

Diaphragm

The diaphragm is a thin muscular and tendinous septum that separates the chest cavity above from the abdominal cavity below (Fig. 2.16). It is pierced by the structures that pass between the chest and the abdomen.

The diaphragm is the most important muscle of respiration. It is dome shaped and consists of a peripheral muscular part, which arises from the margins of the thoracic opening, and a centrally placed tendon (see Fig. 2.16). The origin of the diaphragm can be divided into three parts:

- A **sternal part** arising from the posterior surface of the xiphoid process (see Fig. 2.2)
- A **costal part** arising from the deep surfaces of the lower six ribs and their costal cartilages (see Fig. 2.16)
- A **vertebral part** arising by vertical columns or crura and from the arcuate ligaments

The **right crus** arises from the sides of the bodies of the first three lumbar vertebrae and the intervertebral discs; the **left**

crus arises from the sides of the bodies of the first two lumbar vertebrae and the intervertebral disc (see Fig. 2.16). Lateral to the crura the diaphragm arises from the **medial and lateral arcuate ligaments** (see Fig. 2.16). The medial arcuate ligament extends from the side of the body of the second lumbar vertebra to the tip of the transverse process of the first lumbar vertebra. The lateral arcuate ligament extends from the tip of the transverse process of the first lumbar vertebra to the lower border of the 12th rib. The medial borders of the two crura are connected by a **median arcuate ligament**, which crosses over the anterior surface of the aorta (see Fig. 2.16).

The diaphragm is inserted into a **central tendon**, which is shaped like three leaves. The superior surface of the tendon is partially fused with the inferior surface of the fibrous pericardium. Some of the muscle fibers of the right crus pass up to the left and surround the esophageal orifice in a slinglike loop. These fibers appear to act as a sphincter and possibly assist in the prevention of regurgitation of the stomach contents into the thoracic part of the esophagus (see Fig. 2.16).



CLINICAL NOTES

Traumatic Injury to the Thorax

Traumatic injury to the thorax is common, especially as a result of automobile accidents.

Fractured Sternum

The sternum is a resilient structure that is held in position by relatively pliable costal cartilages and bendable ribs. For these reasons, fracture of the sternum is not common; however, it does occur in high-speed motor vehicle accidents. Remember that the heart lies posterior to the sternum and may be severely contused by the sternum on impact.

Rib Contusion

Bruising of a rib, secondary to trauma, is the most common rib injury. In this painful condition, a small hemorrhage occurs beneath the periosteum.

Rib Fractures

Fractures of the ribs are common chest injuries. In children, the ribs are highly elastic, and fractures in this age group are therefore rare. Unfortunately, the pliable chest wall in the young can be easily compressed so that the underlying lungs and heart may be injured. With increasing age, the rib cage becomes more rigid, owing to the deposit of calcium in the costal cartilages, and the ribs become brittle. The ribs then tend to break at their weakest part, their angles.

The ribs prone to fracture are those that are exposed or relatively fixed. Ribs 5 through 10 are the most commonly fractured ribs. The first four ribs are protected by the clavicle and pectoral muscles anteriorly and by the scapula and its associated muscles posteriorly. The 11th and 12th ribs float and move with the force of impact.

Because the rib is sandwiched between the skin externally and the delicate pleura internally, it is not surprising that the

jagged ends of a fractured rib may penetrate the lungs and present as a **pneumothorax**.

Severe localized pain is usually the most important symptom of a fractured rib. The periosteum of each rib is innervated by the intercostal nerves above and below the rib. To encourage the patient to breathe adequately, it may be necessary to relieve the pain by performing an intercostal nerve block.

Flail Chest

In severe crush injuries, a number of ribs may break. If limited to one side, the fractures may occur near the rib angles and anteriorly near the costochondral junctions. This causes flail chest, in which a section of the chest wall is disconnected to the rest of the thoracic wall. If the fractures occur on either side of the sternum, the sternum may be flail. In either case, the stability of the chest wall is lost, and the flail segment is sucked in during inspiration and driven out during expiration, producing paradoxical and ineffective respiratory movements.

Traumatic Injury to the Back of the Chest

The posterior wall of the chest in the midline is formed by the vertebral column. In severe posterior chest injuries, the possibility of a vertebral fracture with associated injury to the spinal cord should be considered. Remember also the presence of the scapula, which overlies the upper seven ribs. This bone is covered with muscles and is fractured only in cases of severe trauma.

Traumatic Injury to the Abdominal Viscera and the Chest

When the anatomy of the thorax is reviewed, it is important to remember that the upper abdominal organs—namely, the liver, stomach, and spleen—may be injured by trauma to the rib cage. In fact, any injury to the chest below the level of the nipple line may involve abdominal organs as well as chest organs.

Shape of the Diaphragm

As seen from in front, the diaphragm curves up into **right and left domes**, or cupulae. The right dome reaches as high as the upper border of the 5th rib, and the left dome may reach the lower border of the 5th rib. (The right dome lies at a higher level, because of the large size of the right lobe of the liver.) The central tendon lies at the level of the xiphisternal joint. The domes support the right and left lungs, whereas the central tendon supports the heart. The levels of the diaphragm vary with the phase of respiration, the posture, and the degree of distention of the abdominal viscera. The diaphragm is lower when a person is sitting or standing; it is higher in the supine position and after a large meal.

When seen from the side, the diaphragm has the appearance of an inverted J, the long limb extending up from the vertebral column and the short limb extending forward to the xiphoid process (see Fig. 2.2).

Nerve Supply of the Diaphragm

Motor nerve supply: The right and left phrenic nerves (C3, 4, 5).

Sensory nerve supply: The parietal pleura and peritoneum covering the central surfaces of the diaphragm are from the phrenic nerve and the periphery of the diaphragm is from the lower six intercostal nerves.

Action of the Diaphragm

On contraction, the diaphragm pulls down its central tendon and increases the vertical diameter of the thorax.

Functions of the Diaphragm

- **Muscle of inspiration:** On contraction, the diaphragm pulls its central tendon down and increases the vertical diameter of the thorax. The diaphragm is the most important muscle used in inspiration.
- **Muscle of abdominal straining:** The contraction of the diaphragm assists the contraction of the muscles of the anterior abdominal wall in raising the intra-abdominal pressure for micturition, defecation, and parturition. This mechanism is further aided by the person taking a deep breath and closing the glottis of the larynx. The diaphragm is unable to rise because of the air trapped in the respiratory tract. Now and again, air is allowed to escape, producing a grunting sound.
- **Weight-lifting muscle:** In a person taking a deep breath and holding it (fixing the diaphragm), the diaphragm assists the muscles of the anterior abdominal wall in raising the intra-abdominal pressure to such an extent that it helps support the vertebral column and prevent flexion. This greatly assists the postvertebral muscles in the lifting of heavy weights. Needless to say, it is important to have adequate sphincteric control of the bladder and anal canal under these circumstances.
- **Thoracoabdominal pump:** The descent of the diaphragm decreases the intrathoracic pressure and at the same time increases the intra-abdominal pressure. This pressure change compresses the blood in the inferior vena cava and forces it upward into the right atrium of the heart. Lymph within the abdominal lymph vessels is



CLINICAL NOTES

Needle Thoracostomy

A needle thoracostomy is necessary in patients with tension pneumothorax (air in the pleural cavity under pressure) or to drain fluid (blood or pus) away from the pleural cavity to allow the lung to reexpand. It may also be necessary to withdraw a sample of pleural fluid for microbiologic examination.

Anterior Approach

For the anterior approach, the patient is in the supine position. The sternal angle is identified, and then the 2nd costal cartilage, the 2nd rib, and the second intercostal space are found in the midclavicular line.

Lateral Approach

For the lateral approach, the patient is lying on the lateral side. The 2nd intercostal space is identified as above, but the anterior axillary line is used.

The skin is prepared in the usual way, and a local anesthetic is introduced along the course of the needle above the upper border of the 3rd rib. The thoracostomy needle will pierce the following structures as it passes through the chest wall (see Fig. 2.8): (a) skin, (b) superficial fascia (in the anterior approach the pectoral muscles are then penetrated), (c) serratus anterior muscle,

(d) external intercostal muscle, (e) internal intercostal muscle, (f) innermost intercostal muscle, (g) endothoracic fascia, and (h) parietal pleura.

The needle should be kept close to the upper border of the 3rd rib to avoid injuring the intercostal vessels and nerve in the subcostal groove.

Tube Thoracostomy

The preferred insertion site for a tube thoracostomy is the fourth or fifth intercostal space at the anterior axillary line (Fig. 2.14). The tube is introduced through a small incision. The neurovascular bundle changes its relationship to the ribs as it passes forward in the intercostal space. In the most posterior part of the space, the bundle lies in the middle of the intercostal space. As the bundle passes forward to the rib angle, it becomes closely related to the lower border of the rib above and maintains that position as it courses forward.

The introduction of a thoracostomy tube or needle through the lower intercostal spaces is possible provided that the presence of the domes of the diaphragm is remembered as they curve upward into the rib cage as far as the 5th rib (higher on the right). Avoid damaging the diaphragm and entering the peritoneal cavity and injuring the liver, spleen, or stomach.

(continued)

Thoracotomy

In patients with penetrating chest wounds with uncontrolled intrathoracic hemorrhage, thoracotomy may be a life-saving procedure. After preparing the skin in the usual way, the physician makes an incision over the fourth or fifth intercostal space, extending from the lateral margin of the sternum to the anterior axillary line (Fig. 2.15). Whether to make a right or left incision depends on the site of the injury. For access to the heart and the aorta, the chest should be entered from the left side. The following tissues will be incised (see Fig. 2.14): (a) skin, (b) subcutaneous tissue, (c) serratus anterior and pectoral muscles, (d) external intercostal muscle and anterior intercostal membrane, (e) internal intercostal muscle, (f) innermost intercostal muscle, (g) endothoracic fascia, and (h) parietal pleura.

Avoid the **internal thoracic artery**, which runs vertically downward behind the costal cartilages about a fingerbreadth lateral to the margin of the sternum, and the **intercostal vessels and nerve**, which extend forward in the subcostal groove in the upper part of the intercostal space (see Fig. 2.14).

Hiccup

Hiccup is the involuntary spasmodic contraction of the diaphragm accompanied by the approximation of the vocal folds and closure of the glottis of the larynx. It is a common condition

also compressed, and its passage upward within the thoracic duct is aided by the negative intrathoracic pressure. The presence of valves within the thoracic duct prevents backflow.

Openings in the Diaphragm

The diaphragm has three main openings:

- The **aortic opening** lies anterior to the body of the 12th thoracic vertebra between the crura (see Fig. 2.16). It transmits the aorta, the thoracic duct, and the azygos vein.
- The **esophageal opening** lies at the level of the 10th thoracic vertebra in a sling of muscle fibers derived from the right crus (see Fig. 2.16). It transmits the esophagus, the right and left vagus nerves, the esophageal branches of the left gastric vessels, and the lymphatics from the lower third of the esophagus.
- The **caval opening** lies at the level of the 8th thoracic vertebra in the central tendon (see Fig. 2.16). It transmits the inferior vena cava and terminal branches of the right phrenic nerve.

In addition to these openings, the sympathetic splanchnic nerves pierce the crura; the sympathetic trunks pass posterior to the medial arcuate ligament on each side; and the superior epigastric vessels pass between the sternal and costal origins of the diaphragm on each side (see Fig. 2.16).

Internal Thoracic Artery

The internal thoracic artery supplies the anterior wall of the body from the clavicle to the umbilicus. It is a branch of the first part of the subclavian artery in the neck. It descends

in normal individuals and occurs after eating or drinking as a result of gastric irritation of the vagus nerve endings. It may, however, be a symptom of disease such as pleurisy, peritonitis, pericarditis, or uremia.

Paralysis of the Diaphragm

A single dome of the diaphragm may be paralyzed by crushing or sectioning of the phrenic nerve in the neck. This may be necessary in the treatment of certain forms of lung tuberculosis, when the physician wishes to rest the lower lobe of the lung on one side. Occasionally, the contribution from the fifth cervical spinal nerve joins the phrenic nerve late as a branch from the nerve to the subclavius muscle. This is known as the **accessory phrenic nerve**. To obtain complete paralysis under these circumstances, the nerve to the subclavius muscle must also be sectioned.

Penetrating Injuries of the Diaphragm

Penetrating injuries can result from stab or bullet wounds to the chest or abdomen. Any penetrating wound to the chest below the level of the nipples should be suspected of causing damage to the diaphragm until proved otherwise. The arching domes of the diaphragm can reach the level of the 5th rib (the right dome can reach a higher level).

vertically on the pleura behind the costal cartilages, a fingerbreadth lateral to the sternum, and ends in the sixth intercostal space by dividing into the superior epigastric and musculophrenic arteries (see Figs. 2.9 and 2.10).

Branches

- Two **anterior intercostal arteries** for the upper six intercostal spaces
- **Perforating arteries**, which accompany the terminal branches of the corresponding intercostal nerves
- The **pericardiophrenic artery**, which accompanies the phrenic nerve and supplies the pericardium
- **Mediastinal arteries** to the contents of the anterior mediastinum (e.g., the thymus)
- The **superior epigastric artery**, which enters the rectus sheath of the anterior abdominal wall and supplies the rectus muscle as far as the umbilicus
- The **musculophrenic artery**, which runs around the costal margin of the diaphragm and supplies the lower intercostal spaces and the diaphragm

Internal Thoracic Vein

The internal thoracic vein accompanies the internal thoracic artery and drains into the brachiocephalic vein on each side.

Levatores Costarum

There are 12 pairs of muscles. Each levator costa is triangular in shape and arises by its apex from the tip of the transverse process and is inserted into the rib below.

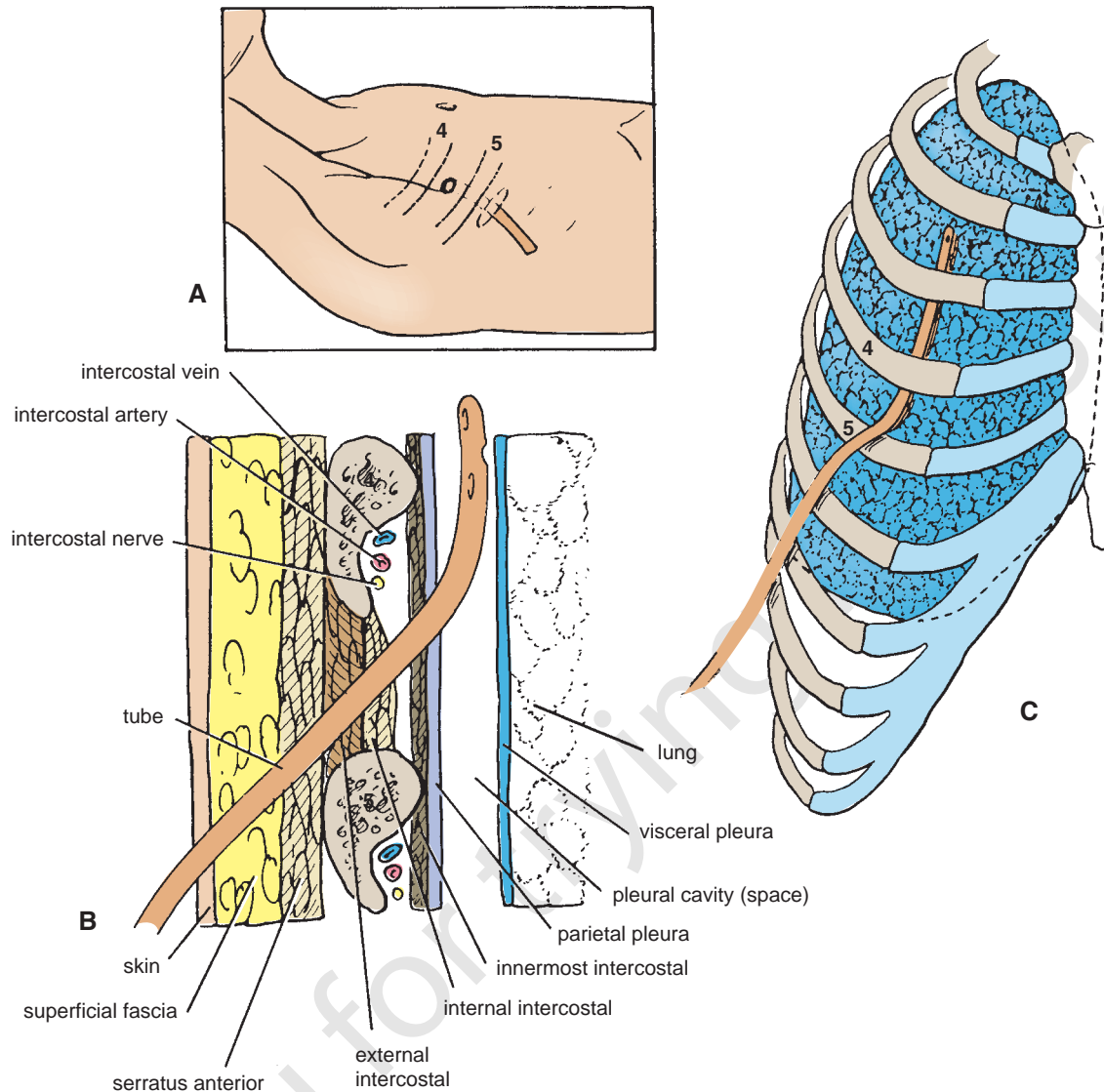


FIGURE 2.14 Tube thoracostomy. **A.** The site for insertion of the tube at the anterior axillary line. The skin incision is usually made over the intercostal space one below the space to be pierced. **B.** The various layers of tissue penetrated by the scalpel and later the tube as they pass through the chest wall to enter the pleural cavity (space). The incision through the intercostal space is kept close to the upper border of the rib to avoid injuring the intercostal vessels and nerve. **C.** The tube advancing superiorly and posteriorly in the pleural space.

- **Action:** Each raises the rib below and is therefore an inspiratory muscle.
- **Nerve supply:** Posterior rami of thoracic spinal nerves.

Serratus Posterior Superior Muscle

The serratus posterior superior is a thin, flat muscle that arises from the lower cervical and upper thoracic spines. Its fibers pass downward and laterally and are inserted into the upper ribs.

- **Action:** It elevates the ribs and is therefore an inspiratory muscle.
- **Nerve supply:** Intercostal nerves.

Serratus Posterior Inferior Muscle

The serratus posterior inferior is a thin, flat muscle that arises from the upper lumbar and lower thoracic spines. Its fibers pass upward and laterally and are inserted into the lower ribs.

- **Action:** It depresses the ribs and is therefore an expiratory muscle.
- **Nerve supply:** Intercostal nerves.

A summary of the muscles of the thorax, their nerve supply, and their actions is given in Table 2.1.

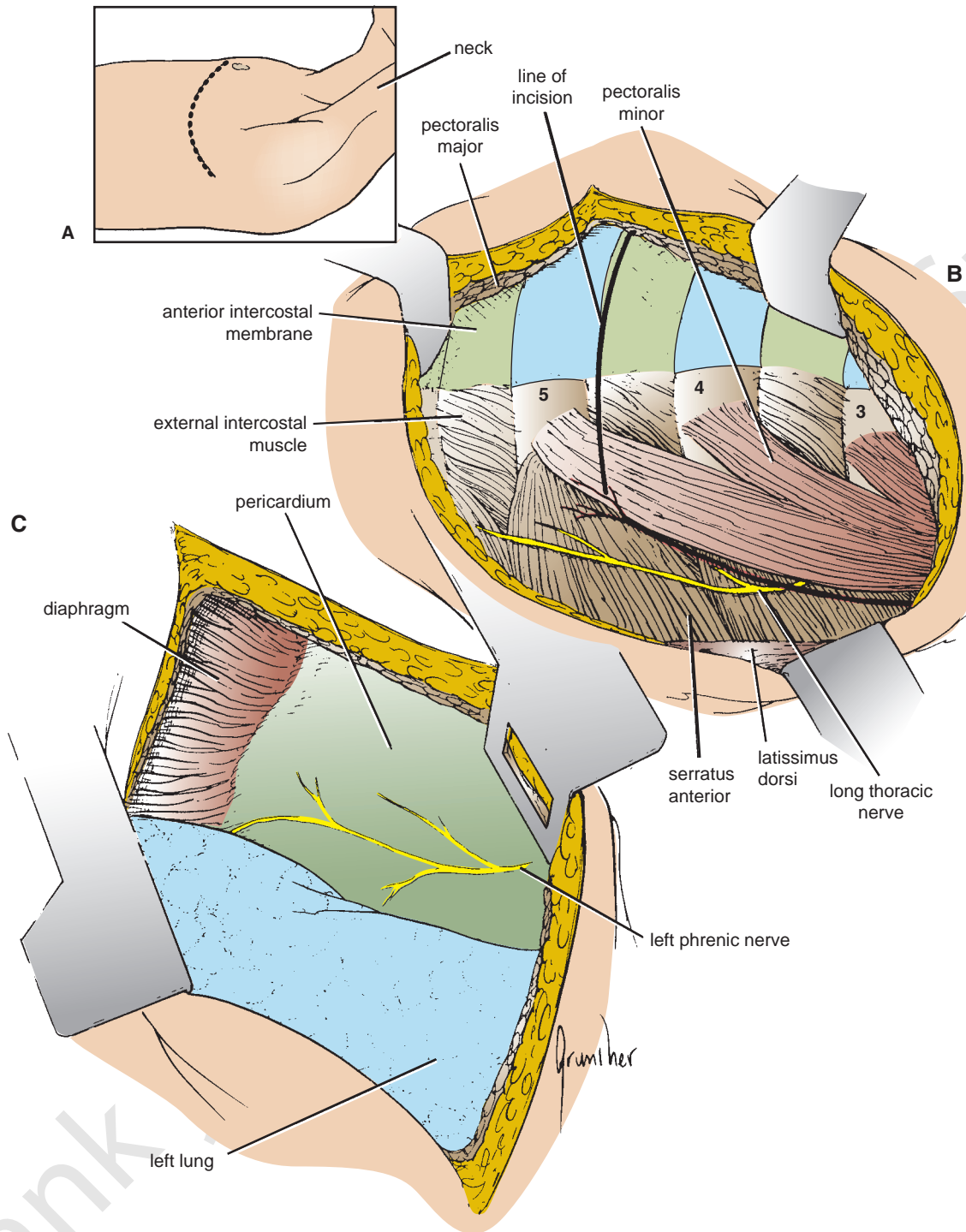


FIGURE 2.15 Left thoracotomy. **A.** Site of skin incision over fourth or fifth intercostal space. **B.** The exposed ribs and associated muscles. The line of incision through the intercostal space should be placed close to the upper border of the rib to avoid injuring the intercostal vessels and nerve. **C.** The pleural space opened and the left side of the mediastinum exposed. The left phrenic nerve descends over the pericardium beneath the mediastinal pleura. The collapsed left lung must be pushed out of the way to visualize the mediastinum.

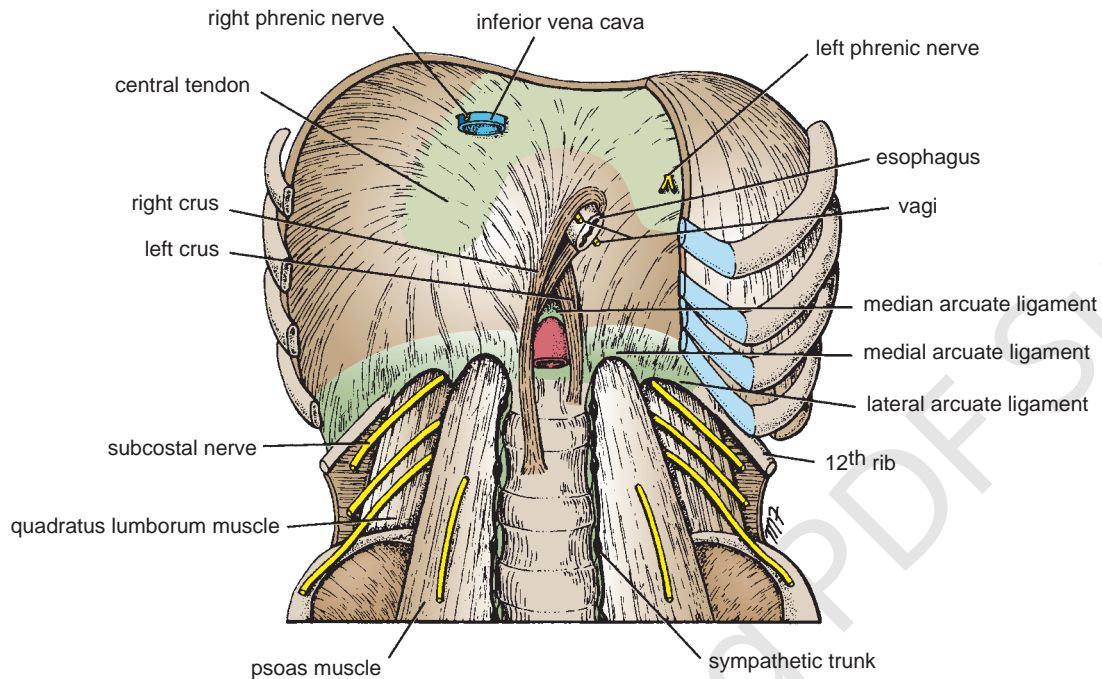


FIGURE 2.16 Diaphragm as seen from below. The anterior portion of the right side has been removed. Note the sternal, costal, and vertebral origins of the muscle and the important structures that pass through it.

TABLE 2.1 Muscles of the Thorax

Name of Muscle	Origin	Insertion	Nerve Supply	Action
External intercostal muscle (11) (fibers pass downward and forward)	Inferior border of rib	Superior border of rib below	Intercostal nerves	With 1st rib fixed, they raise ribs during inspiration and thus increase anteroposterior and transverse diameters of thorax
Internal intercostal muscle (11) (fibers pass downward and backward)	Inferior border of rib	Superior border of rib below	Intercostal nerves	With last rib fixed by abdominal muscles, they lower ribs during expiration
Innermost intercostal muscle (incomplete layer)	Adjacent ribs	Adjacent ribs	Intercostal nerves	Assists external and internal intercostal muscles
Diaphragm (most important muscle of respiration)	Xiphoid process; lower six costal cartilages, first three lumbar vertebrae	Central tendon	Phrenic nerve	Very important muscle of inspiration; increases vertical diameter of thorax by pulling central tendon downward; assists in raising lower ribs Also used in abdominal straining and weight lifting
Levatores costarum (12)	Tip of transverse process of C7 and T1–11 vertebrae	Rib below	Posterior rami of thoracic spinal nerves	Raises ribs and therefore inspiratory muscles
Serratus posterior superior	Lower cervical and upper thoracic spines	Upper ribs	Intercostal nerves	Raises ribs and therefore inspiratory muscles
Serratus posterior inferior	Upper lumbar and lower thoracic spines	Lower ribs	Intercostal nerves	Depresses ribs and therefore expiratory muscles