ramify in the lungs to supply pulmonary tissues.

The bronchial veins drain into:

- either the pulmonary veins or the left atrium; and
- into the azygos vein on the right or into the superior intercostal vein or hemiazygos vein on the left.
Fig. 3.44 Bronchopulmonary segments. A. Right lung. B. Left lung. (Bronchopulmonary segments are numbered and named.)
Fig. 3.45 Pulmonary vessels. **A.** Diagram of an anterior view. **B.** Axial computed tomography image showing the left pulmonary artery branching from the pulmonary trunk. **C.** Axial computed tomography image (just inferior to the image in **B**) showing the right pulmonary artery branching from the pulmonary trunk.
Innervation

Structures of the lung, and the visceral pleura, are supplied by visceral afferents and efferents distributed through the anterior pulmonary plexus and posterior pulmonary plexus (Fig. 3.46). These interconnected plexuses lie anteriorly and posteriorly to the tracheal bifurcation and main bronchi. The anterior plexus is much smaller than the posterior plexus.

Branches of these plexuses, which ultimately originate from the sympathetic trunks and vagus nerves, are distributed along branches of the airway and vessels.

Visceral efferents from:
- the vagus nerves constrict the bronchioles;
- the sympathetic system dilate the bronchioles.

Lymphatic drainage

Superficial, or subpleural, and deep lymphatics of the lung drain into lymph nodes called tracheobronchial nodes around the roots of lobar and main bronchi and along the sides of the trachea (Fig. 3.47). As a group, these lymph nodes extend from within the lung, through the hilum and root, and into the posterior mediastinum.

Efferent vessels from these nodes pass superiorly along the trachea to unite with similar vessels from parasternal nodes and brachiocephalic nodes, which are anterior to brachiocephalic veins in the superior mediastinum, to form the right and left bronchomediastinal trunks. These trunks drain directly into deep veins at the base of the neck, or may drain into the right lymphatic trunk or thoracic duct.
Fig. 3.47 Lymphatic drainage of lungs.
Imaging the lungs
Medical imaging of the lungs is important because they are one of the commonest sites for disease in the body. While the body is at rest, the lungs exchange up to 5 L of air per minute, and this may contain pathogens and other potentially harmful elements (e.g., allergens). Techniques to visualize the lung range from plain chest radiographs to high-resolution computed tomography (CT), which enables precise localization of a lesion within the lung.

High-resolution lung CT
High-resolution computed tomography (HRCT) is a diagnostic method for assessing the lungs but more specifically the interstitium of the lungs. The technique involves obtaining narrow cross-sectional slices of 1 to 2 mm. These scans enable the physician and radiologist to view the patterns of disease and their distribution. Diseases that may be easily demonstrated using this procedure include emphysema, pneumoconiosis (coal worker’s pneumoconiosis), and asbestosis.

Bronchoscopy
Patients who have an endobronchial lesion (i.e., a lesion within a bronchus) may undergo bronchoscopic evaluation of the trachea and its main branches (Fig. 3.48). The bronchoscope is passed through the nose into the oropharynx and is then directed by a control system past the vocal cords into the trachea. The bronchi are inspected and, if necessary, small biopsies are obtained.

Fig. 3.48 Bronchoscopic evaluation. A. Of the lower end of the trachea and its main branches. B. Of tracheal bifurcation showing a tumor at the carina.
In the clinic

Lung cancer
It is important to stage lung cancer because the treatment depends on its stage.

If a small malignant nodule is found within the lung, it can sometimes be excised and the prognosis is excellent. Unfortunately, many patients present with a tumor mass that has invaded structures in the mediastinum or the pleurae or has metastasized. The tumor may then be inoperable and is treated with radiotherapy and chemotherapy.

Spread of the tumor is by lymphatics to lymph nodes within the hila, mediastinum, and root of the neck.

A key factor affecting the prognosis and ability to cure the disease is the distant spread of metastases. Imaging methods to assess spread include plain radiography (Fig. 3.49A), computed tomography (CT; Fig. 3.49B) and magnetic resonance imaging (MRI). Increasingly, radionuclide studies using fluorodeoxyglucose positron emission tomography (FDG PET; Fig. 3.49C) are being used.

In FDG PET a gamma radiation emitter is attached to a glucose molecule. In areas of excessive metabolic activity (i.e., the tumor), excessive uptake occurs and is recorded by a gamma camera.

Fig. 3.49 Imaging of the lungs. A. Standard posterior–anterior view of the chest showing tumor in upper right lung. B. Axial CT image of lungs showing tumor in right lung. C. Radionuclide study using FDG PET showing a tumor in the right lung.
MEDIASTINUM

The mediastinum is a broad central partition that separates the two laterally placed pleural cavities (Fig. 3.50). It extends:

- from the sternum to the bodies of the vertebrae; and
- from the superior thoracic aperture to the diaphragm (Fig. 3.51).

The mediastinum contains the thymus gland, the pericardial sac, the heart, the trachea, and the major arteries and veins.

Additionally, the mediastinum serves as a passageway for structures such as the esophagus, thoracic duct, and various components of the nervous system as they traverse the thorax on their way to the abdomen.

For organizational purposes, the mediastinum is subdivided into several smaller regions. A transverse plane extending from the sternal angle (the junction between the manubrium and the body of the sternum) to the intervertebral disc between vertebrae TIV and TV separates the mediastinum into the:

- superior mediastinum; and
- inferior mediastinum, which is further partitioned into the anterior, middle, and posterior mediastinum by the pericardial sac.

The area anterior to the pericardial sac and posterior to the body of the sternum is the anterior mediastinum. The region posterior to the pericardial sac and the diaphragm and anterior to the bodies of the vertebrae is the posterior mediastinum. The area in the middle, which includes the pericardial sac and its contents, is the middle mediastinum (Fig. 3.52).
Middle mediastinum

The middle mediastinum is centrally located in the thoracic cavity. It contains the pericardium, heart, origins of the great vessels, various nerves, and smaller vessels.

Pericardium

The pericardium is a fibroserous sac surrounding the heart and the roots of the great vessels. It consists of two components, the fibrous pericardium and the serous pericardium (Fig. 3.53).

The fibrous pericardium is a tough connective tissue outer layer that defines the boundaries of the middle mediastinum. The serous pericardium is thin and consists of two parts:

- the parietal layer lines the inner surface of the fibrous;
- the visceral layer (epicardium) of serous pericardium adheres to the heart and forms its outer covering.

The parietal and visceral layers of serous pericardium are continuous at the roots of the great vessels. The narrow space created between the two layers of serous pericardium, containing a small amount of fluid, is the pericardial cavity. This potential space allows for the relatively uninhibited movement of the heart.

Fibrous pericardium

The fibrous pericardium is a cone-shaped bag with its base on the diaphragm and its apex continuous with the adventitia of the great vessels (Fig. 3.53). The base is attached to the central tendon of the diaphragm and to a small muscular area of the diaphragm on the left side. Anteriorly, it is attached to the posterior surface of the sternum by sternopericardial ligaments. These attachments help to retain the heart in its position in the thoracic cavity. The sac also limits cardiac distention.

The phrenic nerves, which innervate the diaphragm and originate from spinal cord levels C3 to C5, pass through the fibrous pericardium and innervate the fibrous pericardium as they travel from their point of origin to their final destination (Fig. 3.54). Their location, within the fibrous pericardium, is directly related to the embryological origin of the diaphragm and the changes that occur during the formation of the pericardial cavity. Similarly, the pericardio-phrenic vessels are also located within and supply the fibrous pericardium as they pass through the thoracic cavity.
Serous pericardium

The parietal layer of serous pericardium is continuous with the visceral layers of serous pericardium around the roots of the great vessels. These reflections of serous pericardium (Fig. 3.55) occur in two locations:

- one superiorly, surrounding the arteries, the aorta and pulmonary trunk;
- the second more posteriorly, surrounding the veins, the superior and inferior vena cava and the pulmonary veins.

The zone of reflection surrounding the veins is J-shaped, and the cul-de-sac formed within the J, posterior to the left atrium, is the oblique pericardial sinus.

A passage between the two sites of reflected serous pericardium is the transverse pericardial sinus. This sinus lies posteriorly to the ascending aorta and the pulmonary trunk, anteriorly to the superior vena cava, and superiorly to the left atrium.

When the pericardium is opened anteriorly during surgery, a finger placed in the transverse sinus separates arteries from veins. A hand placed under the apex of the heart and moved superiorly slips into the oblique sinus.

Vessels and nerves

The pericardium is supplied by branches from the internal thoracic, pericardiophrenic, musculophrenic, and inferior phrenic arteries, and the thoracic aorta.

Veins from the pericardium enter the azygos system of veins and the internal thoracic and superior phrenic veins.
Pericarditis is an inflammatory condition of the pericardium. Common causes are viral and bacterial infections, systemic illnesses (e.g., chronic renal failure) and post–myocardial infarction.

Pericarditis must be distinguished from myocardial infarction because the treatment and prognosis are quite different. As in patients with myocardial infarction, patients with pericarditis complain of continuous central chest pain that may radiate to one or both arms. Unlike myocardial infarction, however, the pain from pericarditis may be relieved by sitting forward. An electrocardiogram (ECG) is used to help differentiate between the two conditions.

In the clinic

Pericarditis
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In the clinic

Pericardial effusion
Normally, only a tiny amount of fluid is present between the visceral and parietal layers of the serous pericardium. In certain situations, this space can be filled with excess fluid (pericardial effusion).

Because the fibrous pericardium is a “relatively fixed” structure that cannot expand easily, a rapid accumulation of excess fluid within the pericardial sac compresses the heart (cardiac tamponade), resulting in biventricular failure. Removing the fluid with a needle inserted into the pericardial sac can relieve the symptoms.

Nerves supplying the pericardium arise from the vagus nerve [X], the sympathetic trunks, and the phrenic nerves.

It is important to note that the source of somatic sensation (pain) from the parietal pericardium is carried by somatic afferent fibers in the phrenic nerves. For this reason, “pain” related to a pericardial problem may be referred to the supraclavicular region of the shoulder or lateral neck area, dermatomes for spinal cord segments C3, C4, and C5.
In the clinic

Constrictive pericarditis
Abnormal thickening of the pericardial sac (constrictive pericarditis) can compress the heart, impairing heart function and resulting in heart failure. The diagnosis is made by inspecting the jugular venous pulse in the neck. In normal individuals, the jugular venous pulse drops on inspiration. In patients with constrictive pericarditis, the reverse happens and this is called Kussmaul’s sign. Treatment often involves surgical opening of the pericardial sac.

Heart

Cardiac orientation
The general shape and orientation of the heart are that of a pyramid that has fallen over and is resting on one of its sides. Placed in the thoracic cavity, the apex of this pyramid projects forward, downward, and to the left, whereas the base is opposite the apex and faces in a posterior direction (Fig. 3.56). The sides of the pyramid consist of:

- a diaphragmatic (inferior) surface on which the pyramid rests;
- an anterior (sternocostal) surface oriented anteriorly;
- a right pulmonary surface; and
- a left pulmonary surface.

Base (posterior surface) and apex
The base of the heart is quadrilateral and directed posteriorly. It consists of:

- the left atrium;
- a small portion of the right atrium; and
- the proximal parts of the great veins (superior and inferior venae cavae and the pulmonary veins) (Fig. 3.57).

Because the great veins enter the base of the heart, with the pulmonary veins entering the right and left sides of the left atrium and the superior and inferior venae cavae at the upper and lower ends of the right atrium, the base of the heart is fixed posteriorly to the pericardial wall, opposite the bodies of vertebrae TV to TVIII (TVI to TIX when standing). The esophagus lies immediately posterior to the base.

From the base the heart projects forward, downward, and to the left, ending in the apex. The apex of the heart is formed by the inferolateral part of the left ventricle (Fig. 3.58) and is positioned deep to the left fifth intercostal space, 8–9 cm from the midsternal line.
Fig. 3.57 Base of the heart.

Fig. 3.58 Anterior surface of the heart.
Surfaces of the heart

The anterior surface faces anteriorly and consists mostly of the right ventricle with some of the right atrium on the right and some of the left ventricle on the left (Fig. 3.58).

The heart in the anatomical position rests on the diaphragmatic surface, which consists of the left ventricle and a small portion of the right ventricle separated by the posterior interventricular groove (Fig. 3.59). This surface faces inferiorly, rests on the diaphragm, is separated from the base of the heart by the coronary sinus, and extends from the base to the apex of the heart.

The left pulmonary surface faces the left lung, is broad and convex, and consists of the left ventricle and a portion of the left atrium (Fig. 3.59).

The right pulmonary surface faces the right lung, is broad and convex, and consists of the right atrium (Fig. 3.59).

Margins and borders

Some general descriptions of cardiac orientation refer to right, left, inferior (acute), and obtuse margins:

- the right and left margins are the same as the right and left pulmonary surfaces of the heart;
- the inferior margin is defined as the sharp edge between the anterior and diaphragmatic surfaces of the heart (Figs 3.56 and 3.58)—it is formed mostly by the right ventricle and a small portion of the left ventricle near the apex; and
- the obtuse margin separates the anterior and left pulmonary surfaces (Fig. 3.56)—it is round and extends from the left auricle to the cardiac apex (Fig. 3.58), and is formed mostly by the left ventricle and superiorly by a small portion of the left auricle.
For radiological evaluations, a thorough understanding of the structures defining the cardiac borders is critical. The right border in a standard posterior–anterior view consists of the superior vena cava, the right atrium, and the inferior vena cava (Fig. 3.60A). The left border in a similar view consists of the arch of the aorta, the pulmonary trunk, and the left ventricle. The inferior border in this radiological study consists of the right ventricle and the left ventricle at the apex. In lateral views, the right ventricle is seen anteriorly, and the left atrium is visualized posteriorly (Fig. 3.60B).

**External sulci**

Internal partitions divide the heart into four chambers (i.e., two atria and two ventricles) and produce surface or external grooves referred to as sulci.

- The **coronary sulcus** circles the heart, separating the atria from the ventricles (Fig. 3.61). As it circles the heart, it contains the right coronary artery, the small cardiac vein, the coronary sinus, and the circumflex branch of the left coronary artery.
- The **anterior and posterior interventricular sulci** separate the two ventricles—the anterior interventricular sulcus is on the anterior surface of the heart and contains the anterior interventricular artery and the great cardiac vein, and the posterior interventricular sulcus is on the diaphragmatic surface of the heart and contains the posterior interventricular artery and the middle cardiac vein.

These sulci are continuous inferiorly, just to the right of the apex of the heart.

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**Fig. 3.60** Chest radiographs. **A.** Standard posterior–anterior view of the chest. **B.** Standard lateral view of the heart.
Fig. 3.61 Sulci of the heart. A. Anterior surface of the heart. B. Diaphragmatic surface and base of the heart.
Cardiac chambers

The heart functionally consists of two pumps separated by a partition (Fig. 3.62A). The right pump receives deoxygenated blood from the body and sends it to the lungs. The left pump receives oxygenated blood from the lungs and sends it to the body. Each pump consists of an atrium and a ventricle separated by a valve.

The thin-walled atria receive blood coming into the heart, whereas the relatively thick-walled ventricles pump blood out of the heart.

More force is required to pump blood through the body than through the lungs, so the muscular wall of the left ventricle is thicker than the right.

Interatrial, interventricular, and atrioventricular septa separate the four chambers of the heart (Fig. 3.62B).
Thorax

The internal anatomy of each chamber is critical to its function.

**Right atrium**

In the anatomical position, the right border of the heart is formed by the right atrium. This chamber also contributes to the right portion of the heart’s anterior surface.

Blood returning to the right atrium enters through one of three vessels. These are:

- the superior and inferior venae cavae, which together deliver blood to the heart from the body; and
- the coronary sinus, which returns blood from the walls of the heart itself.

The superior vena cava enters the upper posterior portion of the right atrium, and the inferior vena cava and coronary sinus enter the lower posterior portion of the right atrium.

From the right atrium, blood passes into the right ventricle through the right atrioventricular orifice. This opening faces forward and medially and is closed during ventricular contraction by the tricuspid valve.

The interior of the right atrium is divided into two continuous spaces. Externally, this separation is indicated by a shallow, vertical groove (the sulcus terminalis cordis), which extends from the right side of the opening of the superior vena cava to the right side of the opening of the inferior vena cava. Internally, this division is indicated by the crista terminalis (Fig. 3.63), which is a smooth, muscular ridge that begins on the roof of the atrium just in front of the opening of the superior vena cava and extends down the lateral wall to the anterior lip of the inferior vena cava.

The space posterior to the crista is the sinus of venae cavae and is derived embryologically from the right horn of the sinus venosus. This component of the right atrium has smooth, thin walls, and both venae cavae empty into this space.

The space anterior to the crista, including the right auricle, is sometimes referred to as the atrium proper. This terminology is based on its origin from the embryonic primitive atrium. Its walls are covered by ridges called the musculi pectinati (pectinate muscles), which fan out...
from the crista like the “teeth of a comb.” These ridges are also found in the right auricle, which is an ear-like, conical, muscular pouch that externally overlaps the ascending aorta.

An additional structure in the right atrium is the **opening of coronary sinus**, which receives blood from most of the cardiac veins and opens medially to the **opening of inferior vena cava**. Associated with these openings are small folds of tissue derived from the valve of the embryonic sinus venosus (the **valve of coronary sinus** and the **valve of inferior vena cava**, respectively). During development, the valve of inferior vena cava helps direct incoming oxygenated blood through the foramen ovale and into the left atrium.

Separating the right atrium from the left atrium is the **interatrial septum**, which faces forward and to the right because the left atrium lies posteriorly and to the left of the right atrium. A depression is clearly visible in the septum just above the orifice of the inferior vena cava. This is the **fossa ovalis** (**oval fossa**), with its prominent margin, the **limbus fossa ovalis** (**border of oval fossa**).

The fossa ovalis marks the location of the embryonic **foramen ovale**, which is an important part of fetal circulation. The foramen ovale allows oxygenated blood entering the right atrium through the inferior vena cava to pass directly to the left atrium and so bypass the lungs, which are nonfunctional before birth.

Finally, numerous small openings—the **openings of the smallest cardiac veins** (**the foramina of the venae cordis minimae**)—are scattered along the walls of the right atrium. These are small veins that drain the myocardium directly into the right atrium.

**Right ventricle**

In the anatomical position, the right ventricle forms most of the anterior surface of the heart and a portion of the diaphragmatic surface. The right atrium is to the right of the right ventricle and the right ventricle is located in front of and to the left of the right atrioventricular orifice. Blood entering the right ventricle from the right atrium therefore moves in a horizontal and forward direction.

The outflow tract of the right ventricle, which leads to the pulmonary trunk, is the **conus arteriosus** (**infundibulum**). This area has smooth walls and derives from the embryonic bulbus cordis.

The walls of the inflow portion of the right ventricle have numerous muscular, irregular structures called **trabeculae carneae** (**Fig. 3.64**). Most of these are either attached to the ventricular walls throughout their length, forming ridges, or attached at both ends, forming bridges.

A few trabeculae carneae (**papillary muscles**) have only one end attached to the ventricular surface, while the other end serves as the point of attachment for tendon-like fibrous cords (**the chordae tendineae**), which connect to the free edges of the cusps of the tricuspid valve.

There are three papillary muscles in the right ventricle. Named relative to their point of origin on the ventricular surface, they are the anterior, posterior, and septal papillary muscles:

- the **anterior papillary muscle** is the largest and most constant papillary muscle, and arises from the anterior wall of the ventricle;
- the **posterior papillary muscle** may consist of one, two, or three structures, with some chordae tendineae arising directly from the ventricular wall;
- the **septal papillary muscle** is the most inconsistent papillary muscle, being either small or absent, with chordae tendineae emerging directly from the septal wall.

A single specialized trabeculum, the **septomarginal trabecula** (**moderator band**), forms a bridge between the lower portion of the **interventricular septum** and the base of the anterior papillary muscle. The septomarginal trabecula carries a portion of the cardiac conduction system, the right bundle of the atrioventricular bundle, to the anterior wall of the right ventricle.

**Tricuspid valve**

The right atrioventricular orifice is closed during ventricular contraction by the **tricuspid valve** (**right atrioventricular valve**), so named because it usually consists of three cusps or leaflets (Fig. 3.64). The base of each cusp is secured to the fibrous ring that surrounds the atrioventricular orifice. This fibrous ring helps to maintain the shape of the opening. The cusps are continuous with each other near their bases at sites termed **commissures**.

The naming of the three cusps, the **anterior**, **septal**, and **posterior cusps**, is based on their relative position in the right ventricle. The free margins of the cusps are attached to the chordae tendineae, which arise from the tips of the papillary muscles.

During filling of the right ventricle, the tricuspid valve is open, and the three cusps project into the right ventricle.

Without the presence of a compensating mechanism, when the ventricular musculature contracts, the valve cusps would be forced upward with the flow of blood and blood would move back into the right atrium. However, contraction of the papillary muscles attached to the cusps by chordae tendineae prevent the cusps from being everted into the right atrium.

Simply put, the papillary muscles and associated chordae tendineae keep the valves closed during the dramatic changes in ventricular size that occur during contraction.
In addition, chordae tendineae from two papillary muscles attach to each cusp. This helps prevent separation of the cusps during ventricular contraction. Proper closing of the tricuspid valve causes blood to exit the right ventricle and move into the pulmonary trunk.

Necrosis of a papillary muscle following a myocardial infarction (heart attack) may result in prolapse of the related valve.

**Pulmonary valve**

At the apex of the infundibulum, the outflow tract of the right ventricle, the opening into the pulmonary trunk is closed by the pulmonary valve (Fig. 3.64), which consists of three semilunar cusps with free edges projecting upward into the lumen of the pulmonary trunk. The free superior edge of each cusp has a middle, thickened portion, the nodule of the semilunar cusp, and a thin lateral portion, the lunula of the semilunar cusp (Fig. 3.65).

The cusps are named the left, right, and anterior semilunar cusps, relative to their fetal position before rotation of the outflow tracks from the ventricles is complete. Each cusp forms a pocket-like sinus (Fig. 3.65)—a
dilation in the wall of the initial portion of the pulmonary trunk. After ventricular contraction, the recoil of blood fills these **pulmonary sinuses** and forces the cusps closed. This prevents blood in the pulmonary trunk from refilling the right ventricle.

**Left atrium**

The **left atrium** forms most of the base or posterior surface of the heart.

As with the right atrium, the left atrium is derived embryologically from two structures.

- The posterior half, or inflow portion, receives the four pulmonary veins (Fig. 3.66). It has smooth walls and derives from the proximal parts of the pulmonary veins that are incorporated into the left atrium during development.
The anterior half is continuous with the left auricle. It contains musculi pectinati and derives from the embryonic primitive atrium. Unlike the crista terminalis in the right atrium, no distinct structure separates the two components of the left atrium.

The interatrial septum is part of the anterior wall of the left atrium. The thin area or depression in the septum is the valve of the foramen ovale and is opposite the floor of the fossa ovalis in the right atrium.

During development, the valve of foramen ovale prevents blood from passing from the left atrium to the right atrium. This valve may not be completely fused in some adults, leaving a “probe patent” passage between the right atrium and the left atrium.

**Left ventricle**

The left ventricle lies anterior to the left atrium. It contributes to the anterior, diaphragmatic, and left pulmonary surfaces of the heart, and forms the apex.

Blood enters the ventricle through the left atrioventricular orifice and flows in a forward direction to the apex. The chamber itself is conical, is longer than the right ventricle, and has the thickest layer of myocardium. The outflow tract (the aortic vestibule) is posterior to the infundibulum of the right ventricle, has smooth walls, and is derived from the embryonic bulbus cordis.

The trabeculae carneae in the left ventricle are fine and delicate in contrast to those in the right ventricle. The general appearance of the trabeculae with muscular ridges and bridges is similar to that of the right ventricle (Fig. 3.67).

Papillary muscles, together with chordae tendineae, are also observed and their structure is as described above for the right ventricle. Two papillary muscles, the anterior and posterior papillary muscles, are usually found in the left ventricle and are larger than those of the right ventricle.

In the anatomical position, the left ventricle is somewhat posterior to the right ventricle. The interventricular septum therefore forms the anterior wall and some of the wall on the right side of the left ventricle. The septum is described as having two parts:

- a muscular part, and
- a membranous part.

![Fig. 3.67 Internal view of the left ventricle.](image-url)
The muscular part is thick and forms the major part of the septum, whereas the membranous part is the thin, upper part of the septum. A third part of the septum may be considered an atrioventricular part because of its position above the septal cusp of the tricuspid valve. This superior location places this part of the septum between the left ventricle and right atrium.

**Mitral valve**

The left atrioventricular orifice opens into the posterior right side of the superior part of the left ventricle. It is closed during ventricular contraction by the mitral valve (left atrioventricular valve), which is also referred to as the bicuspid valve because it has two cusps, the anterior and posterior cusps (Fig. 3.67). The bases of the cusps are secured to a fibrous ring surrounding the opening, and the cusps are continuous with each other at the commissures. The coordinated action of the papillary muscles and chordae tendineae is as described for the right ventricle.

**Aortic valve**

The aortic vestibule, or outflow tract of the left ventricle, is continuous superiorly with the ascending aorta. The opening from the left ventricle into the aorta is closed by the aortic valve. This valve is similar in structure to the pulmonary valve. It consists of three semilunar cusps with the free edge of each projecting upward into the lumen of the ascending aorta (Fig. 3.68).

Between the semilunar cusps and the wall of the ascending aorta are pocket-like sinuses—the right, left, and posterior aortic sinuses. The right and left coronary arteries originate from the right and left aortic sinuses. Because of this, the posterior aortic sinus and cusp are sometimes referred to as the noncoronary sinus and cusp.

The functioning of the aortic valve is similar to that of the pulmonary valve with one important additional process: as blood recoils after ventricular contraction and fills the aortic sinuses, it is automatically forced into the coronary arteries because these vessels originate from the right and left aortic sinuses.

### In the clinic

**Valve disease**

Valve problems consist of two basic types:

- incompetence (insufficiency), which results from poorly functioning valves; and
- stenosis, a narrowing of the orifice, caused by the valve’s inability to open fully.

**Mitral valve disease** is usually a mixed pattern of stenosis and incompetence, one of which usually predominates. Both stenosis and incompetence lead to a poorly functioning valve and subsequent heart changes, which include:

- left ventricular hypertrophy (this is appreciably less marked in patients with mitral stenosis);
- increased pulmonary venous pressure;
- pulmonary edema; and
- enlargement (dilation) and hypertrophy of the left atrium.

**Aortic valve disease**—both aortic stenosis and aortic regurgitation (backflow) can produce marked heart failure.

**Valve disease in the right side of the heart** (affecting the tricuspid or pulmonary valve) is most likely caused by infection. The resulting valve dysfunction produces abnormal pressure changes in the right atrium and right ventricle, and these can induce cardiac failure.
Thorax

In the clinic

Common congenital heart defects
The most common abnormalities that occur during development are those produced by a defect in the atrial and ventricular septa.

A defect in the interatrial septum allows blood to pass from one side of the heart to the other from the chamber with the higher pressure; this is clinically referred to as a shunt. An atrial septal defect (ASD) allows oxygenated blood to flow from the left atrium (higher pressure) across the ASD into the right atrium (lower pressure). Many patients with ASD are asymptomatic, but in some cases the ASD may need to be closed surgically or by endovascular devices. Occasionally, increased blood flow into the right atrium over many years leads to right atrial and right ventricular hypertrophy and enlargement of the pulmonary trunk, resulting in pulmonary arterial hypertension.

The most common of all congenital heart defects are those that occur in the ventricular septum—ventriculoseptal defect (VSD). These lesions are most frequent in the membranous portion of the septum and they allow blood to move from the left ventricle (higher pressure) to the right ventricle (lower pressure); this leads to right ventricular hypertrophy and pulmonary arterial hypertension. If large enough and left untreated, VSDs can produce marked clinical problems that might require surgery.

Occasionally, the ductus arteriosus, which connects the left branch of the pulmonary artery to the inferior aspect of the aortic arch, fails to close at birth. When this occurs, the oxygenated blood in the aortic arch (higher pressure) passes into the left branch of the pulmonary artery (lower pressure) and produces pulmonary hypertension. This is termed a patent or persistent ductus arteriosus (PDA).

All of these defects produce a left-to-right shunt, indicating that oxygenated blood from the left heart is being mixed with deoxygenated blood from the right heart before being recirculated into the pulmonary circulation. These shunts are normally compatible with life, but surgery or endovascular treatment may be necessary.

Rarely, a shunt is right-to-left. In isolation this is fatal; however, this type of shunt is often associated with other anomalies, so some deoxygenated blood is returned to the lungs and the systemic circulation.

Cardiac auscultation
Auscultation of the heart reveals the normal audible cardiac cycle, which allows the clinician to assess heart rate, rhythm, and regularity. Furthermore, cardiac murmurs that have characteristic sounds within the phases of the cardiac cycle can be demonstrated (Fig. 3.69).

Cardiac skeleton
The cardiac skeleton is a collection of dense, fibrous connective tissue in the form of four rings with interconnecting areas in a plane between the atria and the ventricles. The four rings of the cardiac skeleton surround the two atrioventricular orifices, the aortic orifice and opening of the pulmonary trunks. They are the anulus fibrosus. The interconnecting areas include:

- the right fibrous trigone, which is a thickened area of connective tissue between the aortic ring and right atrioventricular ring; and
- the left fibrous trigone, which is a thickened area of connective tissue between the aortic ring and the left atrioventricular ring (Fig. 3.70).
The cardiac skeleton helps maintain the integrity of the
openings it surrounds and provides points of attachment
for the cusps. It also separates the atrial musculature from
the ventricular musculature. The atrial myocardium origi-
nates from the upper border of the rings, whereas the ven-
tricular myocardium originates from the lower border of
the rings.

The cardiac skeleton also serves as a dense connective
tissue partition that electrically isolates the atria from
the ventricles. The atrioventricular bundle, which passes
through the anulus, is the single connection between these
two groups of myocardium.

**Coronary vasculature**

Two coronary arteries arise from the aortic sinuses in the
initial portion of the ascending aorta and supply the muscle
and other tissues of the heart. They circle the heart in the
coronary sulcus, with marginal and interventricular
branches, in the interventricular sulci, converging toward
the apex of the heart (Fig. 3.71).

The returning venous blood passes through cardiac
veins, most of which empty into the coronary sinus. This
large venous structure is located in the coronary sulcus on
the posterior surface of the heart between the left atrium
and left ventricle. The coronary sinus empties into the right
atrium between the opening of the inferior vena cava and
the right atrioventricular orifice.

**Coronary arteries**

*Right coronary artery.* The **right coronary artery** origi-
nates from the right aortic sinus of the ascending aorta. It
passes anteriorly and to the right between the right auricle
and the pulmonary trunk and then descends vertically in
the coronary sulcus, between the right atrium and right
ventricle (Fig. 3.72A). On reaching the inferior margin of
the heart, it turns posteriorly and continues in the sulcus
onto the diaphragmatic surface and base of the heart.
During this course, several branches arise from the main
stem of the vessel:
Fig. 3.71 Cardiac vasculature. A. Anterior view. B. Superior view (atria removed).
Fig. 3.72 A. Anterior view of coronary arterial system. B. Left anterior oblique view of right coronary artery. C. Right anterior oblique view of left coronary artery.
an early atrial branch passes in the groove between the right auricle and ascending aorta, and gives off the sinu-atrial nodal branch, which passes posteriorly around the superior vena cava to supply the sinu-atrial node;

- a right marginal branch is given off as the right coronary artery approaches the inferior (acute) margin of the heart (Fig. 3.72B) and continues along this border toward the apex of the heart;
- as the right coronary artery continues on the base/diaphragmatic surface of the heart, it supplies a small branch to the atrioventricular node before giving off its final major branch, the posterior interventricular branch, which lies in the posterior interventricular sulcus.

The right coronary artery supplies the right atrium and right ventricle, the sinu-atrial and atrioventricular nodes, the interatrial septum, a portion of the left atrium, the posteriorinferior one-third of the interventricular septum, and a portion of the posterior part of the left ventricle.

**Left coronary artery.** The left coronary artery originates from the left aortic sinus of the ascending aorta. It passes between the pulmonary trunk and the left auricle before entering the coronary sulcus. While still posterior to the pulmonary trunk, the artery divides into its two terminal branches, the anterior interventricular and the circumflex (Fig. 3.72A).

- The anterior interventricular branch (left anterior descending artery—LAD) continues around the left side of the pulmonary trunk and descends obliquely toward the apex of the heart in the anterior interventricular sulcus (Fig. 3.72C). During its course, one or two large diagonal branches may arise and descend diagonally across the anterior surface of the left ventricle.

- The circumflex branch courses toward the left, in the coronary sulcus and onto the base/diaphragmatic surface of the heart, and usually ends before reaching the posterior interventricular sulcus. A large branch, the left marginal artery, usually arises from it and continues across the rounded obtuse margin of the heart.

The distribution pattern of the left coronary artery enables it to supply most of the left atrium and left ventricle, and most of the interventricular septum, including the atrioventricular bundle and its branches.

**Variations in the distribution patterns of coronary arteries.** Several major variations in the basic distribution patterns of the coronary arteries occur.

- The distribution pattern described above for both right and left coronary arteries is the most common and consists of a right dominant coronary artery. This means that the posterior interventricular branch arises from the right coronary artery. The right coronary artery therefore supplies a large portion of the posterior wall of the left ventricle and the circumflex branch of the left coronary artery is relatively small.

- In contrast, in hearts with a left dominant coronary artery, the posterior interventricular branch arises from an enlarged circumflex branch and supplies most of the posterior wall of the left ventricle (Fig. 3.73).

- Another point of variation relates to the arterial supply to the sinu-atrial and atrioventricular nodes. In most cases, these two structures are supplied by the right coronary artery. However, vessels from the circumflex branch of the left coronary artery occasionally supply these structures.
Coronary artery disease

Occlusion of a major coronary artery leads to an inadequate oxygenation of an area of myocardium and cell death (i.e., myocardial infarction). The severity depends on the size and location of the artery involved and whether or not the blockage is complete. Partial blockages may produce pain (angina) during or after exercise. The typical symptoms are chest heaviness or pressure, which is severe, lasting more than 20 minutes, and associated with sweating. The pain in the chest (“elephant sitting on my chest” or a clenched fist to describe the pain) often radiates to the arms, especially the left arm, and can be associated with nausea. Men usually experience the classic description. Women are more likely to have atypical features such as a “sharp” quality to the pain, with it localized in the back, shoulder, jaw, neck or epigastrium.

The severity of ischemia and infarction depends on the rate at which the occlusion or stenosis has occurred and whether or not collateral channels have had a chance to develop.

Several procedures are now available to improve blood flow in partially or completely occluded coronary arteries.

- **Coronary angioplasty** is a technique in which a long fine tube (a catheter) is inserted into the femoral artery in the thigh, passed through external and common iliac arteries and into the aorta to the origins of the coronary arteries. A fine wire is then passed into the coronary artery and is used to cross the stenosis. A fine balloon is then passed over the wire and inflated at the level of the obstruction, thus widening it.

- If the coronary artery disease is too severe to be treated by coronary angioplasty, surgical **coronary artery bypass grafting** may be necessary. The great saphenous vein in the lower limb is harvested and used as an autologous graft. It is divided into several pieces, each of which is used to bypass blocked sections of the coronary arteries. The internal thoracic or radial arteries can also be used for this purpose.
The coronary sinus receives four major tributaries: the great, middle, small, and posterior cardiac veins.

**Great cardiac vein.** The great cardiac vein begins at the apex of the heart (Fig. 3.74A). It ascends in the anterior interventricular sulcus, where it is related to the anterior interventricular artery and is often termed the anterior interventricular vein. Reaching the coronary sulcus, the great cardiac vein turns to the left and continues onto the base/diaphragmatic surface of the heart. At this point, it is associated with the circumflex branch of the left coronary artery. Continuing along its path in the coronary sulcus, the great cardiac vein gradually enlarges to form the coronary sinus, which enters the right atrium (Fig. 3.74B).

**Middle cardiac vein.** The middle cardiac vein (posterior interventricular vein) begins near the apex of the heart and ascends in the posterior interventricular sulcus toward the coronary sinus (Fig. 3.74B). It is associated with the posterior interventricular branch of the right or left coronary artery throughout its course.

**Small cardiac vein.** The small cardiac vein begins in the lower anterior section of the coronary sulcus between the right atrium and right ventricle (Fig. 3.74A). It continues in this groove onto the base/diaphragmatic surface of the heart where it enters the coronary sinus at its atrial end. It is a companion of the right coronary artery throughout its course and may receive the right marginal vein (Fig. 3.74A). This small vein accompanies the marginal branch of the right coronary artery along the acute margin of the heart. If the right marginal vein does not join the small cardiac vein, it enters the right atrium directly.

**Posterior cardiac vein.** The posterior cardiac vein lies on the posterior surface of the left ventricle just to the left of the middle cardiac vein (Fig. 3.74B). It either enters the coronary sinus directly or joins the great cardiac vein.

**Other cardiac veins.** Two additional groups of cardiac veins are also involved in the venous drainage of the heart.

- The anterior veins of right ventricle (anterior cardiac veins) are small veins that arise on the anterior surface of the right ventricle (Fig. 3.74A). They cross the coronary sulcus and enter the anterior wall of the right atrium. They drain the anterior portion of the right ventricle. The right marginal vein may be part of this group if it does not enter the small cardiac vein.
- A group of smallest cardiac veins (venae cordis minimae or veins of Thebesius) have also been described. Draining directly into the cardiac chambers, they are numerous in the right atrium and right ventricle, are occasionally associated with the left atrium, and are rarely associated with the left ventricle.
Fig. 3.74 Major cardiac veins. A. Anterior view of major cardiac veins. B. Posteroinferior view of major cardiac veins.
Coronary lymphatics

The lymphatic vessels of the heart follow the coronary arteries and drain mainly into:

- brachiocephalic nodes, anterior to the brachiocephalic veins; and
- tracheobronchial nodes, at the inferior end of the trachea.

Cardiac conduction system

The musculature of the atria and ventricles is capable of contracting spontaneously. The cardiac conduction system initiates and coordinates contraction. The conduction system consists of nodes and networks of specialized cardiac muscle cells organized into four basic components:

- the sinu-atrial node;
- the atrioventricular node;
- the atrioventricular bundle with its right and left bundle branches;
- the subendocardial plexus of conduction cells (the Purkinje fibers).

The unique distribution pattern of the cardiac conduction system establishes an important unidirectional pathway of excitation/contraction. Throughout its course, large branches of the conduction system are insulated from the surrounding myocardium by connective tissue. This tends to decrease inappropriate stimulation and contraction of cardiac muscle fibers.

The number of functional contacts between the conduction pathway and cardiac musculature greatly increases in the subendocardial network.

Thus, a unidirectional wave of excitation and contraction is established, which moves from the papillary muscles and apex of the ventricles to the arterial outflow tracts.

In the clinic

Cardiac conduction system

The cardiac conduction system can be affected by coronary artery disease. The normal rhythm may be disturbed if the blood supply to the coronary conduction system is disrupted. If a dysrhythmia affects the heart rate or the order in which the chambers contract, heart failure and death may ensue.

Sinu-atrial node

Impulses begin at the sinu-atrial node, the cardiac pacemaker. This collection of cells is located at the superior end of the crista terminalis at the junction of the superior vena cava and the right atrium (Fig. 3.75A). This is also the junction between the parts of the right atrium derived from the embryonic sinus venosus and the atrium proper.

The excitation signals generated by the sinu-atrial node spread across the atria, causing the muscle to contract.

Atrioventricular node

Concurrently, the wave of excitation in the atria stimulates the atrioventricular node, which is located near the opening of the coronary sinus, close to the attachment of the septal cusp of the tricuspid valve, and within the atrioventricular septum (Fig. 3.75A).

The atrioventricular node is a collection of specialized cells that forms the beginning of an elaborate system of conducting tissue, the atrioventricular bundle, which extends the excitatory impulse to all ventricular musculature.

Atrioventricular bundle

The atrioventricular bundle is a direct continuation of the atrioventricular node (Fig. 3.75A). It follows along the lower border of the membranous part of the interventricular septum before splitting into right and left bundles.

The right bundle branch continues on the right side of the interventricular septum toward the apex of the right ventricle. From the septum it enters the septomarginal trabecula to reach the base of the anterior papillary muscle. At this point, it divides and is continuous with the final component of the cardiac conduction system, the subendocardial plexus of ventricular conduction cells or Purkinje fibers. This network of specialized cells spreads throughout the ventricle to supply ventricular musculature including the papillary muscles.

The left bundle branch passes to the left side of the muscular interventricular septum and descends to the apex of the left ventricle (Fig. 3.75B). Along its course it gives off branches that eventually become continuous with the subendocardial plexus of conduction cells (Purkinje fibers). As with the right side, this network of specialized cells spreads the excitation impulses throughout the left ventricle.

Cardiac innervation

The autonomic division of the peripheral nervous system is directly responsible for regulating:

- heart rate;
- force of each contraction; and
- cardiac output.
Fig. 3.75 Conduction system of the heart. A. Right chambers. B. Left chambers.
Thorax

Branches from both the parasympathetic and sympathetic systems contribute to the formation of the **cardiac plexus**. This plexus consists of a **superficial part**, inferior to the aortic arch and between it and the pulmonary trunk (Fig. 3.76A), and a **deep part**, between the aortic arch and the tracheal bifurcation (Fig. 3.76B).

From the cardiac plexus, small branches that are mixed nerves containing both sympathetic and parasympathetic fibers supply the heart. These branches affect nodal tissue and other components of the conduction system, coronary blood vessels, and atrial and ventricular musculature.

**Fig. 3.76** Cardiac plexus. A. Superficial. B. Deep.
Parasympathetic innervation
Stimulation of the parasympathetic system:
- decreases heart rate;
- reduces force of contraction; and
- constricts the coronary arteries.

The preganglionic parasympathetic fibers reach the heart as cardiac branches from the right and left vagus nerves. They enter the cardiac plexus and synapse in ganglia located either within the plexus or in the walls of the atria.

Sympathetic innervation
Stimulation of the sympathetic system:
- increases heart rate; and
- increases the force of contraction.

Sympathetic fibers reach the cardiac plexus through the cardiac nerves from the sympathetic trunk. Preganglionic sympathetic fibers from the upper four or five segments of the thoracic spinal cord enter and move through the sympathetic trunk. They synapse in cervical and upper thoracic sympathetic ganglia, and postganglionic fibers proceed as bilateral branches from the sympathetic trunk to the cardiac plexus.

Visceral afferents
Visceral afferents from the heart are also a component of the cardiac plexus. These fibers pass through the cardiac plexus and return to the central nervous system in the cardiac nerves from the sympathetic trunk and in the vagal cardiac branches.

The afferents associated with the vagal cardiac nerves return to the vagus nerve [X]. They sense alterations in blood pressure and blood chemistry and are therefore primarily concerned with cardiac reflexes.

The afferents associated with the cardiac nerves from the sympathetic trunks return to either the cervical or the thoracic portions of the sympathetic trunk. If they are in the cervical portion of the trunk, they normally descend to the thoracic region where they re-enter the upper four or five thoracic spinal cord segments along with the afferents from the thoracic region of the sympathetic trunk. Visceral afferents associated with the sympathetic system conduct pain sensation from the heart, which is detected at the cellular level as tissue-damaging events (i.e., cardiac ischemia). This pain is often “referred” to cutaneous regions supplied by the same spinal cord levels (see p. 00; p. 000).

Pulmonary trunk
The pulmonary trunk is contained within the pericardial sac (Fig. 3.77)., is covered by the visceral layer of serous
pericardium and is associated with the ascending aorta in a common sheath. It arises from the conus arteriosus of the right ventricle at the opening of the pulmonary trunk slightly anterior to the aortic orifice and ascends, moving posteriorly and to the left, lying initially anterior and then to the left of the ascending aorta. At approximately the level of the intervertebral disc between vertebrae TV and TVI, opposite the left border of the sternum and posterior to the third left costal cartilage, the pulmonary trunk divides into:

- the right pulmonary artery, which passes to the right, posterior to the ascending aorta and the superior vena cava, to enter the right lung; and
- the left pulmonary artery, which passes inferiorly to the arch of the aorta and anteriorly to the descending aorta to enter the left lung.

**Ascending aorta**

The ascending aorta is contained within the pericardial sac and is covered by a visceral layer of serous pericardium, which also surrounds the pulmonary trunk in a common sheath (Fig. 3.77A).

The origin of the ascending aorta is the aortic orifice at the base of the left ventricle, which is level with the lower edge of the third left costal cartilage, posterior to the left half of the sternum. Moving superiority, slightly forward and to the right, the ascending aorta continues to the level of the second right costal cartilage. At this point, it enters the superior mediastinum and is then referred to as the arch of the aorta.

Immediately superior to the point where the ascending aorta arises from the left ventricle are three small outward bulges opposite the semilunar cusps of the aortic valve. These are the posterior, right, and left aortic sinuses. The right and left coronary arteries originate from the right and left aortic sinuses, respectively.

**Other vasculature**

The inferior half of the superior vena cava is located within the pericardial sac (Fig. 3.77B). It passes through the fibrous pericardium at approximately the level of the second costal cartilage and enters the right atrium at the lower level of the third costal cartilage. The portion within the pericardial sac is covered with serous pericardium except for a small portion of its posterior surface (Fig. 3.77B).

A very short segment of each of the pulmonary veins is also within the pericardial sac. These veins, usually two from each lung, pass through the fibrous pericardium and enter the superior region of the left atrium on its posterior surface. In the pericardial sac, all but a portion of the posterior surface of these veins is covered by serous pericardium. In addition, the oblique pericardial sinus is between the right and left pulmonary veins, within the pericardial sac (Fig. 3.77).

**Superior mediastinum**

The superior mediastinum is posterior to the manubrium of the sternum and anterior to the bodies of the first four thoracic vertebrae (see Fig. 3.52).

- Its superior boundary is an oblique plane passing from the jugular notch upward and posteriorly to the superior border of vertebra TI.
- Inferiorly, a transverse plane passing from the sternal angle to the intervertebral disc between vertebrae TIV/V separates it from the inferior mediastinum.
- Laterally, it is bordered by the mediastinal part of the parietal pleura on either side.

The superior mediastinum is continuous with the neck superiorly and with the inferior mediastinum inferiorly.

The major structures found in the superior mediastinum include the:

- thymus;
- right and left brachiocephalic veins;
- left superior intercostal vein;
- superior vena cava;
- arch of the aorta with its three large branches;
- trachea;
- esophagus;
- phrenic nerves;
- vagus nerves;
- left recurrent laryngeal branch of the left vagus nerve;
- thoracic duct; and
- other small nerves, blood vessels, and lymphatics (Figs. 3.78 and 3.79).

**Thymus**

The thymus is the most anterior component of the superior mediastinum, lying immediately posterior to the manubrium of the sternum. It is an asymmetric, bilobed structure (Fig. 3.80).
Fig. 3.78 Structures in the superior mediastinum.

Fig. 3.79 Cross-section through the superior mediastinum at the level of vertebra TIII. A. Diagram. B. Axial computed tomography image.
The upper extent of the thymus can reach into the neck as high as the thyroid gland; a lower portion typically extends into the anterior mediastinum over the pericardial sac.

Involved in the early development of the immune system, the thymus is a large structure in the child, begins to atrophy after puberty, and shows considerable size variation in the adult. In the elderly adult, it is barely identifiable as an organ, consisting mostly of fatty tissue that is sometimes arranged as two lobulated fatty structures.

Arteries to the thymus consist of small branches originating from the internal thoracic arteries. Venous drainage is usually into the left brachiocephalic vein and possibly into the internal thoracic veins.

Lymphatic drainage returns to multiple groups of nodes at one or more of the following locations:

- along the internal thoracic arteries (parasternal);
- at the tracheal bifurcation (tracheobronchial); and
- in the root of the neck.

**Right and left brachiocephalic veins**

The left and right brachiocephalic veins are located immediately posterior to the thymus. They form on each side at the junction between the internal jugular and subclavian veins (see Fig. 3.78). The left brachiocephalic vein crosses the midline and joins with the right brachiocephalic vein to form the superior vena cava (Fig. 3.81).

- The **right brachiocephalic vein** begins posterior to the medial end of the right clavicle and passes vertically

**In the clinic**

**Ectopic parathyroid glands in the thymus**

The parathyroid glands develop from the third pharyngeal pouch, which also forms the thymus. The thymus is therefore a common site for ectopic parathyroid glands and, potentially, ectopic parathyroid hormone production.
downward, forming the superior vena cava when it is joined by the left brachiocephalic vein. Venous tributaries include the vertebral, first posterior intercostal, and internal thoracic veins. The inferior thyroid and thymic veins may also drain into it.

- The **left brachiocephalic vein** begins posterior to the medial end of the left clavicle. It crosses to the right, moving in a slightly inferior direction, and joins with the right brachiocephalic vein to form the superior vena cava posterior to the lower edge of the right first costal cartilage close to the right sternal border. Venous tributaries include the vertebral, first posterior intercostal, left superior intercostal, inferior thyroid, and internal thoracic veins. It may also receive thymic and pericardial veins. The left brachiocephalic vein crosses the midline posterior to the manubrium in the adult. In infants and children the left brachiocephalic vein rises above the superior border of the manubrium and therefore is less protected.

**Left superior intercostal vein**

The **left superior intercostal vein** receives the second, third and sometimes the fourth posterior intercostal veins, usually the left bronchial veins, and sometimes the left pericardiacophrenic vein. It passes over the left side of the aortic arch, lateral to the left vagus nerve and medial to the left phrenic nerve, before entering the left brachiocephalic vein (Fig. 3.82). Inferiorly, it may connect with the accessory hemiazygos vein (superior hemiazygos vein).

**Superior vena cava**

The vertically oriented superior vena cava begins posterior to the lower edge of the right first costal cartilage, where the right and left brachiocephalic veins join, and terminates at the lower edge of the right third costal cartilage, where it joins the right atrium (see Fig. 3.78).

The lower half of the superior vena cava is within the pericardial sac and is therefore contained in the middle mediastinum.

The superior vena cava receives the azygos vein immediately before entering the pericardial sac and may also receive pericardial and mediastinal veins.

The superior vena cava can be easily visualized forming part of the right superolateral border of the mediastinum on a chest radiograph (see Fig. 3.60A).
Venous access for central and dialysis lines

Large systemic veins are used to establish central venous access for administering large amounts of fluid, drugs, and blood. Most of these lines (small bore tubes) are introduced through venous puncture into the axillary, subclavian, or internal jugular veins. The lines are then passed through the main veins of the superior mediastinum, with the tips of the lines usually residing in the distal portion of the superior vena cava or in the right atrium.

Similar devices, such as dialysis lines, are inserted into patients who have renal failure, so that a large volume of blood can be aspirated through one channel and re-infused through a second channel.
**Arch of aorta and its branches**

The thoracic portion of the aorta can be divided into **ascending aorta**, **arch of aorta**, and **thoracic (descending) aorta**. Only the arch of the aorta is in the superior mediastinum. It begins when the ascending aorta emerges from the pericardial sac and courses upward, backward, and to the left as it passes through the superior mediastinum, ending on the left side at vertebral level TIV/V (see Fig. 3.78). Extending as high as the midlevel of the manubrium of sternum, the arch is initially anterior and finally lateral to the trachea.

Three branches arise from the superior border of the arch of the aorta: at their origins, all three are crossed anteriorly by the left brachiocephalic vein.

**The first branch**

Beginning on the right, the first branch of the arch of aorta is the **brachiocephalic trunk** (Fig. 3.83). It is the largest of the three branches and, at its point of origin...
behind the manubrium of sternum, is slightly anterior to the other two branches. It ascends slightly posteriorly and to the right. At the level of the upper edge of the right sternoclavicular joint, the brachiocephalic trunk divides into:

- the **right common carotid artery**; and
- the **right subclavian artery** (see Fig. 3.78).

The arteries mainly supply the right side of the head and neck and the right upper limb, respectively.

Occasionally, the brachiocephalic trunk has a small branch, the **thyroid ima artery**, which contributes to the vascular supply of the thyroid gland.

**The second branch**

The second branch of the arch of aorta is the **left common carotid artery** (Fig. 3.83). It arises from the arch immediately to the left and slightly posterior to the brachiocephalic trunk and ascends through the superior mediastinum along the left side of the trachea.

The left common carotid artery supplies the left side of the head and neck.

**The third branch**

The third branch of the arch of the aorta is the **left subclavian artery** (Fig. 3.83). It arises from the arch of aorta immediately to the left of, and slightly posterior to, the left common carotid artery and ascends through the superior mediastinum along the left side of the trachea.

The left subclavian artery is the major blood supply to the left upper limb.

**Ligamentum arteriosum**

The **ligamentum arteriosum** is also in the superior mediastinum and is important in embryonic circulation, when it is a patent vessel (the **ductus arteriosus**). It connects the pulmonary trunk with the arch of aorta and allows blood to bypass the lungs during development (Fig. 3.83). The vessel closes soon after birth and forms the ligamentous connection observed in the adult.

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**In the clinic**

**Coarctation of the aorta**

Coarctation of the aorta is a congenital abnormality in which the aortic lumen is constricted just distal to the origin of the left subclavian artery. At this point, the aorta becomes significantly narrowed and the blood supply to the lower limbs and abdomen is diminished. Over time, collateral vessels develop around the chest wall and abdomen to supply the lower body. The coarctation also affects the heart, which has to pump the blood at higher pressure to maintain peripheral perfusion. This in turn may produce cardiac failure.

**Thoracic aorta**

Diffuse atherosclerosis of the thoracic aorta may occur in patients with vascular disease, but this rarely produces symptoms. There are, however, two clinical situations in which aortic pathology can produce life-threatening situations.

**Trauma**

The aorta has three fixed points of attachment:

- the aortic valve;
- the ligamentum arteriosum;
- the point of entry behind the crura of the diaphragm.

The rest of the aorta is relatively free from attachment to other structures of the mediastinum. A serious deceleration injury (e.g., in a road traffic accident) is most likely to cause aortic trauma at these fixed points.

**Aortic dissection**

In certain conditions, such as in severe arteriovascular disease, the wall of the aorta can split longitudinally, creating a false channel, which may or may not rejoin into the true lumen distally. This aortic dissection occurs between the intima and media anywhere along its length. If it occurs in the ascending aorta or arch of the aorta, blood flow in the coronary and cerebral arteries may be disrupted, resulting in myocardial infarction or stroke. In the abdomen the visceral vessels may be disrupted, producing ischemia to the gut or kidneys.
Trachea and esophagus

The trachea is a midline structure that is palpable in the jugular notch as it enters the superior mediastinum. Posterior to it is the esophagus, which is immediately anterior to the vertebral column (Fig. 3.84, and see Figs. 3.78 and 3.79). Significant mobility exists in the vertical positioning of these structures as they pass through the superior mediastinum. Swallowing and breathing cause positional shifts, as may disease and the use of specialized instrumentation.

As the trachea and esophagus pass through the superior mediastinum, they are crossed laterally by the azygos vein on the right side and the arch of aorta on the left side.

The trachea divides into the right and left main bronchi at, or just inferior to, the transverse plane between the sternal angle and vertebral level TIV/V (Fig. 3.85), whereas the esophagus continues into the posterior mediastinum.

Nerves of the superior mediastinum

Vagus nerves

The vagus nerves [X] pass through the superior and posterior divisions of the mediastinum on their way to the abdominal cavity. As they pass through the thorax, they provide parasympathetic innervation to the thoracic viscera and carry visceral afferents from the thoracic viscera.

Aortic arch and its anomalies

A right-sided arch of aorta occasionally occurs and may be asymptomatic. It can be associated with dextrocardia (right-sided heart) and, in some instances, with complete situs inversus (left-to-right inversion of the body’s organs). It can also be associated with abnormal branching of the great vessels.

In the clinic

Abnormal origin of great vessels

Great vessels occasionally have an abnormal origin, including:

- a common origin of the brachiocephalic trunk and the left common carotid artery;
- the left vertebral artery originating from the aortic arch; and
- the right subclavian artery originating from the distal portion of the aortic arch and passing behind the esophagus to supply the right arm—as a result, the great vessels form a vascular ring around the trachea and the esophagus, which can potentially produce difficulty swallowing.
Visceral afferents in the vagus nerves relay information to the central nervous system about normal physiological processes and reflex activities. They do not transmit pain sensation.

**Right vagus nerve**

The right vagus nerve enters the superior mediastinum and lies between the right brachiocephalic vein and the brachiocephalic trunk. It descends in a posterior direction toward the trachea (Fig. 3.86), crosses the lateral surface of the trachea and passes posteriorly to the root of the right lung to reach the esophagus. Just before the esophagus, it is crossed by the arch of the azygos vein.

As the right vagus nerve passes through the superior mediastinum, it gives branches to the esophagus, cardiac plexus, and pulmonary plexus.

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**Fig. 3.85** Trachea in the superior mediastinum.

**Fig. 3.86** Right vagus nerve passing through the superior mediastinum.
**Left vagus nerve**

The **left vagus nerve** enters the superior mediastinum posterior to the left brachiocephalic vein and between the left common carotid and left subclavian arteries (Fig. 3.87). As it passes into the superior mediastinum, it lies just deep to the mediastinal part of the parietal pleura and crosses the left side of the arch of aorta. It continues to descend in a posterior direction and passes posterior to the root of the left lung to reach the esophagus in the posterior mediastinum.

As the left vagus nerve passes through the superior mediastinum, it gives branches to the esophagus, the cardiac plexus, and the pulmonary plexus.

The left vagus nerve also gives rise to the **left recurrent laryngeal nerve**, which arises from it at the inferior margin of the arch of aorta just lateral to the ligamentum arteriosum. The left recurrent laryngeal nerve passes inferior to the arch of aorta before ascending on its medial surface. Entering a groove between the trachea and esophagus, the left recurrent laryngeal nerve continues superiorly to enter the neck and terminate in the larynx (Fig. 3.88).

![Figure 3.87](image_url)
Phrenic nerves

The phrenic nerves arise in the cervical region mainly from the fourth, but also from the third and fifth cervical spinal cord segments.

The phrenic nerves descend through the thorax to supply motor and sensory innervation to the diaphragm and its associated membranes. As they pass through the thorax, they provide innervation through somatic afferent fibers to the mediastinal pleura, fibrous pericardium, and parietal layer of serous pericardium.

Right phrenic nerve

The right phrenic nerve enters the superior mediastinum lateral to the right vagus nerve and lateral and slightly posterior to the beginning of the right brachiocephalic vein (see Fig. 3.86). It continues inferiorly along the right side of this vein and the right side of the superior vena cava.

Left phrenic nerve

The left phrenic nerve enters the superior mediastinum in a position similar to the path taken by the right phrenic nerve. It lies lateral to the left vagus nerve and lateral and slightly posterior to the beginning of the left brachiocephalic vein (see Fig. 3.82), and continues to descend across the left lateral surface of the arch of aorta, passing superficially to the left vagus nerve and the left superior intercostal vein.

On entering the middle mediastinum, the left phrenic nerve follows the left side of the pericardial sac, within the fibrous pericardium, anterior to the root of the left lung, and is accompanied by the pericardiacophrenic vessels (see Fig. 3.54). It leaves the thorax by piercing the diaphragm near the apex of the heart.

The vagus nerves, recurrent laryngeal nerves, and hoarseness

The left recurrent laryngeal nerve is a branch of the left vagus nerve. It passes between the pulmonary artery and the aorta, a region known clinically as the aortopulmonary window and may be compressed in any patient with a pathological mass in this region. This compression results in vocal cord paralysis and hoarseness of the voice. Lymph node enlargement, often associated with the spread of lung cancer, is a common condition that may produce compression. Chest radiography is therefore usually carried out for all patients whose symptoms include a hoarse voice.

More superiorly, the right vagus nerve gives off the right recurrent laryngeal nerve which “hooks” around the right subclavian artery at the superior sulcus of the right lung. If a patient has a hoarse voice and a right vocal cord palsy is demonstrated at laryngoscopy, chest radiography with an apical lordotic view should be obtained to assess for cancer in the right lung apex (Pancoast’s tumor).
Thoracic duct in the superior mediastinum

The thoracic duct, which is the major lymphatic vessel in the body, passes through the posterior portion of the superior mediastinum (see Figs. 3.79 and 3.84). It:

- enters the superior mediastinum inferiorly, slightly to the left of the midline, having moved to this position just before leaving the posterior mediastinum opposite vertebral level TIV/V; and
- continues through the superior mediastinum, posterior to the arch of aorta, and the initial portion of the left subclavian artery, between the esophagus and the left mediastinal part of the parietal pleura.

Posterior mediastinum

The posterior mediastinum is posterior to the pericardial sac and diaphragm and anterior to the bodies of the mid and lower thoracic vertebrae (see Fig. 3.52).

- Its superior boundary is a transverse plane passing from the sternal angle to the intervertebral disc between vertebrae TIV and TV.
- Its inferior boundary is the diaphragm.
- Laterally, it is bordered by the mediastinal part of parietal pleura on either side.
- Superiorly, it is continuous with the superior mediastinum.

Major structures in the posterior mediastinum include the:

- esophagus and its associated nerve plexus;
- thoracic aorta and its branches;
- azygos system of veins;
- thoracic duct and associated lymph nodes;
- sympathetic trunks; and
- thoracic splanchnic nerves.

Esophagus

The esophagus is a muscular tube passing between the pharynx in the neck and the stomach in the abdomen. It begins at the inferior border of the cricoid cartilage, opposite vertebra CVI, and ends at the cardiac opening of the stomach, opposite vertebra TXI.

The esophagus descends on the anterior aspect of the bodies of the vertebrae, generally in a midline position as it moves through the thorax (Fig. 3.89). As it approaches the diaphragm, it moves anteriorly and to the left, crossing from the right side of the thoracic aorta to eventually assume a position anterior to it. It then passes through the esophageal hiatus, an opening in the muscular part of the diaphragm, at vertebral level TX.

The esophagus has a slight anterior-to-posterior curvature that parallels the thoracic portion of the vertebral column, and is secured superiorly by its attachment to the pharynx and inferiorly by its attachment to the diaphragm.

Relationships to important structures in the posterior mediastinum

In the posterior mediastinum, the esophagus is related to a number of important structures. The right side is covered by the mediastinal part of the parietal pleura.

Posterior to the esophagus, the thoracic duct is on the right side inferiorly, but crosses to the left more superiorly. Also on the left side of the esophagus is the thoracic aorta.

Anterior to the esophagus, below the level of the tracheal bifurcation, are the right pulmonary artery and the left main bronchus. The esophagus then passes immediately posteriorly to the left atrium, separated from it only by pericardium. Inferior to the left atrium, the esophagus is related to the diaphragm.

Structures other than the thoracic duct posterior to the esophagus include portions of the hemiazygos veins, the right posterior intercostal vessels, and, near the diaphragm, the thoracic aorta.

The esophagus is a flexible, muscular tube that can be compressed or narrowed by surrounding structures at four locations (Fig. 3.90):

- the junction of the esophagus with the pharynx in the neck;
- in the superior mediastinum where the esophagus is crossed by the arch of aorta;
- in the posterior mediastinum where the esophagus is compressed by the left main bronchus;
- in the posterior mediastinum at the esophageal hiatus in the diaphragm.

These constrictions have important clinical consequences. For example, a swallowed object is most likely to lodge at a constricted area. An ingested corrosive substance would move more slowly through a narrowed region, causing more damage at this site than elsewhere along the esophagus. Also, constrictions present problems during the passage of instruments.
Arterial supply and venous and lymphatic drainage

The arterial supply and venous drainage of the esophagus in the posterior mediastinum involves many vessels. Esophageal arteries arise from the thoracic aorta, bronchial arteries, and ascending branches of the left gastric artery in the abdomen.

Venous drainage involves small vessels returning to the azygos vein, hemiazygos vein, and esophageal branches to the left gastric vein in the abdomen.

Lymphatic drainage of the esophagus in the posterior mediastinum returns to posterior mediastinal and left gastric nodes.

Innervation

Innervation of the esophagus, in general, is complex. Esophageal branches arise from the vagus nerves and sympathetic trunks.

Striated muscle fibers in the superior portion of the esophagus originate from the branchial arches and are innervated by branchial efferents from the vagus nerves.

Smooth muscle fibers are innervated by components of the parasympathetic part of the autonomic division of the peripheral nervous system, visceral efferents from the vagus nerves. These are preganglionic fibers that synapse in the myenteric and submucosal plexuses of the enteric nervous system in the esophageal wall.
Sensory innervation of the esophagus involves visceral afferent fibers originating in the vagus nerves, sympathetic trunks, and splanchnic nerves.

The visceral afferents from the vagus nerves are involved in relaying information back to the central nervous system about normal physiological processes and reflex activities. They are not involved in the relay of pain recognition.

The visceral afferents that pass through the sympathetic trunks and the splanchnic nerves are the primary participants in detection of esophageal pain and transmission of this information to various levels of the central nervous system.

**Esophageal plexus**

After passing posteriorly to the root of the lungs, the right and left vagus nerves approach the esophagus. As they reach the esophagus, each nerve divides into several branches that spread over this structure, forming the esophageal plexus (Fig. 3.91). There is some mixing of fibers from the two vagus nerves as the plexus continues inferiorly on the esophagus toward the diaphragm. Just above the diaphragm, fibers of the plexus converge to form two trunks:

- the **anterior vagal trunk** on the anterior surface of the esophagus, mainly from fibers originally in the left vagus nerve;
- the **posterior vagal trunk** on the posterior surface of the esophagus, mainly from fibers originally in the right vagus nerve.

The vagal trunks continue on the surface of the esophagus as it passes through the diaphragm into the abdomen.

**Thoracic aorta**

The thoracic portion of the descending aorta (thoracic aorta) begins at the lower edge of vertebra TIV, where it is continuous with the arch of aorta. It ends anterior to the
lower edge of vertebrae TXII, where it passes through the aortic hiatus posterior to the diaphragm. Situated to the left of the vertebral column superiorly, it approaches the midline inferiorly, lying directly anterior to the lower thoracic vertebral bodies (Fig. 3.92). Throughout its course, it gives off a number of branches, which are summarized in Table 3.3.

**Azygos system of veins**

The azygos system of veins consists of a series of longitudinal vessels on each side of the body that drain blood from the body wall and move it superiorly to empty into the superior vena cava. Blood from some of the thoracic viscera may also enter the system, and there are anastomotic connections with abdominal veins.

The longitudinal vessels may or may not be continuous and are connected to each other from side to side at various points throughout their course (Fig. 3.93).

The azygos system of veins serves as an important anastomotic pathway capable of returning venous blood from the lower part of the body to the heart if the inferior vena cava is blocked.

The major veins in the system are:

- the azygos vein, on the right; and
- the hemiazygos vein and the accessory hemiazygos vein, on the left.

There is significant variation in the origin, course, tributaries, anastomoses, and termination of these vessels.

**Azygos vein**

The azygos vein arises opposite vertebra LI or LII at the junction between the right ascending lumbar vein and the right subcostal vein (Fig. 3.93). It may also arise as a direct branch of the inferior vena cava, which is joined by a common trunk from the junction of the right ascending lumbar vein and the right subcostal vein.
Table 3.3  Branches of the thoracic aorta

<table>
<thead>
<tr>
<th>Branches</th>
<th>Origin and course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pericardial branches</td>
<td>A few small vessels to the posterior surface of the pericardial sac</td>
</tr>
<tr>
<td>Bronchial branches</td>
<td>Vary in number, size, and origin—usually, two left bronchial arteries from the thoracic aorta and one right bronchial artery from the third posterior intercostal artery or the upper left bronchial artery</td>
</tr>
<tr>
<td>Esophageal branches</td>
<td>Four or five vessels from the anterior aspect of the thoracic aorta, which form a continuous anastomotic chain—anastomotic connections include esophageal branches of the inferior thyroid artery superiorly, and esophageal branches of the left inferior phrenic and the left gastric arteries inferiorly</td>
</tr>
<tr>
<td>Mediastinal branches</td>
<td>Several small branches supplying lymph nodes, vessels, nerves, and areolar tissue in the posterior mediastinum</td>
</tr>
<tr>
<td>Posterior intercostal arteries</td>
<td>Usually nine pairs of vessels branching from the posterior surface of the thoracic aorta—usually supply lower nine intercostal spaces (first two spaces are supplied by the supreme intercostal artery—a branch of the costocervical trunk)</td>
</tr>
<tr>
<td>Superior phrenic arteries</td>
<td>Small vessels from the lower part of the thoracic aorta supplying the posterior part of the superior surface of the diaphragm—they anastomose with the musculophrenic and pericardiophrenic arteries</td>
</tr>
<tr>
<td>Subcostal artery</td>
<td>The lowest pair of branches from the thoracic aorta located inferior to rib XII</td>
</tr>
</tbody>
</table>

Fig. 3.93  Azygos system of veins.
The azygos vein enters the thorax through the aortic hiatus of the diaphragm, or it enters through or posterior to the right crus of the diaphragm. It ascends through the posterior mediastinum, usually to the right of the thoracic duct. At approximately vertebral level TIV, it arches anteriorly, over the root of the right lung, to join the superior vena cava before the superior vena cava enters the pericardial sac.

Tributaries of the azygos vein include:

- the right superior intercostal vein (a single vessel formed by the junction of the second, third, and fourth intercostal veins);
- fifth to eleventh right posterior intercostal veins;
- the hemiazygos vein;
- the accessory hemiazygos vein;
- esophageal veins;
- mediastinal veins;
- pericardial veins; and
- right bronchial veins.

Hemiazygos vein

The hemiazygos vein (inferior hemiazygos vein) usually arises at the junction between the left ascending lumbar vein and the left subcostal vein (Fig. 3.93). It may also arise from either of these veins alone and often has a connection to the left renal vein.

The hemiazygos vein usually enters the thorax through the left crus of the diaphragm, but may enter through the aortic hiatus. It ascends through the posterior mediastinum, on the left side, to approximately vertebral level TIX. At this point, it crosses the vertebral column, posterior to the thoracic aorta, esophagus, and thoracic duct, to enter the azygos vein.

Tributaries joining the hemiazygos vein include:

- the lowest four or five left posterior intercostal veins;
- esophageal veins; and
- mediastinal veins.

Accessory hemiazygos vein

The accessory hemiazygos vein (superior hemiazygos vein) descends on the left side from the superior portion of the posterior mediastinum to approximately vertebral level TVIII (Fig. 3.93). At this point, it crosses the vertebral column to join the azygos vein, or ends in the hemiazygos vein, or has a connection to both veins. Usually, it also has a connection superiorly to the left superior intercostal vein.

Vessels that drain into the accessory hemiazygos vein include:

- the fourth to eighth left posterior intercostal veins; and
- sometimes, the left bronchial veins.

Thoracic duct in the posterior mediastinum

The thoracic duct is the principal channel through which lymph from most of the body is returned to the venous system. It begins as a confluence of lymph trunks in the abdomen, sometimes forming a saccular dilation referred to as the cisterna chyli (chyle cistern), which drains the abdominal viscera and walls, pelvis, perineum, and lower limbs.

The thoracic duct extends from vertebra LII to the root of the neck.

Entering the thorax, posterior to the aorta, through the aortic hiatus of the diaphragm, the thoracic duct ascends through the posterior mediastinum to the right of midline between the thoracic aorta on the left and the azygos vein on the right (Fig. 3.94). It lies posterior to the diaphragm and the esophagus and anterior to the bodies of the vertebra.

At vertebral level TV, the thoracic duct moves to the left of midline and enters the superior mediastinum. It continues through the superior mediastinum and into the neck.
After being joined, in most cases, by the **left jugular trunk**, which drains the left side of the head and neck, and the **left subclavian trunk**, which drains the left upper limb, the thoracic duct empties into the junction of the left subclavian and left internal jugular veins.

The thoracic duct usually receives the contents from:

- the confluence of lymph trunks in the abdomen;
- descending thoracic lymph trunks draining the lower six or seven intercostal spaces on both sides;
- upper intercostal lymph trunks draining the upper left five or six intercostal spaces;
- ducts from posterior mediastinal nodes; and
- ducts from posterior diaphragmatic nodes.

**Sympathetic trunks**

The **sympathetic trunks** are an important component of the sympathetic part of the autonomic division of the PNS and are usually considered a component of the posterior mediastinum as they pass through the thorax.
This portion of the sympathetic trunks consists of two parallel cords punctuated by 11 or 12 ganglia (Fig. 3.95). The ganglia are connected to adjacent thoracic spinal nerves by white and gray rami communicantes and are numbered according to the thoracic spinal nerve with which they are associated.

In the superior portion of the posterior mediastinum, the trunks are anterior to the neck of the ribs. Inferiorly, they become more medial in position until they lie on the lateral aspect of the vertebral bodies. The sympathetic trunks leave the thorax by passing posterior to diaphragm under the medial arcuate ligament or through the crura of the diaphragm. Throughout their course the trunks are covered by parietal pleura.

**Branches from the ganglia**

Two types of medial branches are given off by the ganglia:

- the first type includes branches from the upper five ganglia:
The least splanchnic nerve (lowest splanchnic nerve) usually arises from the twelfth thoracic ganglion. It descends and passes into the abdomen through the crus of the diaphragm to end in the renal plexus.

**Anterior mediastinum**

The anterior mediastinum is posterior to the body of the sternum and anterior to the pericardial sac (see Fig. 3.52).

- Its superior boundary is a transverse plane passing from the sternal angle to the intervertebral disc between vertebra TIV and TV, separating it from the superior mediastinum.
- Its inferior boundary is the diaphragm.
- Laterally, it is bordered by the mediastinal part of parietal pleura on either side.

The major structure in the anterior mediastinum is a portion of thymus, described previously (see Fig. 3.80). Also present are fat, connective tissue, lymph nodes, mediastinal branches of the internal thoracic vessels, and sternopericardial ligaments, which pass from the posterior surface of the body of the sternum to the fibrous pericardium.
Surface anatomy

Thorax surface anatomy
The ability to visualize how anatomical structures in the thorax are related to surface features is fundamental to a physical examination. Figs. 3.96 and 3.97 have been rendered to show landmarks on the body’s surface that can be used to locate deep structures and to assess function by auscultation and percussion.

How to count ribs
Knowing how to count ribs is important because different ribs provide palpable landmarks for the positions of deeper structures. To determine the location of specific ribs, palpate the jugular notch at the superior extent of the manubrium of the sternum. Move down the sternum until a ridge is felt. This ridge is the sternal angle, which identi-
flies the articulation between the manubrium of sternum and the body of sternum. The costal cartilage of rib II articulates with the sternum at this location. Identify rib II. Then continue counting the ribs, moving in a downward and lateral direction (Fig. 3.98).

**Surface anatomy of the breast in women**

Although breasts vary in size, they are normally positioned on the thoracic wall between ribs II and VI and overlie the pectoralis major muscles. Each mammary gland extends
superolaterally around the lower margin of the pectoralis major muscle and enters the axilla (Fig. 3.99). This portion of the gland is the axillary tail or axillary process. The positions of the nipple and areola vary relative to the chest wall depending on breast size.

**Visualizing structures at the TIV/V vertebral level**

The TIV/V vertebral level is a transverse plane that passes through the sternal angle on the anterior chest wall and the intervertebral disc between TIV and TV vertebrae posteriorly. This plane can easily be located, because the joint between the manubrium of sternum and the body of sternum forms a distinct bony protuberance that can be palpated. At the TIV/V level (Fig. 3.100):

- the costal cartilage of rib II articulates with the sternum;
- the superior mediastinum is separated from the inferior mediastinum;
- the ascending aorta ends and the arch of aorta begins;
- the arch of aorta ends and the thoracic aorta begins;
- the trachea bifurcates.

**Fig. 3.99** A. Close-up view of nipple and surrounding areola of the breast. B. Lateral view of the chest wall of a woman showing the axillary process of the breast.

**Fig. 3.100** Anterior view of the chest wall of a man showing the locations of various structures related to the TIV/V level.
Visualizing structures in the superior mediastinum

A number of structures in the superior mediastinum in adults can be visualized based on their positions relative to skeletal landmarks that can be palpated through the skin (Fig. 3.101).

- On each side, the internal jugular and subclavian veins join to form the brachiocephalic veins behind the sternal ends of the clavicles near the sternoclavicular joints.
- The left brachiocephalic vein crosses from left to right behind the manubrium of sternum.
- The brachiocephalic veins unite to form the superior vena cava behind the lower border of the costal cartilage of the right first rib.

- The arch of aorta begins and ends at the transverse plane between the sternal angle anteriorly and vertebral level TIV/V posteriorly. The arch may reach as high as the midlevel of the manubrium of sternum.

Visualizing the margins of the heart

Surface landmarks can be palpated to visualize the outline of the heart (Fig. 3.102).

- The upper limit of the heart reaches as high as the third costal cartilage on the right side of the sternum and the second intercostal space on the left side of the sternum.

![Fig. 3.101 Anterior view of the chest wall of a man showing the locations of different structures in the superior mediastinum as they relate to the skeleton.](image-url)
Thorax

- The right margin of the heart extends from the right third costal cartilage to near the right sixth costal cartilage.
- The left margin of the heart descends laterally from the second intercostal space to the apex located near the midclavicular line in the fifth intercostal space.
- The lower margin of the heart extends from the sternal end of the right sixth costal cartilage to the apex in the fifth intercostal space near the midclavicular line.

**Where to listen for heart sounds**

To listen for valve sounds, position the stethoscope downstream from the flow of blood through the valves (Fig. 3.103).

- The tricuspid valve is heard just to the left of the lower part of the sternum near the fifth intercostal space.
- The mitral valve is heard over the apex of the heart in the left fifth intercostal space at the midclavicular line.
- The pulmonary valve is heard over the medial end of the left second intercostal space.
- The aortic valve is heard over the medial end of the right second intercostal space.

**Visualizing the pleural cavities and lungs, pleural recesses, and lung lobes and fissures**

Palpable surface landmarks can be used to visualize the normal outlines of the pleural cavities and the lungs and to determine the positions of the pulmonary lobes and fissures.

Superiorly, the parietal pleura projects above the first costal cartilage. Anteriorly, the costal pleura approaches
the midline posterior to the upper portion of the sternum. Posterior to the lower portion of the sternum, the left parietal pleura does not come as close to the midline as it does on the right side. This is because the heart bulges onto the left side (Fig. 3.104A).

Inferiorly, the pleura reflects onto the diaphragm above the costal margin and courses around the thoracic wall following an VIII, X, XII contour (i.e., rib VIII in the midclavicular line, rib X in the midaxillary line, and vertebra TXII posteriorly).

The lungs do not completely fill the area surrounded by the pleural cavities, particularly anteriorly and inferiorly.

- Costomediastinal recesses occur anteriorly, particularly on the left side in relationship to the heart bulge.
- Costodiaphragmatic recesses occur inferiorly between the lower lung margin and the lower margin of the pleural cavity.

In quiet respiration, the inferior margin of the lungs travels around the thoracic wall following a VI, VIII, X contour (i.e., rib VI in the midclavicular line, rib VIII in the midaxillary line, and vertebra TX posteriorly).

In the posterior view, the oblique fissure on both sides is located in the midline near the spine of vertebra TIV (Figs. 3.104B and 3.105A). It moves laterally in a downward direction, crossing the fourth and fifth intercostal spaces and reaches rib VI laterally.

In the anterior view, the horizontal fissure on the right side follows the contour of rib IV and its costal cartilage and the oblique fissures on both sides follow the contour of rib VI and its costal cartilage (Fig. 3.105B).

Where to listen for lung sounds
The stethoscope placements for listening for lung sounds are shown in Fig. 3.106.
Fig. 3.104 Views of the chest wall showing the surface projections of the lobes and the fissures of the lungs. A. Anterior view in a woman. On the right side, the superior, middle, and inferior lobes are illustrated. On the left side, the superior and inferior lobes are illustrated. B. Posterior view in a woman. On both sides, the superior and inferior lobes are illustrated. The middle lobe on the right side is not visible in this view.
Fig. 3.105 Views of the chest wall.

A. Posterior view in a woman with arms abducted and hands positioned behind her head. On both sides, the superior and inferior lobes of the lungs are illustrated. When the scapula is rotated into this position, the medial border of the scapula parallels the position of the oblique fissure and can be used as a guide for determining the surface projection of the superior and inferior lobes of the lungs.

B. Lateral view in a man with his right arm abducted. The superior, middle, and inferior lobes of the right lung are illustrated. The oblique fissure begins posteriorly at the level of the spine of vertebra TIV, passes inferiorly crossing rib IV, the fourth intercostal space, and rib V. It crosses the fifth intercostal space at the midaxillary line and continues anteriorly along the contour of rib VI. The horizontal fissure crosses rib V in the midaxillary space and continues anteriorly, crossing the fourth intercostal space and following the contour of rib IV and its costal cartilage to the sternum.
Fig. 3.106 Views of the chest wall of a man with stethoscope placements for listening to the lobes of the lungs. A. Anterior views. B. Posterior views.
Clinical cases

Case 1

CERVICAL RIB

A young man has black areas of skin on the tips of his fingers of his left hand. A clinical diagnosis of platelet emboli was made and a source of the emboli sought.

Emboli can arise from many sources. They are clots and plugs of tissue, usually platelets, that are carried from a source to eventually reside in small vessels which they may occlude. Arterial emboli may arise anywhere from the left side of the heart and the arteries to the organ affected. Valve disease secondary to rheumatic fever makes the mitral and aortic valve more susceptible to infection. This condition is known as infective endocarditis. In cases of infected emboli, bacteria grow on the valve and are showered off into the peripheral circulation.

A plain neck radiograph demonstrated a cervical rib (Fig. 3.107).

Fig. 3.107 Neck radiograph demonstrating bilateral cervical ribs.

Cervical ribs may produce three distinct disease entities:

- Arterial compression and embolization—the rib (or band) on the undersurface of the distal portion of the subclavian artery reduces the diameter of the vessel and allows eddy currents to form. Platelets aggregate and atheroma may develop in this region. This debris can be dislodged and flow distally within the upper limb vessels to block off blood flow to the fingers and the hand, a condition called distal embolization.

- Compression of T1 nerve—the T1 nerve, which normally passes over rib 1, is also elevated, thus the patient may experience a sensory disturbance over the medial aspect of the forearm, and develop wasting of the intrinsic muscles of the hand.

- Compression of the subclavian vein—this may induce axillary vein thrombosis.

A Doppler ultrasound scan revealed marked stenosis of the subclavian artery at the outer border of the rib with abnormal flow distal to the narrowing. Within this region of abnormal flow there was evidence of thrombus adherent to the vessel wall.

This patient underwent surgical excision of the cervical rib and had no further symptoms.
A 52-year-old man presented with headaches and shortness of breath. He also complained of coughing up small volumes of blood. Clinical examination revealed multiple dilated veins around the neck. A chest radiograph demonstrated an elevated diaphragm on the right and a tumor mass, which was believed to be a primary bronchogenic carcinoma.

By observing the clinical findings and applying anatomical knowledge, the site of the tumor can be inferred.

The multiple dilated veins around the neck are indicative of venous obstruction. The veins are dilated on both sides of the neck, implying that the obstruction must be within a common vessel, the superior vena cava. Anterior to the superior vena cava in the right side of the chest is the phrenic nerve, which supplies the diaphragm. Because the diaphragm is elevated, suggesting paralysis, it is clear that the phrenic nerve has been involved with the tumor.

A 35-year-old man was shot during an armed robbery. The bullet entry wound was in the right fourth intercostal space, above the nipple. A chest radiograph obtained on admission to the emergency room demonstrated complete collapse of the lung.

A further chest radiograph performed 20 minutes later demonstrated an air/fluid level in the pleural cavity (Fig. 3.108).

Three common pathological processes may occur in the pleural cavity.

- If air is introduced into the pleural cavity, a pneumothorax develops and the lung collapses because of its own elastic recoil. The pleural space fills with air, which may further compress the lung. Most patients with a collapsed lung are unlikely to have respiratory impairment. Under certain conditions, air may enter the pleural cavity at such a rate that it shifts and pushes the mediastinum to the opposite side of the chest. This is called tension pneumothorax and is potentially lethal, requiring urgent treatment by insertion of an intercostal tube to remove the air. The commonest causes of pneumothorax are rib fractures and positive pressure ventilation lung damage.
- The pleural cavity may fill with fluid (a pleural effusion) and this can be associated with many diseases (e.g., lung infection, cancer, abdominal sepsis). It is important to aspirate fluid from these patients to relieve any respiratory impairment and to carry out laboratory tests on the fluid to determine its nature.
- Severe chest trauma can lead to development of hemopneumothorax. A tube must be inserted to remove the blood and air that has entered the pleural space and prevent respiratory impairment.
This man needs treatment to drain either the air or fluid or both.

The pleural space can be accessed by passing a needle between the ribs into the pleural cavity. In a normal healthy adult, the pleural space is virtually nonexistent; therefore, any attempt to introduce a needle into this space is unlikely to succeed and the procedure may damage the underlying lung.

Before any form of chest tube is inserted, the rib must be well anesthetized by infiltration because its periosteum is extremely sensitive. The intercostal drain should pass directly on top of the rib. Insertion adjacent to the lower part of the rib may damage the artery, vein, and nerve, which lie within the neurovascular bundle.

appropriate sites for insertion of a chest drain are:
- in the midaxillary line in the fifth intercostal interspace; and
- in the midclavicular line in the second intercostal interspace.

These positions are determined by palpating the sternal angle, which is the point of articulation of rib II. Counting inferiorly will determine the rib number and simple observation will determine the points of the midaxillary and the midclavicular line. Insertion of any tube or needle below the level of rib V runs an appreciable risk of crossing the pleural recesses and placing the needle or the drain into either the liver or the spleen, depending upon which side the needle is inserted.

**Case 4**

MYOCARDIAL INFARCTION

A 65-year-old man was admitted to the emergency room with severe central chest pain that radiated to the neck and predominantly to the left arm. He was overweight and a known heavy smoker.

On examination he appeared gray and sweaty. His blood pressure was 74/40 mm Hg (normal range 120/80 mm Hg). An electrocardiogram (ECG) was performed and demonstrated anterior myocardial infarction. An urgent echocardiograph demonstrated a poor left ventricular function. The cardiac angiogram revealed an occluded vessel (Fig. 3.109A and 3.109B).

**Fig. 3.109** A. Normal left coronary artery angiogram. B. Left coronary artery angiogram showing decreased flow due to blockages.
This patient underwent an emergency coronary artery bypass graft and made an excellent recovery. He has now lost weight, stopped smoking, and exercises regularly.

When cardiac cells die during a myocardial infarction, pain fibers (visceral afferents) are stimulated. These visceral sensory fibers follow the course of sympathetic fibers that innervate the heart and enter the spinal cord between T1 and T4 levels. At this level, somatic afferent nerves from spinal nerves T1 to T4 also enter the spinal cord via the posterior roots. Both types of afferents (visceral and somatic) synapse with interneurons, which then synapse with second neurons whose fibers pass across the cord and then ascend to the somatosensory areas of the brain that represent the T1 to T4 levels. The brain is unable to distinguish clearly between the visceral sensory distribution and the somatic sensory distribution and therefore the pain is interpreted as arising from the somatic regions rather than the visceral organ (i.e., the heart; Fig. 3.109C).

The patient was breathless because his left ventricular function was poor.

When the left ventricle fails, it produces two effects.

- First, the contractile force is reduced. This reduces the pressure of the ejected blood and lowers the blood pressure.
- The left atrium has to work harder to fill the failing left ventricle. This extra work increases left atrial pressure, which is reflected in an increased pressure in the pulmonary veins, and this subsequently creates a higher pulmonary venular pressure. This rise in pressure will cause fluid to leak from the capillaries into the pulmonary interstitium and then into the alveoli. Such fluid is called pulmonary edema and it markedly restricts gas exchange. This results in shortness of breath.

This man had a blocked left coronary artery, as shown in Fig. 3.109B.
It is important to know which coronary artery is blocked.

- The left coronary artery supplies the majority of the left side of the heart. The left main stem vessel is approximately 2 cm long and divides into the circumflex artery, which lies between the atrium and the ventricle in the coronary sulcus, and the anterior interventricular artery, which is often referred to as the left anterior descending artery (LAD).

- When the right coronary artery is involved with arterial disease and occludes, associated disorders of cardiac rhythm often result because the sinoatrial and the atrioventricular nodes derive their blood supplies predominantly from the right coronary artery.

When this patient sought medical care, his myocardial function was assessed using ECG, echocardiography, and angiography.

During a patient's initial examination, the physician will usually assess myocardial function.

After obtaining a clinical history and carrying out a physical examination, a differential diagnosis for the cause of the malfunctioning heart is made. Objective assessment of myocardial and valve function is obtained in the following ways:

- **ECG/EKG (electrocardiography)**—a series of electrical traces taken around the long and short axes of the heart that reveal heart rate and rhythm and conduction defects. In addition, it demonstrates the overall function of the right and left sides of the heart and points of dysfunction. Specific changes in the ECG relate to the areas of the heart that have been involved in a myocardial infarction. For example, a right coronary artery occlusion produces infarction in the area of myocardium it supplies, which is predominantly the inferior aspect; the infarct is therefore called an inferior myocardial infarction. The ECG changes are demonstrated in the leads that visualize the inferior aspect of the myocardium (namely, leads II, III, and aVF).

- **Chest radiography**—reveals the size of the heart and chamber enlargement. Careful observation of the lungs will demonstrate excess fluid (pulmonary edema), which builds up when the left ventricle fails and can produce marked respiratory compromise and death unless promptly treated.

- **Blood tests**—the heart releases enzymes during myocardial infarction, namely lactate dehydrogenase (LDH), creatine kinase (CK), and aspartate transaminase (AST). These plasma enzymes are easily measured in the hospital laboratory and used to determine the diagnosis at an early stage. Further specific enzymes termed isoenzymes can also be determined (creatine kinase MB isoenzyme [CKMB]). Newer tests include an assessment for troponin (a specific component of the myocardium), which is released when cardiac cells die during myocardial infarction.

- **Exercise testing**—patients are connected to an ECG monitor and exercised on a treadmill. Areas of ischemia, or poor blood flow, can be demonstrated, so localizing the vascular abnormality.

- **Nuclear medicine**—thallium (a radioactive X-ray emitter) and its derivatives are potassium analogs. They are used to determine areas of coronary ischemia. If no areas of myocardial uptake are demonstrated when these substances are administered to a patient the myocardium is dead.

- **Coronary angiography**—small arterial catheters are maneuvered from a femoral artery puncture site through the femoral artery and aorta and up to the origins of the coronary vessels. X-ray contrast medium is then injected to demonstrate the coronary vessels and their important branches. If there is any narrowing (stenosis), angioplasty may be carried out. In angioplasty tiny balloons are passed across the narrowed areas and inflated to refashion the vessel and so prevent further coronary ischemia and myocardial infarction.
Case 5

BROKEN PACEMAKER

An elderly woman was admitted to the emergency room with severe cardiac failure. She had a left-sided pacemaker box, which had been inserted for a cardiac rhythm disorder (fast atrial fibrillation) many years previously. An ECG demonstrated fast atrial fibrillation. A chest radiograph showed that the wire from the pacemaker had broken under the clavicle.

Anatomical knowledge of this region of the chest explains why the wire broke.

Many patients have cardiac pacemakers. A wire arises from the pacemaker, which lies within the subcutaneous tissue over the pectoralis major muscle and travels from the pacemaker under the skin to pierce the axillary vein just beneath the clavicle, lateral to the subclavius muscle. The wire then passes through the subclavian vein, the brachiocephalic vein, the superior vena cava, the right atrium, and lies on the wall of the right ventricle (where it can stimulate the heart to contract). If the wire pierces the axillary vein directly adjacent to the subclavius muscle, it is possible that after many years of shoulder movement the subclavius muscle stresses and breaks the wire, causing the pacemaker to fail. Every effort is made to place the insertion point of the wire as far laterally as feasible within the first part of the axillary vein.

Case 6

COARCTATION OF THE AORTA

A 20-year-old man visited his family doctor because he had a cough. A chest radiograph demonstrated translucent notches along the inferior border of ribs III to VI (Fig. 3.110). He was referred to a cardiologist and a diagnosis of coarctation of the aorta was made. The rib notching was caused by dilated collateral intercostal arteries.

Coarctation of the aorta is a narrowing of the aorta distal to the left subclavian artery. This narrowing can markedly reduce blood flow to the lower body. Many of the vessels above the narrowing therefore enlarge due to the increased pressure so that blood can reach the aorta below the level of the narrowing. Commonly, the internal thoracic, superior epigastric, and musculophrenic arteries enlarge anteriorly. These arteries supply the anterior intercostal arteries, which anastomose with the posterior intercostal arteries that allow blood to flow retrogradely into the aorta.

The first and second posterior intercostal vessels are supplied from the costocervical trunk, which arises from the subclavian artery proximal to the coarctation, so do not enlarge and do not induce rib notching.

Fig. 3.110 Chest radiograph demonstrating translucent notches along the inferior border of ribs III to VI.
Case 7

AORTIC DISSECTION

A 62-year-old man was admitted to the emergency room with severe interscapular pain. His past medical history indicates he is otherwise fit and well, however it was noted he was 6’ 9” and had undergone previous eye surgery for dislocating lenses.

On examination the man was pale, clammy, and hypotensive. The pulse in his right groin was weak. An ECG demonstrated an inferior myocardial infarction. Serum blood tests revealed poor kidney function and marked acidosis.

The patient was transferred to the CT scanner and a diagnosis of aortic dissection was made.

Aortic dissection is an uncommon disorder in which a small tear occurs within the aortic wall (Fig. 3.111). The aortic wall contains three layers, an intima, a media, and an adventitia. A tear in the intima extends into the media and peels it away, forming two channels. Usually the blood re-enters the main vessel wall distal to its point of entry.

The myocardial infarction

Aortic dissection may extend retrogradely to involve the coronary sinus of the right coronary artery. Unfortunately, in this patient’s case the right coronary artery became occluded as the dissection passed into the origin. In normal individuals the right coronary artery supplies the anterior inferior aspect of the myocardium, and this is evident as an anterior myocardial infarction on an ECG.

The ischemic left leg

The two channels within the aorta have extended throughout the length of the aorta into the right iliac system and to the level of the right femoral artery. Although blood flows through these structures it often causes reduced blood flow. Hence the reduced blood flow into the left lower limb rendering it ischemic.

The patient became acidotic.

Fig. 3.111 CT image of aortic dissection. The illustration (right) shows the line of the CT cut.

(continued)
Thorax

Case 7 (continued)

All cells in the body produce acid which is excreted in the urine or converted into water with the production of carbon dioxide which is removed with ventilation. Unfortunately, when organs become extremely ischemic they release significant amounts of hydrogen iron. Typically this occurs when the gut becomes ischemic and with the pattern of dissection the celiac trunk, superior mesenteric artery and inferior mesenteric artery can be effectively removed from the circulation or blood flow within these vessels can be significantly impeded rendering the gut ischemic and hence accounting for the relatively high hydrogen iron levels.

Case 8

PNEUMONIA

A 35-year-old male patient presented to his family practitioner because of recent weight loss (14 lb over the previous 2 months). He also complained of a cough with streaks of blood in the sputum (hemoptysis) and left-sided chest pain. Recently, he noticed significant sweating, especially at night, which necessitated changing his sheets.

On examination the patient had a low-grade temperature and was tachypneic (breathing fast). There was reduced expansion of the left side of the chest. When the chest was percussed it was noted that the anterior aspect of the left chest was dull, compared to the resonant percussion note of the remainder of the chest. Auscultation (listening with a stethoscope) revealed decreased breath sounds, which were hoarse in nature (bronchial breathing).

A diagnosis of chest infection was made.

Chest infection is a common disease. In most patients the infection affects the large airways and bronchi. If the infection continues, exudates and transudates are produced, filling the alveoli and the secondary pulmonary lobules. The diffuse patchy nature of this type of infection is termed bronchial pneumonia.

Given the patient’s specific clinical findings, bronchial pneumonia was unlikely.

Kidney ischemia

Similarly the dissection can impair blood flow to the kidneys which decreases their ability to function.

Treatment

The patient underwent emergency surgery and survived. Interestingly, the height of the patient and the previous lens surgery would suggest a diagnosis of Marfan syndrome, and a series of blood tests and review of the family history revealed this was so.
Knowing the position of the oblique fissure, any consolidation within the left upper lobe will produce this veil-like shadowing. Lateral radiographs are usually not necessary, but would demonstrate opacification anteriorly and superiorly that ends abruptly at the oblique fissure.

Upper lobe pneumonias are unusual because most patients develop gravity dependent infection. Certain infections, however, are typical within the middle and upper lobes, commonly, tuberculosis (TB) and histoplasmosis.

A review of the patient’s history suggested a serious and chronic illness and the patient was admitted to hospital.

After admission a bronchoscopy was carried out and sputum was aspirated from the left upper lobe bronchus. This was cultured in the laboratory and also viewed under the microscope and tuberculous bacilli (TB) were identified.

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**Case 8 (continued)**

ESOPHAGEAL CANCER

A 68-year-old man came to his family physician complaining of discomfort when swallowing (dysphagia). The physician examined the patient and noted since his last visit he had lost approximately 18 lb over 6 months. Routine blood tests revealed the patient was anemic and he was referred to the gastroenterology unit. A diagnosis of esophageal cancer was made and the patient underwent a resection, which involved a chest and abdominal incision. After 4 years the patient remains well though still subject to follow-up.

The patient underwent a flexible endoscopic examination of the esophagus in which a tube is placed through the mouth and into the esophagus and a camera is placed on the end of the tub. It is also possible to use biopsy forceps to obtain small portions of tissue for adequate diagnosis.

The diagnosis of esophageal carcinoma was made (squamous cell type) and the patient underwent a staging procedure.

Staging of any malignancy is important, because it determines the extent of treatment and allows the physician to determine the patient’s prognosis. In this case our patient underwent a CT scan of the chest and abdomen, which revealed no significant lymph nodes around the lower third esophageal tumor.

The abdominal scan revealed no evidence of spread to the nodes around the celiac trunk and no evidence of spread to the liver.

Bleeding was the cause of the anemia.

Many tumors of the gastrointestinal system are remarkably friable, and with the passage of digested material across the tumor, low grade chronic bleeding occurs. Over a period of time the patient is rendered anemic, which in the first instance is asymptomatic; however, it can be diagnosed on routine blood tests.

Complex surgery is planned.

The length of the esophagus is approximately 22 cm (take a ruler and measure 22 cm—I suspect this will be a significantly shorter than you imagine the esophagus to be!). Tumor spread can occur through the submucosal route and also through locoregional lymph nodes. The lymph nodes drain along the arterial supply to the esophagus, which is predominantly supplied by the inferior thyroid artery, esophageal branches from the
### Case 9 (continued)

Thoracic aorta, and branches from the left gastric artery. The transsthoracic esophagectomy procedure involves placing the patient supine. A laparotomy is performed to assess for any evidence of disease in the abdominal cavity. The stomach is mobilized with preservation of the right gastric and right gastro-omental arteries. The short gastric vessels and left gastric vessels are divided, and a pyloromyotomy is also performed.

The abdominal wound is then closed and the patient is then placed in the left lateral position. A right posterolateral thoracotomy is performed through the fifth intercostal space, and the azygos vein is divided to provide full access to the whole length of the esophagus. The stomach is delivered through the diaphragmatic hiatus. The esophagus is resected and the stomach is anastomosed to the cervical esophagus.

The patient made an uneventful recovery.

Most esophageal cancers are diagnosed relatively late and often have lymph node metastatic spread. A number of patients will also have a spread of tumor to the liver. The overall prognosis for esophageal cancer is poor, with approximately a 25%, 5-year survival rate.

Diagnosing esophageal cancer in its early stages before lymph node spread is ideal and can produce a curative procedure.

Our patient went on to have chemotherapy and enjoys a good quality of life 4 years after his operation.

### Case 10

**VENOUS ACCESS**

A 45-year-old woman, with a history of breast cancer in the left breast, returned to her physician. Unfortunately the disease had spread to the axillary lymph nodes and bones (bony metastatic disease). A surgeon duly resected the primary breast tumor with a wide local excision and then performed an axillary nodal clearance. The patient was then referred to an oncologist for chemotherapy. Chemotherapy was delivered through a portacath, which is a subcutaneous reservoir from which a small catheter passes under the skin into the internal jugular vein. The patient duly underwent a portacath insertion without complication, completed her course of chemotherapy and is currently doing well 5 years later.

The portacath was placed on the patient’s right anterior chest wall and the line was placed into the right internal jugular vein. The left internal jugular vein and subcutaneous tissues were not used. The reason for not using this site was that the patient had previously undergone an axillary dissection on the left, and the lymph nodes and lymphatics were removed. Placement of a portacath in this region may produce an inflammatory response and may even get infected. Unfortunately, because there are no lymphatics to drain away infected material and to remove bacteria, severe sepsis and life threatening infection may ensue.

**How was it placed?**

The ultrasound shows an axial image across the root of the neck on the right demonstrating the right common carotid artery and the right internal jugular vein. The internal jugular vein is the larger on the two structures and generally demonstrates normal respiratory variation, compressibility and a size dependence upon the patient’s position (when the patient is placed in the head down position, the vein fills and makes puncture easy).

**The risks of the procedure**

As with all procedures and operations there is always a small risk of complication. These risks are always balanced against the potential benefits of the procedure.

(continued)
Placing the needle into the internal jugular vein can be performed under ultrasound guidance, which reduces the risk of puncturing the common carotid artery. Furthermore, by puncturing under direct vision it is less likely that the operator will hit the lung apex and pierce the superior pleural fascia, which may produce a pneumothorax.

The position of the indwelling catheter

The catheter is placed through the right internal jugular vein and into the right brachiocephalic vein. The tip of the catheter is then placed more inferiorly at the junction of the right atrium and the superior vena cava. The reason for placing the catheter in such a position relates to the agents that are infused. Most chemotherapeutic agents are severely cytotoxic (kill cells) and enabling good mixing with the blood prevents thrombosis and vein wall irritation.