3 Anatomy of the Thoracic Wall, Pulmonary Cavities, and Mediastinum

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Contents

1. INTRODUCTION

The thorax is the body cavity, surrounded by the bony rib cage, that contains the heart and lungs, the great vessels, the esophagus and trachea, the thoracic duct, and the autonomic innervation for these structures. The inferior boundary of the thoracic cavity is the respiratory diaphragm, which separates the thoracic and abdominal cavities. Superiorly, the thorax communicates with the root of the neck and the upper extremity. The wall of the thorax contains the muscles involved with respiration and those connecting the upper extremity to the axial skeleton. The wall of the thorax is responsible for protecting the contents of the thoracic cavity and for generating the negative pressure required for respiration. The thorax is covered by skin and superficial fascia, which contains the mammary tissue.

This chapter reviews the mediastinum and pulmonary cavities within the thorax and discusses their contents. The wall of the thorax and its associated muscles, nerves, and vessels are covered in relationship to respiration. The surface anatomical landmarks that designate deeper anatomical structures and sites of access and auscultation are reviewed. The goal of this chapter is to provide a complete picture of the thorax and its contents, with detailed anatomy of thoracic structures excluding the heart. A detailed description of cardiac anatomy is the subject of Chapter 4.

2. OVERVIEW OF THE THORAX

Anatomically, the thorax is typically divided into compartments; there are two bilateral pulmonary cavities; each contains a lung with its pleural covering (Fig. 1). The space between the pleural cavities is the mediastinum, which contains all the other structures found in the thorax. The mediastinum is divided into the superior and inferior compartments by a plane referred to as the "transverse thoracic plane"; it passes through the mediastinum at the level of the sternal angle and the junction of the T4 and T5 vertebrae (Fig. 1).

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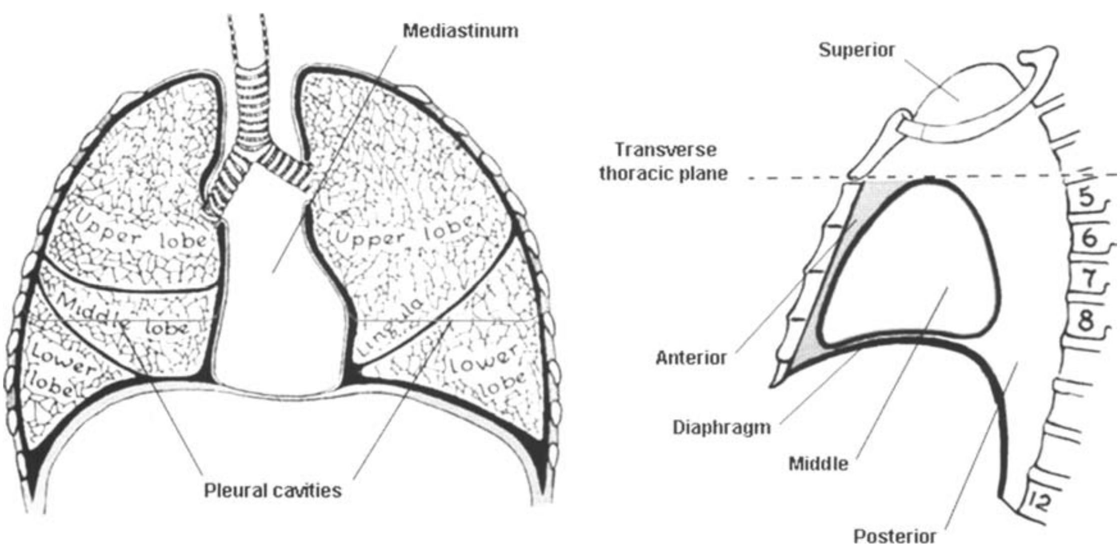


Fig. 1. The left panel is a diagrammatic representation of the pulmonary cavities, one on each side of the thorax with the mediastinum between. The right panel illustrates the divisions of the mediastinum. Adapted from Figs. 1.14 (left) and 1.24 of *Grant's Dissector*, 12th Ed., E. K. Sauerland (ed.). © 1999 Lippincott, Williams, and Wilkins, Philadelphia, PA.

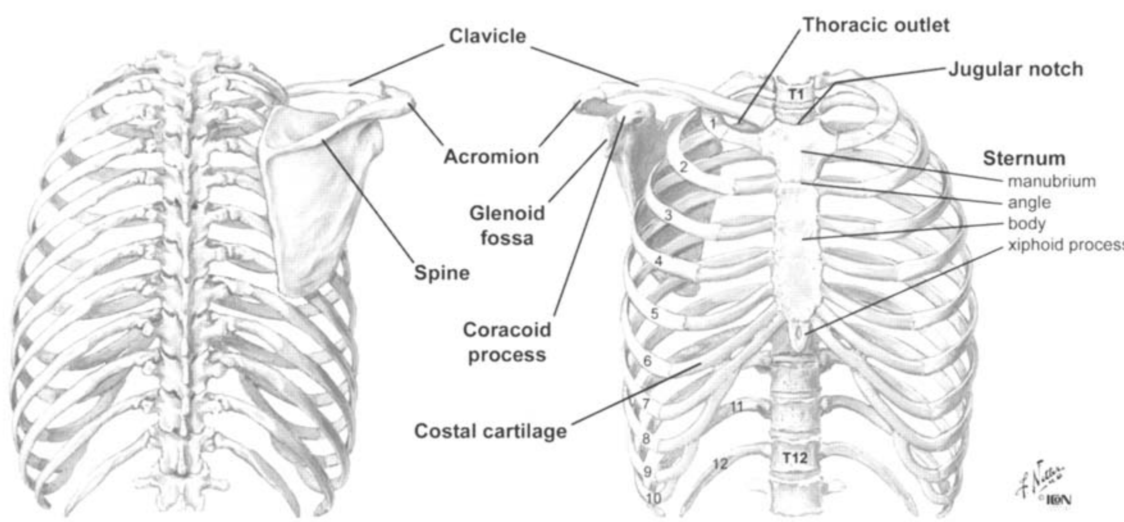


Fig. 2. The left panel illustrates the bones of the thorax from a posterior view. The right panel is an anterior view of the bony thorax.

The superior mediastinum contains the major vessels supplying the upper extremity, the neck, and the head. The inferior mediastinum, the space between the transverse thoracic plane and the diaphragm, is further divided into the anterior, middle, and posterior mediastinum. The middle mediastinum is the space containing the heart and pericardium. The anterior mediastinum is the space between the pericardium and the sternum. The posterior mediastinum extends from the pericardium to the posterior wall of the thorax.

The inferior aperture of the thorax is formed by the lower margin of the ribs and costal cartilages and is closed off from the abdomen by the respiratory diaphragm (Fig. 1). The superior aperture of the thorax leads to the neck and the upper extremity. It is formed by the first ribs and their articulation with the manubrium and first thoracic vertebra. The root of the neck is open to the superior aperture of the thorax, and numerous structures pass from the neck to the thoracic cavity. The clavicle crosses the first rib at its anterior edge close to its articulation with the manubrium. Structures exiting the superior thoracic aperture and communicating with the upper extremity pass between the first rib and clavicle.

3. BONES OF THE THORACIC WALL

3.1. The Thoracic Cage

The skeleton of the thoracic wall is composed of the 12 ribs, the thoracic vertebra and intervertebral discs, and the sternum. Attached to the thorax are the bones of the pectoral girdle, the clavicle and the scapula (Fig. 2). Of these, the clavicle is particularly important because it forms, with the first rib, the thoracic outlet to the upper extremity.

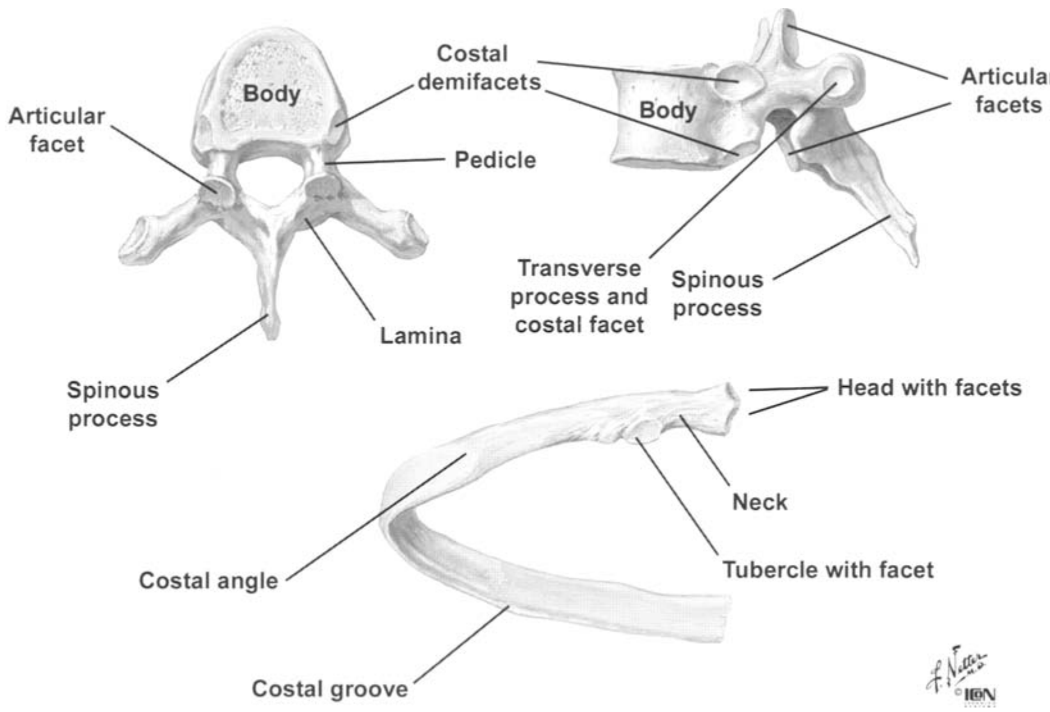


Fig. 3. The T6 vertebra as viewed from above (upper left) and laterally (upper right) and a typical rib (bottom).

The thoracic vertebrae comprise the middle portion of the posterior wall of the thorax. Each thoracic vertebra has a body anteriorly, two pedicles and two lamina that together form an arch creating the vertebral foramen; a relatively long spinous process projecting posteriorly and inferiorly; and two transverse processes projecting laterally and somewhat posteriorly (Fig. 3). Each thoracic vertebra articulates with at least one rib.

The first through 9th thoracic vertebrae have a set of costal facets on their bodies for articulation with the head of the rib. These costal facets are also called *demifacets*. The superior demifacet articulates with the head of the rib of the same number as the vertebra. The inferior demifacet articulates with the head of the rib below. The head of rib 1 articulates only with the T1 vertebra. Thus, this vertebra has a single facet for articulation with rib 1 and a demifacet for articulation with rib 2. The heads of ribs 10–12 articulate only with the vertebra of the same number. The articular facet on vertebrae T10–T12 is located at the junction of the body and pedicle (T10) or fully on the pedicle (T11 and T12). The first 10 thoracic vertebrae also have costal facets on their transverse processes for articulation with the tubercles of the ribs of the same number. The transverse processes of the thoracic vertebrae get progressively shorter, and the transverse processes of T11 and T12 do not articulate with the tubercles of their respective ribs.

The ribs form the largest part of the bony wall of the thorax (Fig. 2). Each rib articulates with one or two thoracic vertebrae, and the upper 10 ribs articulate directly or indirectly with the sternum anteriorly. The upper 7 ribs are referred to as "true" ribs because each connects to the sternum via its own costal cartilage. Ribs 8–10 are referred to as "false" ribs because they connect indirectly to the sternum. Each of these ribs is connected to the rib immediately above via their costal cartilage and ultimately to the sternum via the costal cartilage of the 7th rib. Ribs 11 and 12 are referred to as "floating" ribs because they do not connect to the sternum, but end in the musculature of the abdominal wall.

Each rib has a head that articulates with the thoracic vertebra and a thin flat shaft that is curved (Fig. 3). The costal angle, the sharpest part of the curved shaft, is located where the rib turns anteriorly. At the inferior margin of the shaft, the internal surface of the rib is recessed to form the costal groove. This depression provides some protection to the intercostal neurovascular bundle, something that must be considered when designing devices for intercostal access to the thorax. The heads of ribs 2–9 have two articular facets for articulation with the vertebra of the same level and the vertebra above. The heads of ribs 1, 10, 11, and 12 only articulate with the vertebra of the same number and consequently have only one articular facet. In ribs 1–10, the head is connected to the shaft by a narrowing called the "neck." At the junction of the head and the neck is a tubercle that has an articular surface for articulation with the costal facet of the transverse process. Ribs 11 and 12 do not articulate with the transverse process of their respective vertebra and do not have a tubercle or a neck portion.

The sternum is the flat bone that makes up the median anterior part of the thoracic cage (Fig. 2). It is composed of three parts: the manubrium, body, and xiphoid process. The manubrium (from the Latin word for *handle*, like the handle of a sword) is the superior part of the sternum; it is the widest and thickest part. The manubrium alone articulates with the clavicle and the first rib. The sternal heads of the clavicle can be readily seen and palpated at their junction with the manubrium. The depression between the sternal heads of the clavicle above the manubrium is the suprasternal, or jugular, notch.

The manubrium and the body of the sternum lie in slightly different planes and thus form a noticeable and easily palpated angle, the sternal angle (of Louis), at the point where they articulate. The second rib articulates with both the body of the sternum and the manubrium and can easily be identified just lateral to the sternal angle. The body of the sternum is formed from the fusion of segmental bones (the sternebrae). The remnants of this fusion can be seen in the transverse ridges of the sternal body, especially in young people. The third through sixth ribs articulate with the body of the sternum, and the seventh rib articulates at the junction of the sternum and xiphoid process.

The xiphoid process is the most inferior part of the sternum and is easily palpated. It lies at the level of thoracic vertebra 10 and marks the inferior boundary of the thoracic cavity anteriorly. It also lies at the level even with the central tendon of the diaphragm and the inferior border of the heart.

3.2. The Pectoral Girdle

Many of the muscles encountered on the wall of the anterior thorax are attached to the bones of the pectoral girdle and the upper extremity. Because movement of these bones can have an impact on the anatomy of vascular structures communicating between the thorax and upper extremity, it is important to include these structures in a discussion of the thorax.

The clavicle is a somewhat S-shaped bone that articulates at its medial end with the manubrium of the sternum and at its lateral end with the acromion of the scapula (Fig. 2). It is convex medially and concave laterally. The scapula is a flat triangular bone, concave anteriorly, that rests upon the posterior thoracic wall. It has a posterior raised ridge called the "spine" that ends in a projection of bone called the "acromion," which articulates with the clavicle. The coracoid process is an anterior projection of bone from the superior border of the clavicle that serves as an attachment point for muscles that act on the scapula and upper extremity. The head of the humerus articulates with the glenoid fossa of the scapula, forming the glenohumeral joint. The clavicle serves as a strut to hold the scapula in position away from the lateral aspect of the thorax. It is a highly mobile bone, with a high degree of freedom at the sternoclavicular joint that facilitates movement of the shoulder girdle against the thorax. The anterior extrinsic muscles of the shoulder pass from the wall of the thorax to the bones of the shoulder girdle.

4. MUSCLES OF THE THORACIC WALL

4.1. The Pectoral Muscles

Several muscles of the thoracic wall, including the most superficial ones that create some of the contours of the thoracic wall, are muscles that act on the upper extremity. Some of these muscles form important surface landmarks on the thorax, and others have relationships to vessels that communicate with the thorax. In addition to moving the upper extremity, some of these muscles also can play a role in movement of the thoracic wall and participate in respiration. The pectoralis major muscle forms the surface contour of the upper lateral part of the thoracic wall (Fig. 4). It originates on the clavicle (clavicular head) and the sternum and ribs (sternocostal head) and inserts on the greater tubercle of the humerus. The lower margin of this muscle, passing from the thorax to the humerus, forms the major part of the anterior axillary fold. The pectoralis major muscle is a powerful adductor and medial rotator of the arm.

The pectoralis minor muscle is a much smaller muscle and lies directly beneath the pectoralis major muscle (Fig. 4). It originates on ribs 3–5 and inserts on the coracoid process of the scapula. This muscle forms part of the anterior axillary fold medially. It acts to depress the scapula and stabilizes it when upward force is exerted on the shoulder.

The anterior part of the deltoid muscle also forms a small aspect of the anterior thoracic wall. This muscle has its origin on the lateral part of the clavicle and the acromion and spine of the scapula (Fig. 4). It inserts on the deltoid tubercle of the humerus and is the most powerful abductor of the arm. The deltoid muscle borders the pectoralis major muscle. The depression found at the junction of these two muscles is called the *deltopectoral groove*. Importantly, within this groove the cephalic vein can consistently be found. The muscles diverge at their origins on the clavicle, creating an opening bordered by these two muscles and the clavicle known as the *deltopectoral triangle*. Through this space the cephalic vein passes to join the axillary vein.

The subclavius is a small muscle originating on the lateral inferior aspect of the clavicle and inserting on the sternal end of the first rib (Fig. 4). This muscle depresses the clavicle and exerts a medial traction on the clavicle that stabilizes the sternoclavicular joint. In addition to these actions, the subclavius muscle provides a soft surface on the inferior aspect of the clavicle that serves to cushion the contact of this bone with structures passing under the clavicle (i.e., nerves of the brachial plexus and the subclavian artery) when the clavicle is depressed during movement of the shoulder girdle, especially when the clavicle is fractured.

The serratus anterior muscle originates on the lateral aspect of the first eight ribs and passes laterally to insert on the medial aspect of the scapula (Fig. 5). This muscle forms the "serrated" contour of the lateral thoracic wall in individuals with good muscle definition. The serratus anterior forms the medial border of the axilla and acts to pull the scapula forward (protraction) and to stabilize the scapula against a posterior force on the shoulder.

4.2. The Intercostal Muscles

Each rib is connected to the ones above and below by a series of three intercostal muscles. The external intercostal muscles are the most superficial (Fig. 5). These muscles course in an obliquely medial direction as they pass from superior to inferior between the ribs. Toward the midline anteriorly, the external intercostal muscle fibers are replaced by the external intercostal membrane. Deep to the external intercostals are the internal intercostals (Fig. 5). The direction of the internal intercostal muscle fibers is perpendicular to the external intercostals. On the posterior end of the ribs, the internal intercostal muscle fibers are replaced by the internal intercostal membrane.

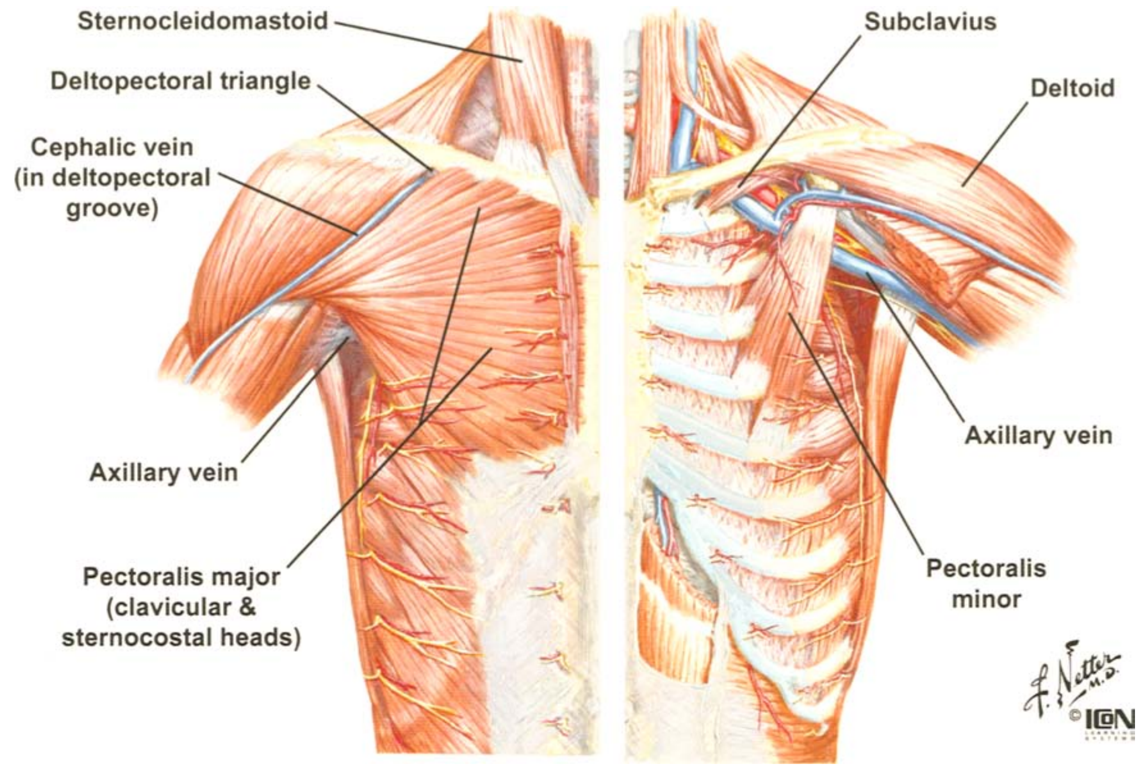


Fig. 4. The musculature of the anterior thoracic wall. The left panel shows the superficial muscles intact. The right panel shows structures deep to the pectoralis major muscle.

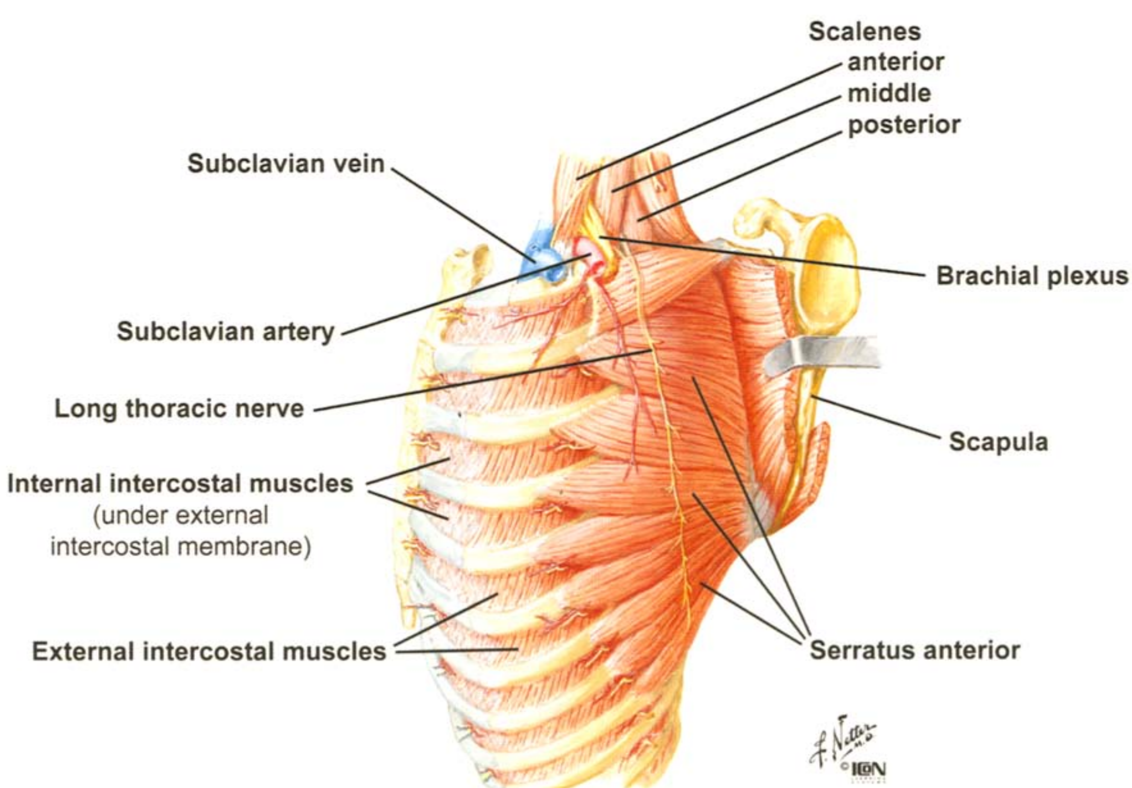


Fig. 5. A lateral view of the musculature of the thoracic wall.

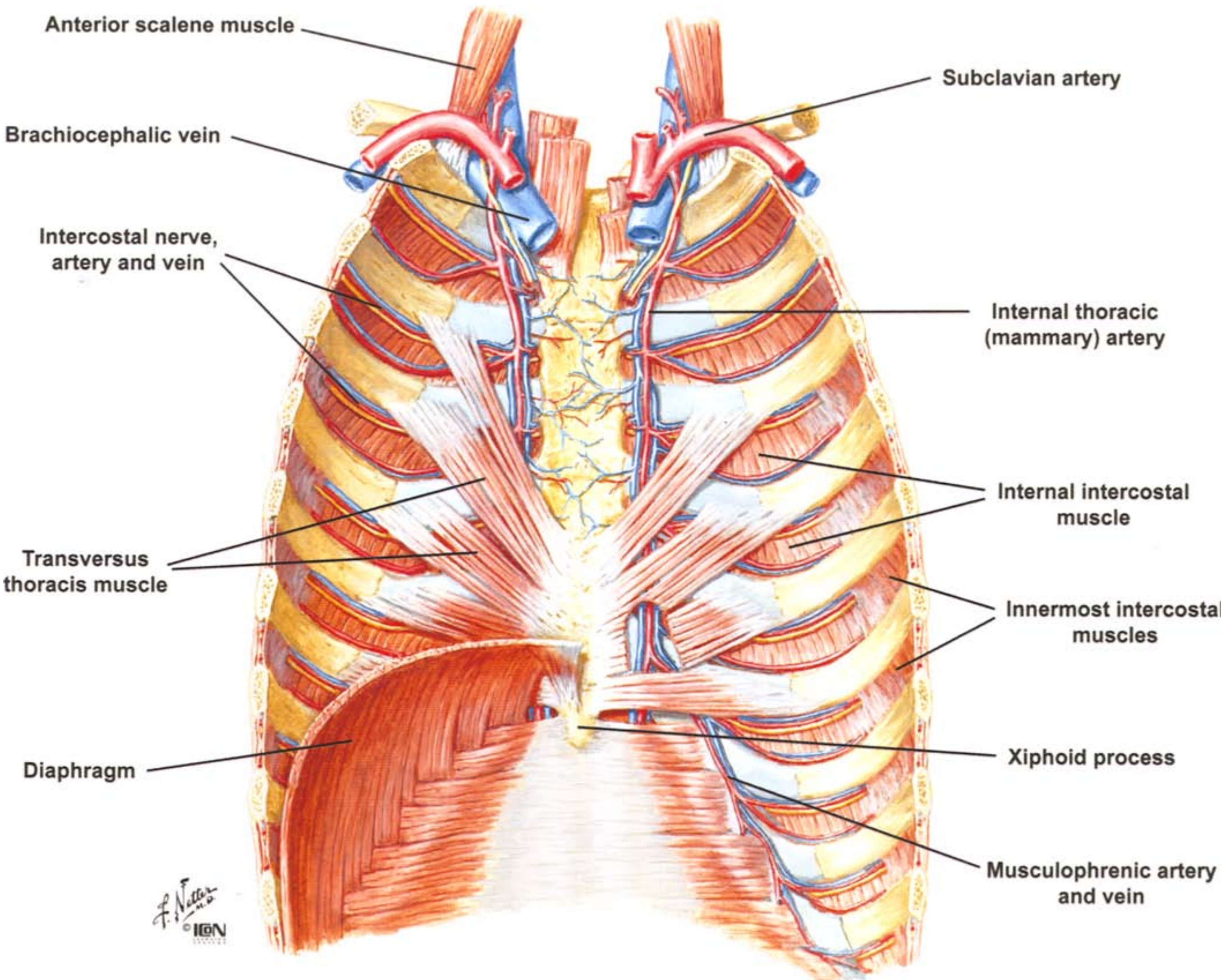


Fig. 6. The deep musculature of the anterior thoracic wall viewed from the posterior side.

The deepest layer of intercostal muscles is the innermost intercostal muscles (Fig. 6). These muscles have a fiber direction similar to that of the internal intercostals, but form a separate plane. The intercostal nerves and vessels pass between the internal and innermost intercostal muscles.

There are two additional sets of muscles in the same layer as the innermost intercostals: the subcostals and the transversus thoracis muscles. The subcostal muscles are located posteriorly and span more than one rib. The transversus thoracic muscles are found anteriorly and are continuous with the innermost muscle layer of the abdomen, the transversus abdominus, inferiorly. The transversus thoracis muscles pass from the internal surface of the sternum to ribs 2–6.

The intercostal muscles, especially the external and internal intercostals, are involved with respiration by elevating or depressing the ribs. The external intercostal muscles and the anterior interchondral part of the internal intercostals act to elevate the ribs. The lateral parts of the internal intercostal muscles depress the ribs. The innermost intercostals most likely have an action similar to that of the internal intercostals. The subcostal muscles probably help to elevate the ribs. The transversus thoracis muscles have little, if any, effect on respiration.

4.3. Respiratory Diaphragm

The respiratory diaphragm is the musculotendinous sheet separating the abdominal and thoracic cavities (Fig. 7). It is also considered the primary muscle of respiration. The diaphragm originates along the inferior border of the rib cage, the xiphoid process of the sternum, the posterior abdominal wall musculature, and the upper lumbar vertebra. The medial and lateral arcuate ligaments are thickenings of the investing fascia over the quadratus lumborum (lateral) and the psoas major (medial) muscles of the posterior abdominal wall that serve as attachments for the diaphragm (Fig. 7). The vertebral origins of the diaphragm are the right and left crura. The crura originate on the bodies of lumbar vertebrae 1–3, their intervertebral discs, and the anterior longitudinal ligament spanning these vertebrae.

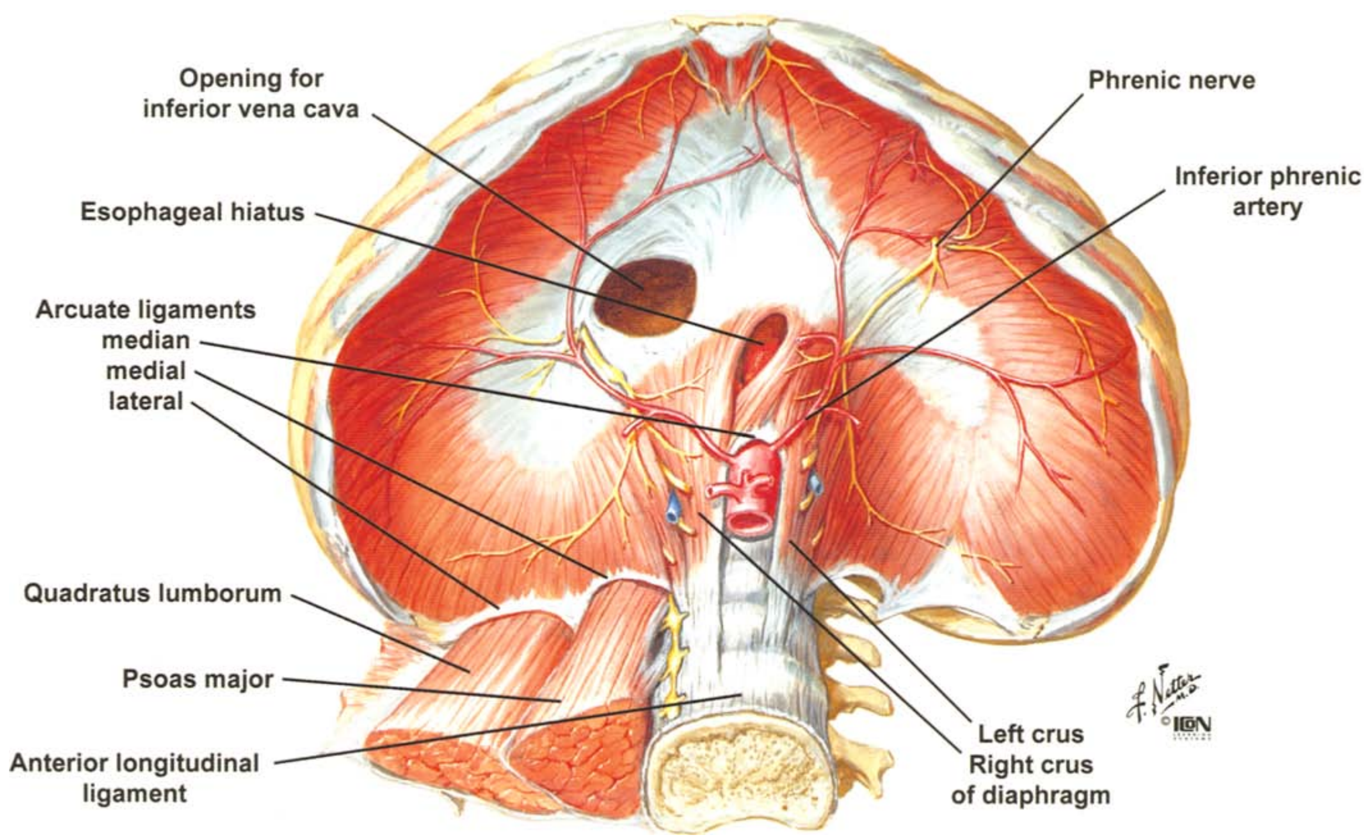


Fig. 7. The abdominal side of the respiratory diaphragm illustrating the origins of the muscle.

The diaphragm ascends from its origin to form a right and left dome; the right dome is typically higher than the left. The muscular part of the diaphragm contracts during respiration, causing the dome of the diaphragm to descend, increasing the volume of the thoracic cavity. The aponeurotic central part of the diaphragm, called the *central tendon*, contains the opening for the vena cava. The esophagus also passes through the diaphragm, and the hiatus for the esophagus is created by a muscular slip originating from the right crus of the diaphragm. The aorta passes from the thorax to the abdomen behind the diaphragm, under the median arcuate ligament created by the intermingling of fibers from the right and left crura of the diaphragm. The vena cava, esophagus, and aorta pass from the thorax to the abdomen at thoracic vertebral levels 8, 10, and 12, respectively.

4.4. Other Muscles of Respiration

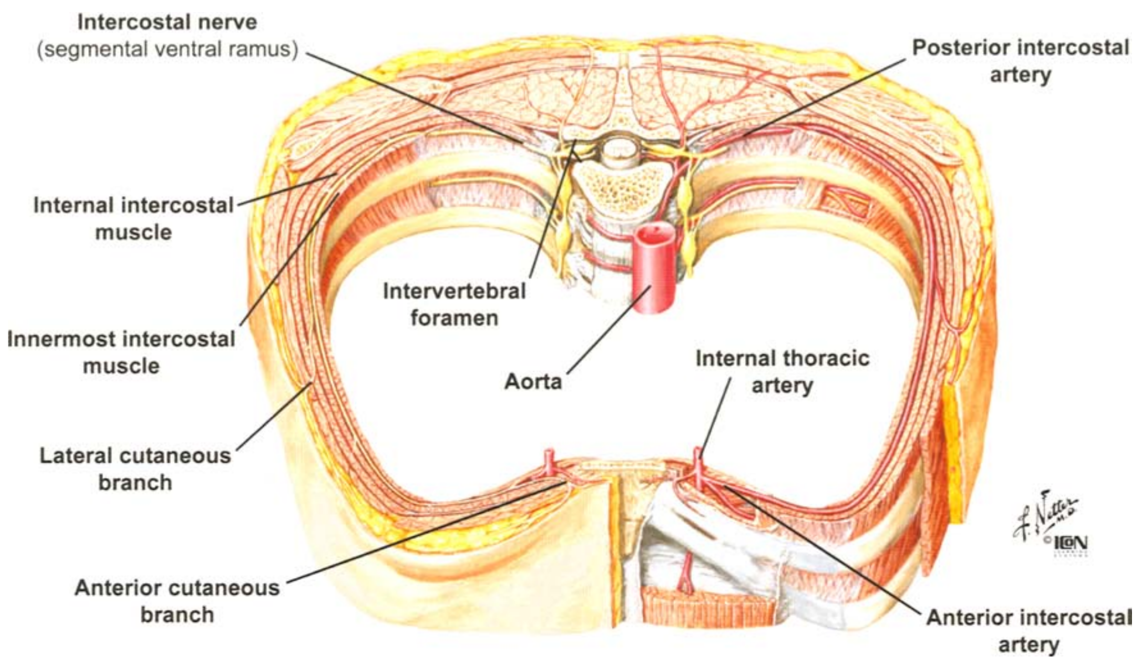
The scalene muscles and the sternocleidomastoid muscle in the neck also contribute to respiration, especially during deep respiration (Figs. 4 and 5). The scalene muscles have their origin on the transverse processes of cervical vertebrae 4 to 6. The anterior and middle scalenes insert on the first rib and the posterior scalene on the second rib. As its name suggests, the sternocleidomastoid has its origin on the mastoid process of the skull and inserts on the medial aspect of the clavicle and the manubrium of the sternum. When contracting with the head and neck fixed, these muscles exert an upward pull on the thorax and assist in respiration.

The muscles of the anterior abdominal wall are also involved with respiration. These muscles, the rectus abdominus, external and internal abdominal obliques, and transversus abdominus, act together during forced expiration to pull down on the rib cage and to increase intra-abdominal pressure, forcing the diaphragm to expand upward. The mechanics of respiration are explained in detail in Section 11.3.

5. NERVES OF THE THORACIC WALL

The wall of the thorax receives its innervation from intercostal nerves (Fig. 8). These nerves are the ventral rami of segmental nerves leaving the spinal cord at the thoracic vertebral levels. Intercostal nerves are mixed nerves that carry both somatic motor and sensory nerves and autonomics to the skin. The intercostal nerves pass out of the intervertebral foramina and run inferior to the rib. As they reach the costal angle, the nerves pass between the innermost and the internal intercostal muscles.

The motor innervation to all the intercostal muscles comes from the intercostal nerves. These nerves give off lateral and anterior cutaneous branches that provide cutaneous sensory innervation to the skin of the thorax. The intercostal nerves also carry sympathetic nerve fibers to the sweat glands, smooth muscle, and blood vessels. However, the first two intercostal nerves are considered atypical. The first intercostal nerve divides shortly after it emerges from the intervertebral foramen. The larger superior part of this nerve joins the brachial plexus to provide innervation to the upper extremity. The lateral cuta-



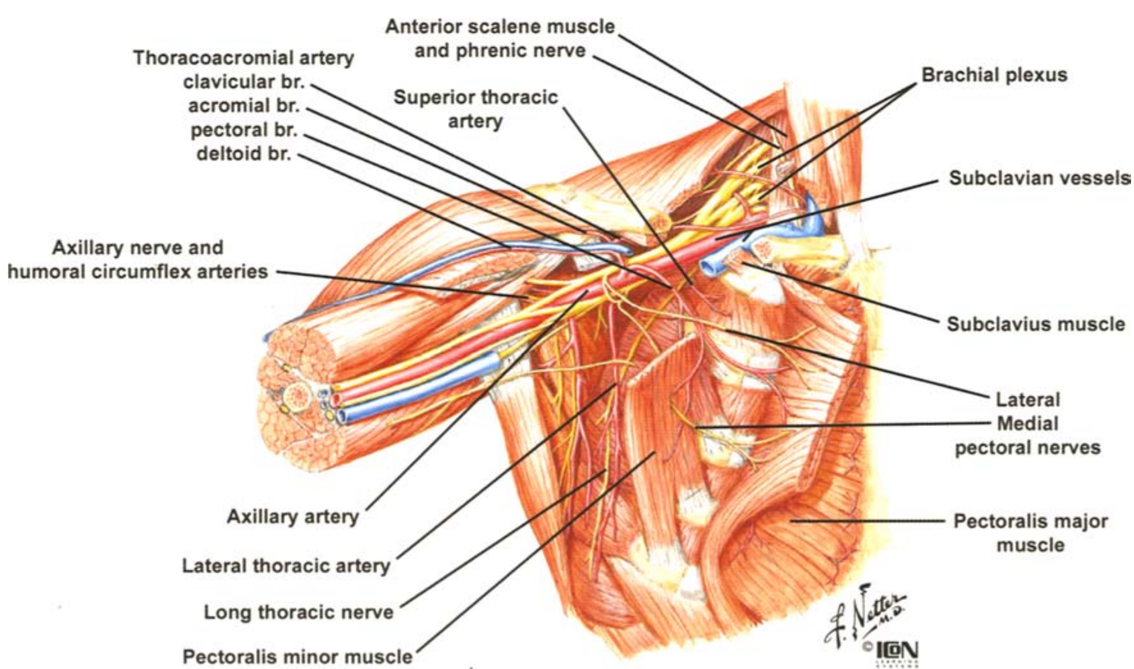


Fig. 9. The nerves and arteries of the axilla viewed with the pectoralis major and minor muscles reflected.

neous branch of the second intercostal nerve is large and typically pierces the serratus anterior muscle, passes through the axilla and into the arm as the intercostobrachial nerve, and provides sensory innervation to the floor of the axilla and medial aspect of the arm (Fig. 9). The nerve associated with the 12th rib is the subcostal nerve, because there is no rib below this level. It is a nerve of the abdominal wall.

The pectoral muscles receive motor innervation from branches of the brachial plexus of nerves (derived from cervical levels 5–8 and thoracic level 1) that supply the muscles of the shoulder and upper extremity. The lateral and medial pectoral nerves, branches of the lateral and medial cords of the brachial plexus, supply the pectoralis major and minor muscles (Fig. 9). The pectoralis major muscle is innervated by both nerves and the pectoralis minor muscle by only the medial pectoral nerve, which pierces this muscle before entering the pectoralis major muscle. The serratus anterior muscle is innervated by the long thoracic nerve, which originates from ventral rami of C5, C6, and C7 (Figs. 5 and 9). The deltoid muscle is innervated by the axillary nerve, a terminal branch of the posterior cord of the brachial plexus. Finally, the subclavius muscle is innervated by its own nerve from the superior trunk of the brachial plexus.

6. VESSELS OF THE THORACIC WALL

The intercostal muscles and the skin of the thorax receive their blood supply from both the intercostal arteries and the internal thoracic artery (Fig. 8). Intercostal arteries 3–11 (and the subcostal artery) are branches directly from the thoracic descending aorta. The first two intercostal arteries are branches of the supreme intercostal artery, which is a branch of the costocervical trunk from the subclavian artery. The posterior intercostals run with the intercostal nerve and pass with the nerve between the innermost and internal intercostal muscles. The intercostals then anastomose with anterior intercostal branches arising from the internal thoracic artery descending immediately lateral to the sternum. The internal thoracic arteries are anterior branches from the subclavian arteries bilaterally. The anterior and posterior intercostal anastomoses create an anastomotic network around the thoracic wall. The intercostal arteries are accompanied by intercostal veins (Fig. 6). These veins drain to the azygos system of veins in the posterior mediastinum. The anatomy of the azygos venous system is described in detail in Section 10.2. Anteriorly, the intercostal veins drain to the internal thoracic veins, which in turn drain to the subclavian veins in the superior mediastinum.

The intercostal nerves, arteries, and veins run together in each intercostal space close to the rib above. They are characteristically found in this order (vein, artery, nerve), with the vein closest to the rib.

The diaphragm receives blood from the musculophrenic artery, a terminal branch of the internal thoracic artery, which runs along the anterior superior surface of the diaphragm (Fig. 6). There is also a substantial blood supply to the inferior aspect of the diaphragm from the inferior phrenic arteries, the most superior branches from the abdominal aorta that branch along the inferior surface of the diaphragm (Fig. 7).

The muscles of the pectoral region get their blood supply from branches of the axillary artery. This artery is the continuation of the subclavian artery emerging from the thorax and passing under the clavicle (Fig. 9). The first branch of the axillary artery, the superior (supreme) thoracic artery, gives blood supply to the first two intercostal spaces. The second branch forms the thoracoacromial artery or trunk. Subsequently, this artery gives off four sets of branches (pectoral, deltoid, clavicular, and acromial) that supply blood to the pectoral muscles, the deltoid muscle, the clavicle, and the subclavius muscle, respectively. The lateral thoracic artery, the third branch from the subclavian artery, participates along with the intercostal arteries in supplying the serratus anterior muscle. Additional distal branches from the axillary artery, the humeral circumflex arteries, also participate in blood supply to the deltoid muscle. Venous blood returns through veins of the same names to the axillary vein.

7. THE SUPERIOR MEDIASTINUM

The superior mediastinum is the space behind the manubrium of the sternum (Fig. 1). It is bounded by parietal (mediastinal) pleura on each side and the first four thoracic vertebrae behind. It is continuous with the root of the neck at the top of the first ribs and with the inferior mediastinum below the transverse thoracic plane, a horizontal plane that passes from the sternal angle through the space between the T4 and T5 vertebrae. Because of the inferior sloping of the first ribs, the superior mediastinum is wedge shaped as it is longer posteriorly. The superior mediastinum contains several important structures, including the branches of the aortic arch, the veins that coalesce to form the superior vena cava, the trachea, the esophagus, the vagus and phrenic nerves, the cardiac plexus of autonomic nerves, the thoracic duct, and the thymus (Fig. 10).

7.1. Arteries in the Superior Mediastinum

As the aorta emerges from the pericardial sac, it begins to arch posteriorly (Fig. 11). At the level of the T4 vertebra, the aorta has become vertical again, descending through the posterior mediastinum. The intervening segment is the arch of the aorta, and it courses from right to left as it arches posteriorly. It passes over the right pulmonary artery and ends by passing posterior to the left pulmonary artery. The trachea and esophagus pass posterior and to the right of the aortic arch.

The arch of the aorta gives off the major arteries that supply blood to the head and to the upper extremity. This branching is asymmetrical. The first and most anterior branch from the aorta is the brachiocephalic trunk. This arterial trunk bends toward the right as it ascends, and as it reaches the upper limit of the superior mediastinum, it bifurcates into the right common carotid and right subclavian arteries. The next two branches from the aortic arch, from anterior to posterior, are the left common carotid and the left subclavian arteries. These two arteries ascend almost vertically to the left of the trachea. The common carotid arteries will supply the majority of the blood to the head and neck. The subclavian arteries continue as the axillary and brachial arteries and supply the upper extremity.

The arch of the aorta and its branches make contact with the upper lobe of the right lung, and their impressions are normally seen on the fixed lung after removal. The brachiocephalic trunk, left common carotid, and the left subclavian do not give off consistent branches in the superior mediastinum. However, the subclavian arteries at the root of the neck give off the internal thoracic arteries, which reenter the superior mediastinum and descend along each side of the sternum.

On occasion, there will be an artery that branches from the aortic arch, the right common carotid, or one of the subclavian arteries and supplies the thyroid gland in the midline. This variant artery is called a *thyroid ima*. Because this artery is often found crossing the region where a tracheostomy is performed, it is important to remember that this artery is present in about 10% of individuals.

7.2. Brachiocephalic Veins

The bilateral brachiocephalic veins are formed by the merging of the internal jugular vein and the subclavian vein on both sides at the base of the neck (Fig. 11). The right brachiocephalic vein descends nearly vertically; the left crosses obliquely behind the manubrium to join the right and then form the superior vena cava. The superior vena cava continues inferiorly into the middle mediastinum, entering the pericardial sac. The brachiocephalic veins run anterior in the superior mediastinum.

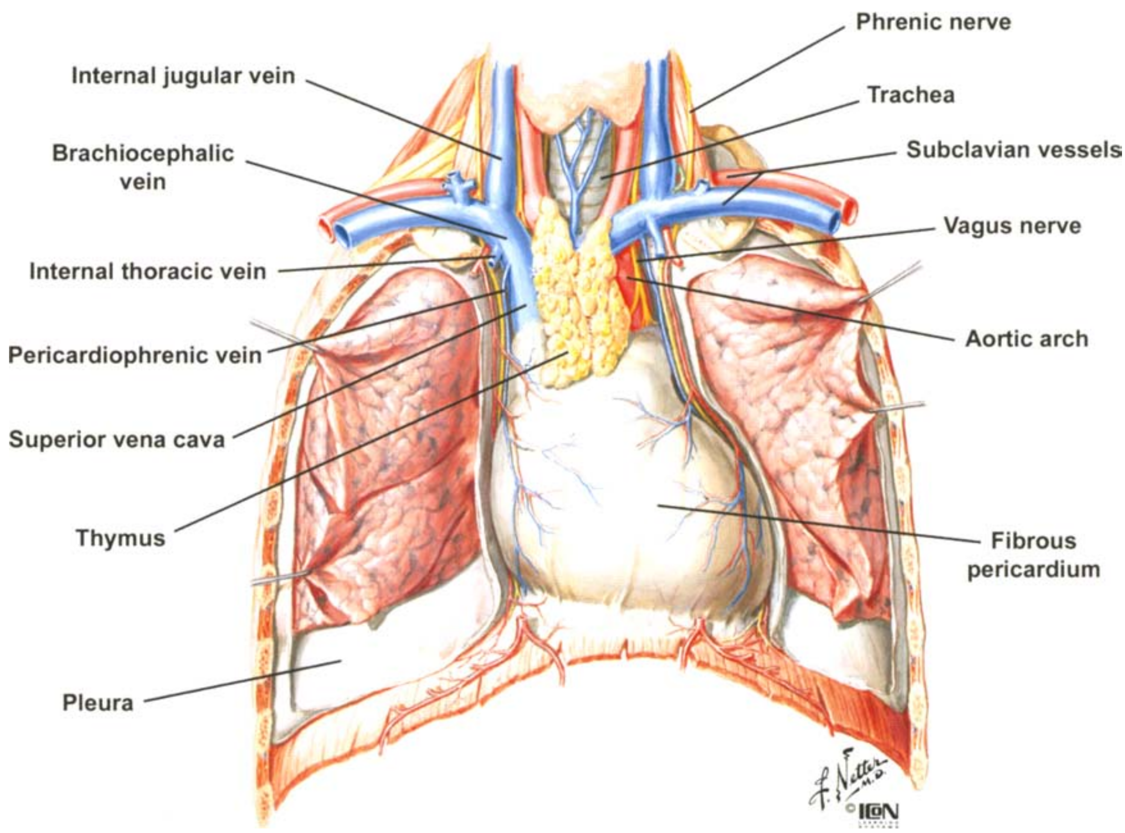


Fig. 10. Contents of the superior and middle mediastinum.

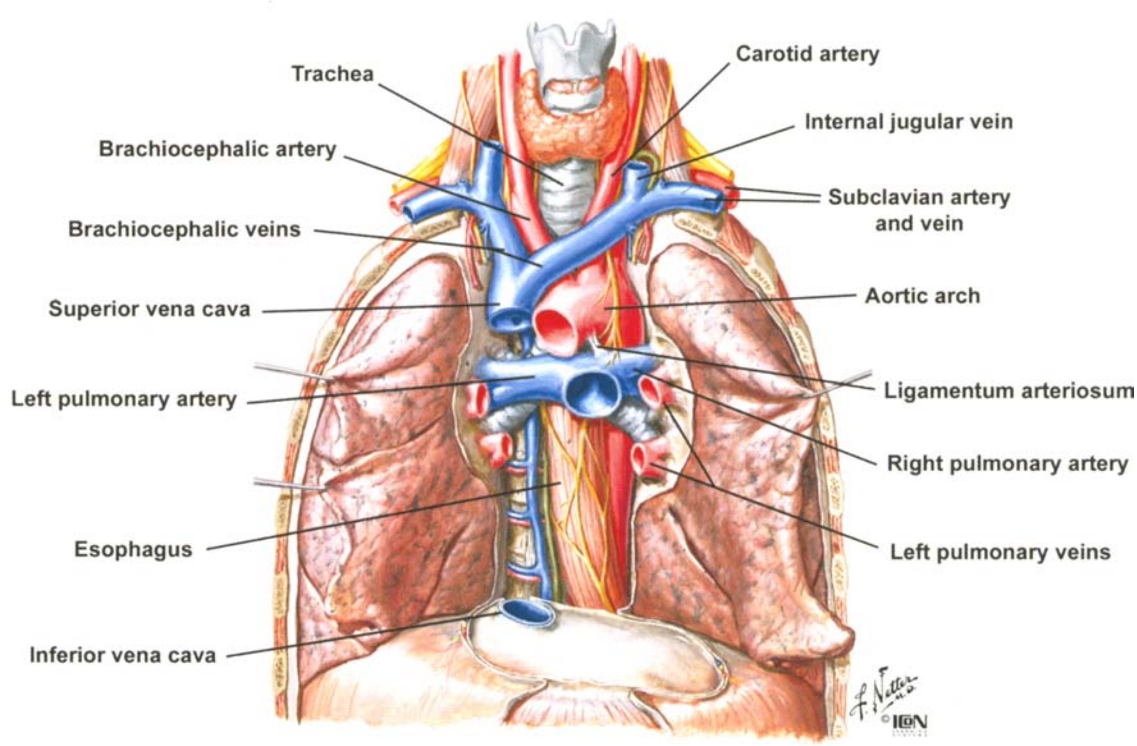


Fig. 11. Vessels of the superior and middle mediastinum.

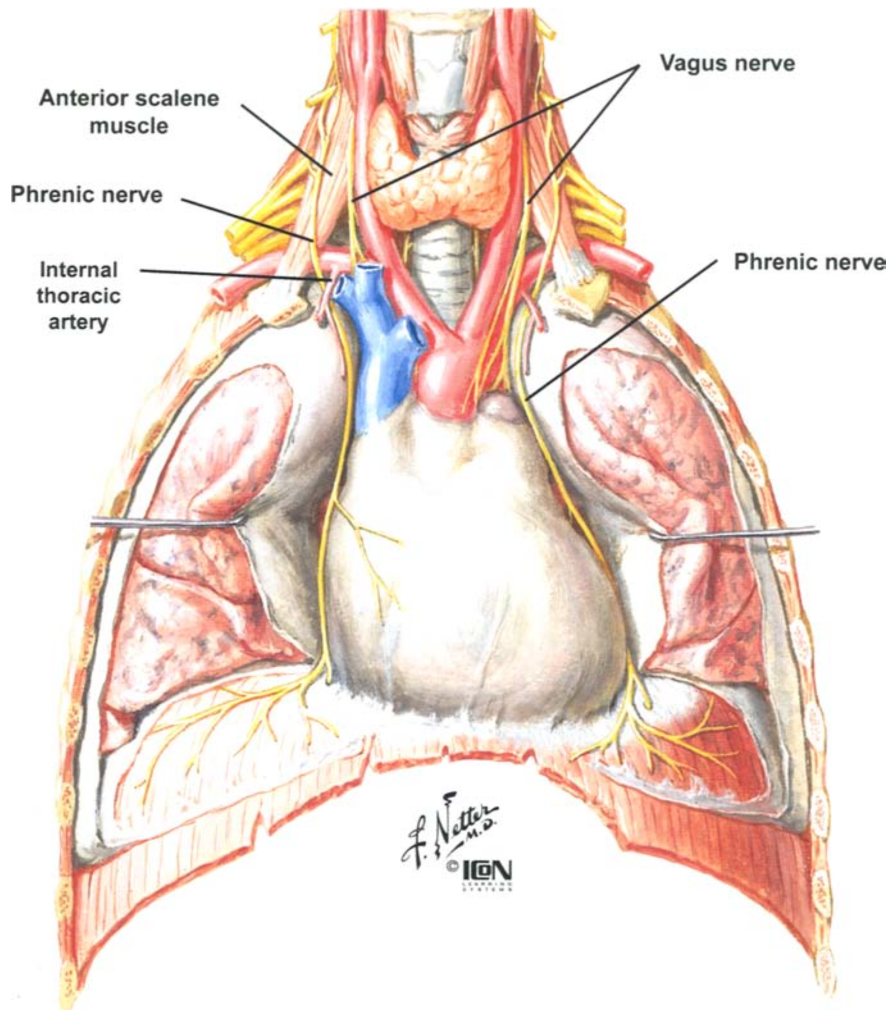


Fig. 12. Course of the phrenic nerve and vagus nerve in the superior and middle mediastinum.

The left brachiocephalic vein passes anterior to the three branches of the aortic arch and is separated from the manubrium only by the thymus (Fig. 10). The brachiocephalic veins receive the internal thoracic veins, the inferior thyroid veins, and the small pericardiophrenic veins. They also receive the superior intercostal veins from behind.

7.3. The Trachea and Esophagus

The trachea is a largely cartilaginous tube that runs from the larynx inferiorly through the superior mediastinum and ends by branching into the main bronchi (Fig. 11). It serves as a conduit for air to the lungs. The trachea can be palpated at the root of the neck, superior to the manubrium in the midline. The esophagus is a muscular tube that connects the pharynx with the stomach. The upper part of the esophagus descends behind the trachea, and in contact with it, through the superior mediastinum (Fig. 11). The esophagus continues through the posterior mediastinum behind the heart, pierces the diaphragm at the T10 level, and enters the stomach at the cardia. Both the trachea and esophagus are crossed on the left by the arch of the aorta. The impression of the aorta on the esophagus can usually be seen on a posterior-to-anterior radiograph of the esophagus coated with barium contrast. The trachea and esophagus are crossed on the right side by the azygos vein at the lower border of the superior mediastinum. Both the trachea and esophagus come into contact with the upper lobe of the right lung. The esophagus also contacts the upper lobe of the left lung. The arch of the aorta and its branches shield the trachea from the left lung.

7.4. Nerves of the Superior Mediastinum

Both the vagus nerve (cranial nerve 10) and the phrenic nerve pass through the superior mediastinum. The phrenic nerve originates from the ventral rami from cervical levels 3–5. This nerve travels inferiorly in the neck on the surface of the anterior scalene muscle, entering the superior mediastinum behind the subclavian vein and passing under the internal thoracic artery (Fig. 12). On the right, the phrenic nerve passes through the superior mediastinum lateral to the subclavian artery and the arch of the aorta. On the left, the phrenic nerve passes lateral to the brachiocephalic vein and the superior vena cava. The phrenic nerves then enter the middle mediastinum, where they pass anterior to the root of the lung, across the pericardium, finally piercing the diaphragm lateral to the base of the pericardium. Throughout their course, the phrenic nerves pass under the mediastinal pleura.

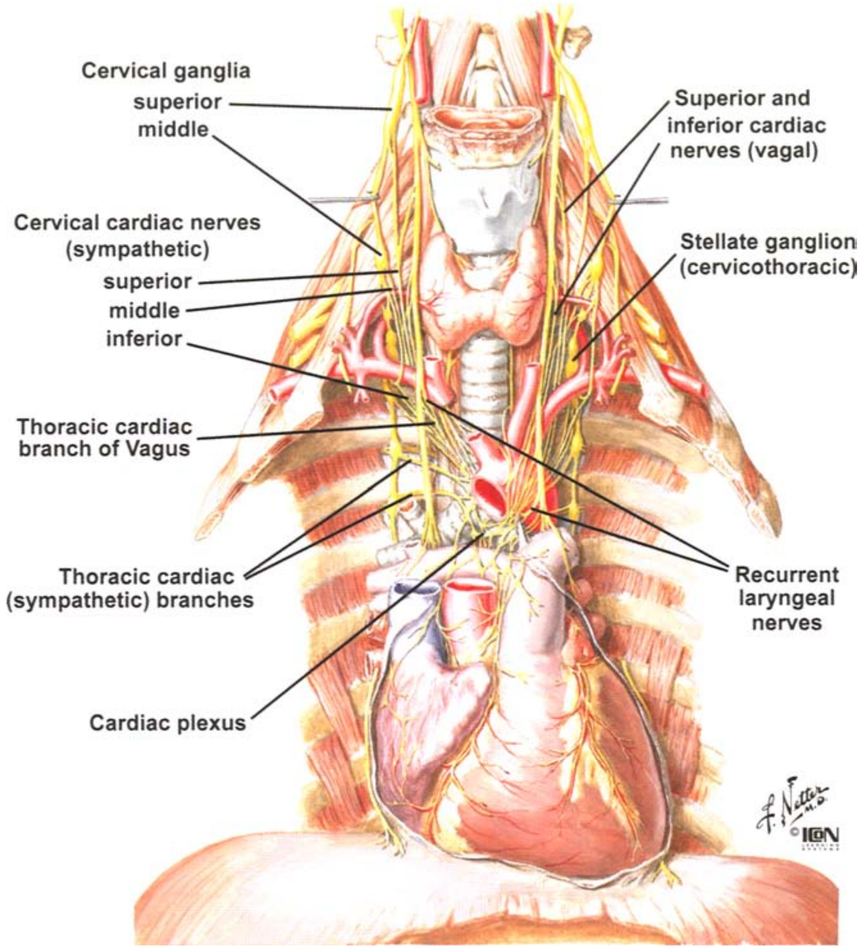


Fig. 13. Pattern of innervation in the superior mediastinum.

The phrenic nerves provide the motor innervation to the diaphragm ("C-3-4-5 keeps your diaphragm alive"); they provide sensory innervation to the pericardium, mediastinal and diaphragmatic pleura, and diaphragmatic peritoneum on the inferior surface of the diaphragm. The course of the right phrenic nerve behind the subclavian vein makes it susceptible to stimulation if current leaks from a pacing lead within the vessel.

The bilateral vagus nerves pass out of the skull via the jugular foramen and descend through the neck in the carotid sheath, just lateral to the common carotid arteries. These nerves are the parasympathetic supply to the thorax and most of the abdomen. On the right, the vagus crosses anterior to the subclavian artery, then turns posterior to pass behind the root of the lung and onto the esophagus. Before the right vagus enters the superior mediastinum, it gives off a recurrent laryngeal branch that passes behind the subclavian artery and ascends into the neck. On the left, the vagus passes lateral to the arch of the aorta, then turns posterior to pass behind the root of the lung and onto the esophagus (Fig. 12). At the level of the aortic arch, it gives off the left recurrent laryngeal nerve, which passes under the aorta just posterior to the ligamentum arteriosum and ascends into the neck.

The recurrent laryngeal nerves are the motor to most of the muscles of the larynx. It should be noted that an aneurysm in the arch of the aorta can injure the left recurrent laryngeal nerve and manifest as hoarseness of the voice caused by unilateral paralysis of the laryngeal musculature.

The right and left vagi contribute to the esophageal plexus of nerves in the middle mediastinum. The right and left vagi give off cardiac branches in the neck (superior and inferior cardiac nerves) and a variable number of small cardiac nerves in the superior mediastinum (thoracic cardiac branches) that provide parasympathetic innervation to the heart via the cardiac nerve plexus.

Sympathetic innervation to the heart is also found in the superior mediastinum. The heart receives postganglionic branches from the superior, middle, and inferior cardiac nerves, each branching from their respective sympathetic ganglia in the neck (Fig. 13). There are also thoracic cardiac nerves emanating from the upper four or five thoracic sympathetic ganglia. The uppermost thoracic ganglion and the inferior cervical ganglion are often fused to form an elongated ganglion called the *stellate ganglion*, which will give off the inferior cardiac nerve.

The cardiac plexus is located between the trachea, the arch of the aorta, and the pulmonary trunk (Fig. 13). It is a network of sympathetic and parasympathetic nerves derived from the branches described in this section and provides the overall-

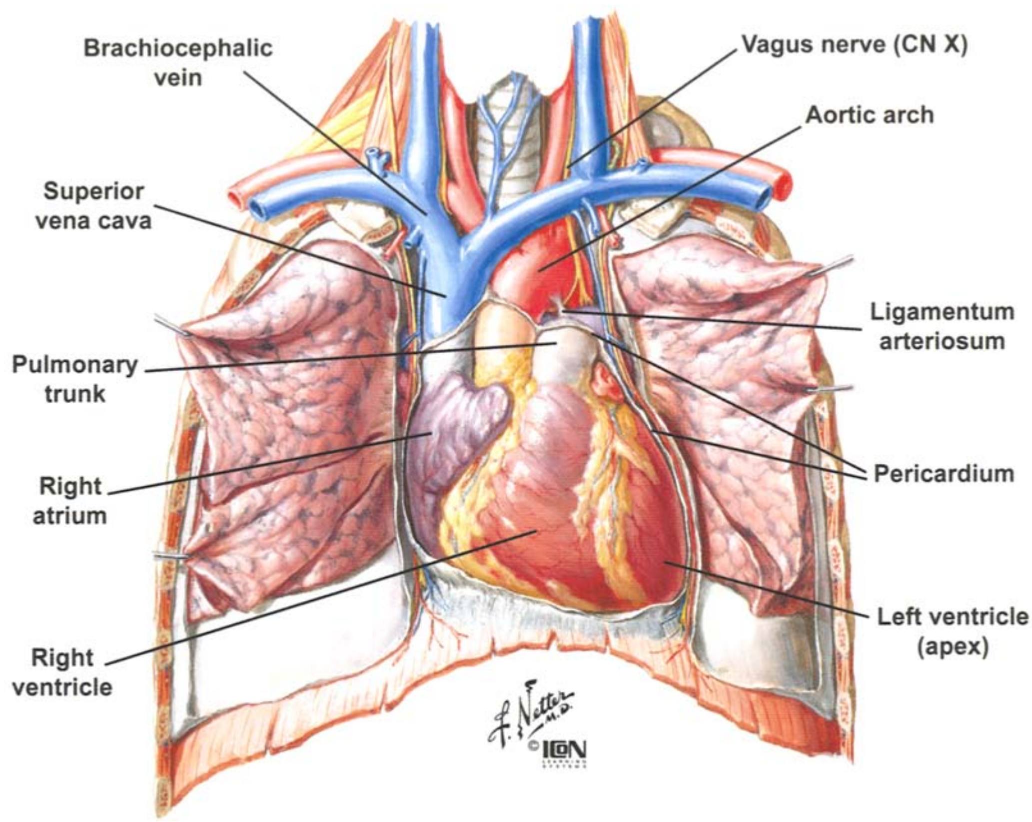


Fig. 14. The position of the heart in the middle mediastinum and the relationship of the pericardium to the heart and great vessels.

autonomic innervation to the heart. Nerves from the plexus reach the heart by traveling along the vasculature and primarily innervate the conduction system and the atria. The sympathetic components cause the strength and pace of the heartbeats to increase. The parasympathetics counter this effect. Pain afferents from the heart travel with the sympathetic nerves to the upper thoracic and lower cervical levels. This distribution accounts for the pattern of referred heart pain to the upper thorax, shoulder, and arm. (For more details on this autonomic innervation, *see* Chapter 10)

7.5. The Thymus

The thymus is found in the most anterior part of the superior mediastinum (Fig. 10). It is considered an endocrine gland, but is actually more important as a lymphoid organ. The thymus produces lymphocytes that populate the lymphatic system and bloodstream. It is particularly active in young individuals and becomes much less prominent with aging. The thymus is located directly behind the manubrium and may extend into the neck and inferiorly into the anterior mediastinum. It lies in contact with the aorta, left brachiocephalic vein, and trachea.

8. THE MIDDLE MEDIASTINUM

8.1. The Pericardium

The middle mediastinum is the central area of the inferior mediastinum occupied by the great vessels, pericardium, and heart (Fig. 14). Within this space, the heart is situated with the right atrium on the right, the right ventricle anterior, the left ventricle to the left and posterior, and the left atrium entirely posterior. The apex, a part of the left ventricle, is projected inferiorly and to the left.

The pericardium is the closed sac that contains the heart and the proximal portion of the great vessels. It is attached to the diaphragm inferiorly. The pericardium is a serous membrane, with a visceral and a parietal layer, into which the heart projects such that there is a potential space within the pericardial sac called the *pericardial cavity*. The visceral pericardium, also called the *epicardium*, covers the entire surface of the heart and base of the great vessels, reflecting to become parietal pericardium on the great vessels. The parietal pericardium is characterized by a thickened, strong outer layer called the *fibrous pericardium*. The fibrous pericardium is fused to the layer of parietal serous pericardium, creating a single layer with two surfaces. The fibrous pericardium has little elasticity and, by its fusion with the base of the great vessels, effectively creates a closed space in which the heart beats. The pericardial cavity can accumulate fluids under pathological conditions and create pressure within the pericardium, a condition known as *cardiac tamponade*. For a complete description of the pericardium and its features, *see* Chapter 7.

8.2. The Great Vessels

Great vessels is a composite term used for describing the large arteries and veins directly entering and exiting the heart

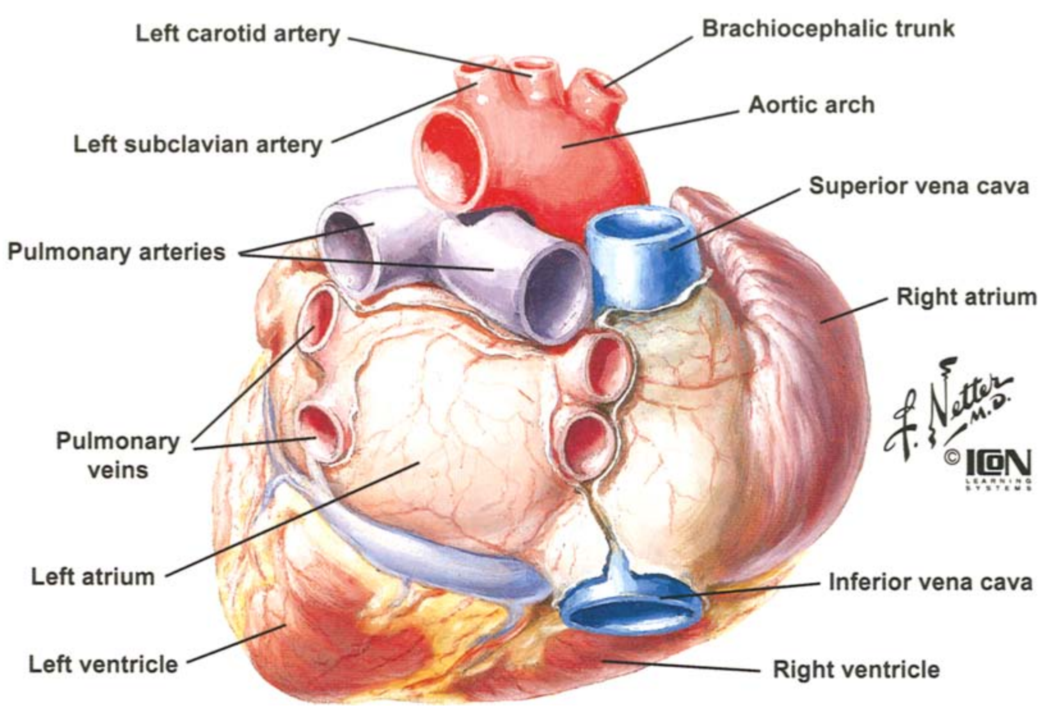


Fig. 15. The great vessels as viewed from the posterior side of the heart.

(Figs. 11 and 15). They include the superior and inferior vena cava, aorta, pulmonary trunk, and pulmonary veins. All of these vessels are found within the middle mediastinum. The inferior vena cava and the pulmonary veins are the shortest of the great vessels. The inferior vena cava enters the right atrium from below almost immediately after passing through the diaphragm. The pulmonary veins (normally two emerging from each lung) enter the left atrium with a very short intrapericardial portion. The superior vena cava is formed from the confluence of the right and left brachiocephalic veins. It also receives the azygos vein from behind and empties into the superior aspect of the right atrium. The pulmonary trunk ascends from the right ventricle on the anterior surface of the heart at an oblique angle to the left and posterior, passing anterior to the base of the aorta in its course.

As the pulmonary trunk emerges from the pericardium, it bifurcates into left and right pulmonary arteries, which enter the hilum of each lung (Fig. 11). The right pulmonary artery passes under the arch of the aorta to reach the right lung. The left pulmonary artery is connected to the arch of the aorta by the ligamentum arteriosum, the remnant of the ductus arteriosus, the connection between the aorta and pulmonary trunk present in the fetus. The aorta ascends from the left atrium at an angle to the right and curves back to the left and posterior as it becomes the aortic arch. As the aorta exits the pericardium, it arches over the right pulmonary trunk, passing to the left of the trachea and esophagus and entering the posterior mediastinum as the descending aorta (Fig. 15). Backflow of blood into either the aorta or the pulmonary trunk is prevented by the semilunar valves. The semilunar valves, each with a set of three leaflets, are found at the base of each of these great vessels. Immediately above these valves are the "aortic and pulmonary sinuses," which are regions where the arteries are dilated. The coronary arteries branch from the right and left aortic sinuses (*see* Chapter 4).

Also passing through the middle mediastinum are the phrenic nerves and the pericardiophrenic vessels (Fig. 10). The phrenic nerves pass out of the neck and through the superior mediastinum. They travel through the middle mediastinum on the lateral surfaces of the fibrous pericardium and under the mediastinal pleura to reach the diaphragm. The phrenic nerve on each side is accompanied by a pericardiophrenic artery, a branch from the proximal internal thoracic artery, and a pericardiophrenic vein, which empties into the subclavian vein. These vessels, as their names imply, supply the pericardium and the diaphragm as well as the mediastinal pleura.

9. THE ANTERIOR MEDIASTINUM

The anterior mediastinum is the subdivision of the inferior mediastinum bounded by the sternum anteriorly and the pericardium posteriorly (Fig. 1). It contains sternopericardial ligaments, made up of loose connective tissue, the internal thoracic vessels and their branches, lymphatic vessels and nodes, and fat. In children, the thymus often extends from the superior mediastinum into the anterior mediastinum.

10. THE POSTERIOR MEDIASTINUM

The posterior mediastinum is the division of the inferior mediastinum bounded by the pericardium anteriorly and the posterior thoracic wall posteriorly (Fig. 1). Structures found in the posterior mediastinum include the descending aorta, azygos system of veins, thoracic duct, esophagus, esophageal

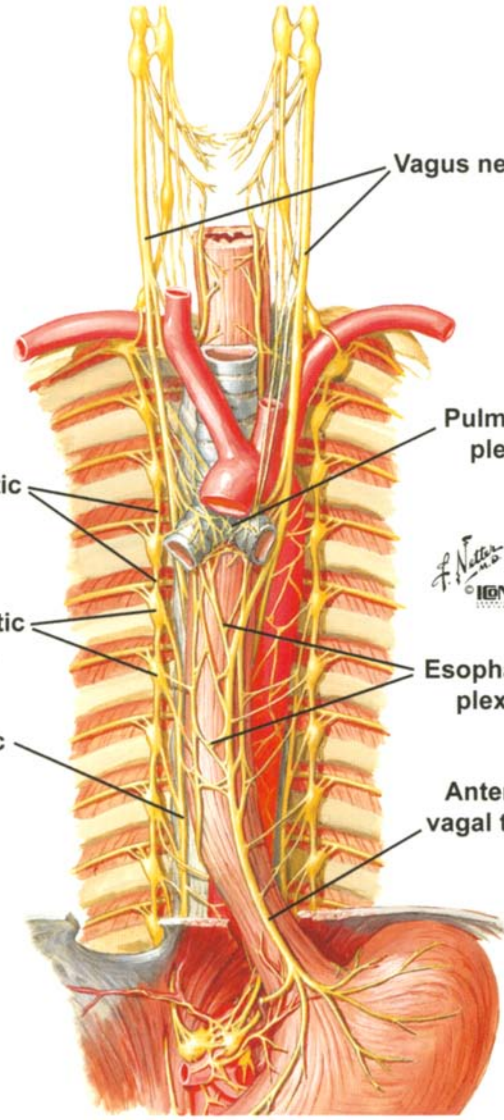


Fig. 16. Course of the esophagus in the posterior mediastinum and the esophageal plexus of nerves.

plexus, thoracic sympathetic trunk, and thoracic splanchnic nerves.

10.1. The Esophagus and Esophageal Plexus

The esophagus descends into the posterior mediastinum, passing along the right side of the descending aorta (Fig. 11). It passes directly behind the left atrium and veers to the left before passing through the esophageal hiatus of the diaphragm at the level of T10. Because of the juxtaposition of the esophagus to the heart, high-resolution ultrasound images of the heart can be obtained via the esophagus. As the bilateral vagus nerves approach the esophagus, they divide into several commingling branches, forming the esophageal plexus (Fig. 16). Toward the distal end of the esophagus, the plexus begins to coalesce into anterior and posterior vagal trunks that pass with the esophagus into the abdomen. The left side of the esophageal plexus from the left vagus nerve contributes preferentially to the anterior vagal trunk and likewise for the right vagus and the posterior vagal trunk, reflecting the normal rotation of the gut. The parasympathetic branches of the anterior and posterior vagal trunks comprise the innervation to the abdominal viscera as far as the splenic flexure.

10.2. The Azygos System of Veins

The azygos venous system in the thorax is responsible primarily for draining venous blood from the thoracic wall to the superior vena cava (Fig. 17). The azygos veins also receive venous blood from the viscera of the thorax, such as the esophagus, bronchi, and pericardium. The term *azygos* means unpaired and describes the asymmetry in this venous system. The system consists of the azygos vein on the right and the hemiazygos and accessory hemiazygos veins on the left.

Both the azygos vein and the hemiazygos vein are formed from the lumbar veins ascending from the abdomen and unit-

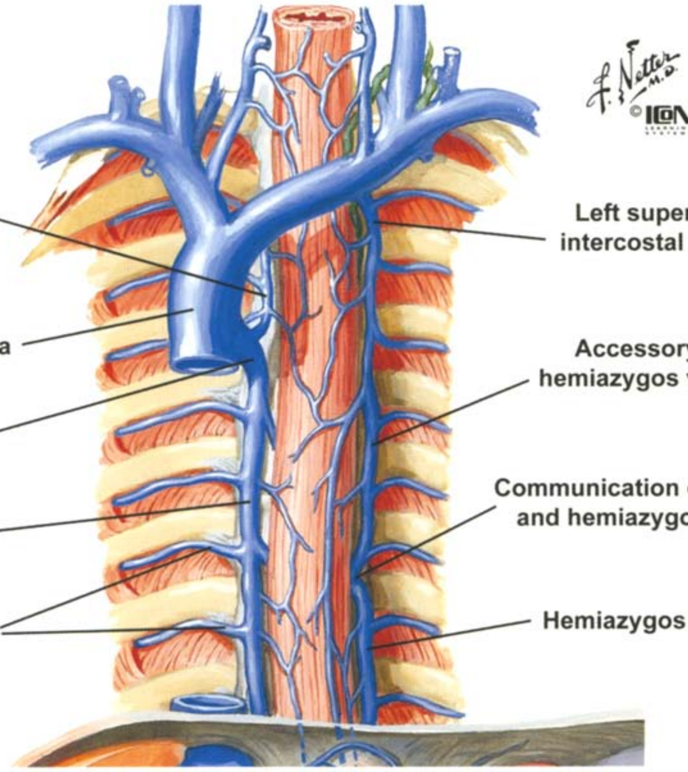


Fig. 17. The azygos venous system in the posterior mediastinum. This figure illustrates a "typical" pattern of the azygos and hemiazygos veins.

ing with the subcostal vein. On the right, the azygos vein is continuous, collecting blood from the right intercostal veins before arching over the root of the lung to join the superior vena cava. On the left, the hemiazygos vein ends typically at the level of T8 by crossing over to communicate with the azygos vein on the right. Above the hemiazygos vein, the accessory hemiazygos vein collects blood from the posterior intercostal veins. It typically communicates with the hemiazygos vein and crosses over to communicate with the azygos vein. On both sides, the second and third intercostal spaces are drained to a superior intercostal vein that not only drains directly to the subclavian vein, but also communicates with the azygos and accessory hemiazygos veins on their respective sides. The first intercostal vein drains directly to the subclavian vein. There is a tremendous amount of variation in the azygos system of veins, all of which is generally functionally inconsequential. However, it should be noted that the azygos system can be quite different in some of the large animal models used to study cardiac function (*see* Chapter 5).

10.3. The Thoracic Duct and Lymphatics

The thoracic duct is the largest lymphatic vessel in the body (Fig. 18). It conveys lymph from the cisterna chyli, which is the collection site for all lymph from the abdomen, pelvis, and lower extremities, back to the venous system. The thoracic duct enters the posterior mediastinum through the aortic hiatus and travels between the thoracic aorta and the azygos vein behind the esophagus. It ascends through the superior mediastinum to the left and empties into the venous system at or close to the junction of the internal jugular and subclavian veins. The thoracic duct often appears white because of the presence of chyle in the lymph and beaded because of the many valves within the duct. The thoracic duct also receives lymphatic drainage from posterior mediastinal lymph nodes, which collect lymph from the esophagus, posterior intercostal spaces, and posterior parts of the pericardium and diaphragm.

10.4. The Descending Thoracic Aorta

The descending thoracic aorta is the continuation of the aortic arch through the posterior mediastinum (Fig. 19). It begins to the left of the T5 vertebra and gradually moves to the middle of the vertebral column as it descends. It passes behind the diaphragm, under the median arcuate ligament (the aortic hiatus), and into the abdomen at the level of T12. The thoracic aorta gives off the 3rd–11th posterior intercostal arteries and the subcostal artery. It also supplies blood to the proximal bronchi and the esophagus via bronchial and esophageal branches. The superior phrenic arteries supply the posterior aspect of the diaphragm and anastomose with the musculophrenic and pericardiacophrenic branches of the internal thoracic artery.

10.5. The Thoracic Sympathetic Nerves

The sympathetic chain of ganglia, or "sympathetic trunk," extends from the sacral region to the cervical spine. It is also called the thoracolumbar division of the autonomic nervous system because preganglionic neurons of this system have their cell bodies in the thoracic and lumbar segments of the spinal cord, from T1 to L2. The thoracic portion of the sympathetic

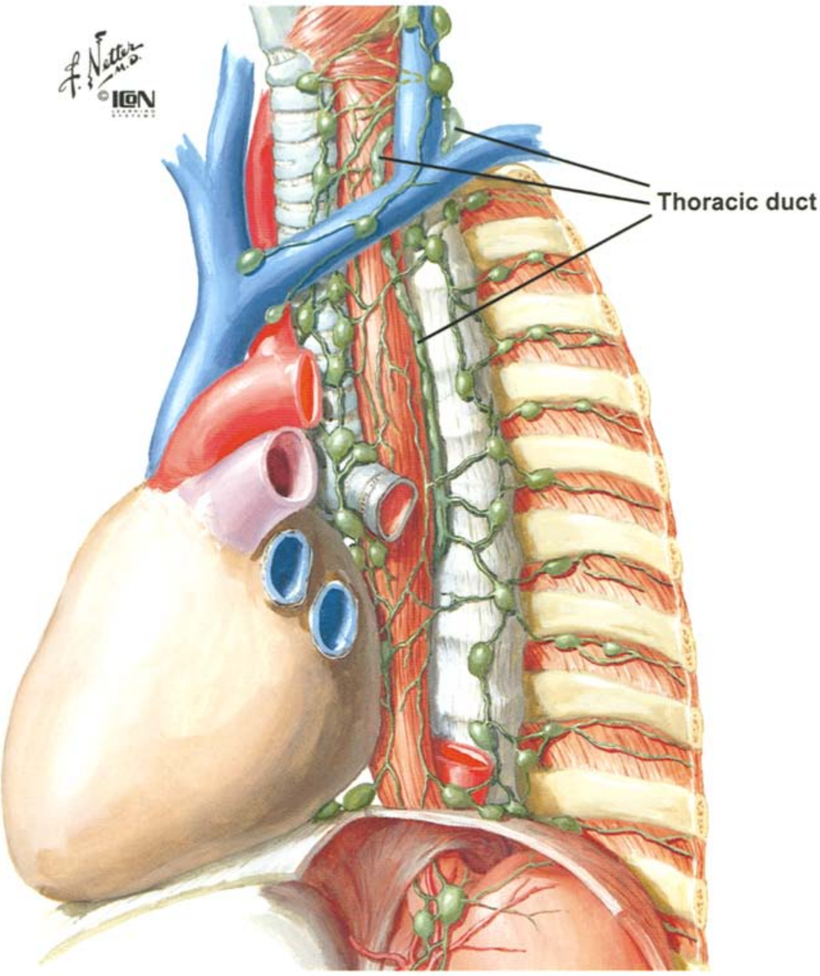


Fig. 18. The course of the thoracic duct in the posterior mediastinum through the superior mediastinum and ending at the junction of the internal jugular and subclavian veins.

trunk is found in the posterior mediastinum (Fig. 16). It is composed of sympathetic ganglia, located along the spine at the junction of the vertebrae and the heads of the ribs, and the intervening nerve segments that connect the ganglia. These sympathetic ganglia are also called *paravertebral sympathetic ganglia* because of their position along side the vertebral column.

There is approximately one sympathetic chain ganglion for each spinal nerve. There are fewer ganglia than nerves because some adjacent ganglia fuse during embryological development. Such fusion is most evident in the cervical region, where there are eight spinal nerves but only three sympathetic ganglia: the superior, middle, and inferior cervical ganglia (Fig. 13). The inferior cervical ganglion and the first thoracic (T1) ganglion are often fused, forming the cervicothoracic or stellate ("star-shaped") ganglion.

An axon of the sympathetic nervous system that emerges from the spinal cord in the thorax travels with the ventral nerve root to a ventral ramus (in the thorax, this would be an intercostal nerve) (Fig. 20). After traveling a short distance on this nerve, this presynaptic (preganglionic) neuron enters the chain ganglion at its level (Fig. 21). Within the ganglion, it either synapses or travels superiorly or inferiorly to synapse at another spinal cord level (C1 to S4). After synapsing, the postsynaptic (postganglionic) neuron travels out of the ganglion and on to the ventral ramus to its target structure or organ.

Presynaptic sympathetic nerves travel from the ventral ramus to the chain ganglion, and postsynaptic nerves travel back to the ventral ramus via small nerve fibers called *rami communicantes* (so named because they communicate between the ventral ramus and the sympathetic ganglion). The presynaptic neurons have myelin protective coatings, and the postsynaptic neurons do not. This pattern of myelination is true of all nerves in the autonomic system. The myelin coating appears white, and thus the presynaptic (myelinated) rami communicantes are called white rami communicantes, and the postsynaptic (unmyelinated) neurons are called the gray rami communicantes. The gray and white rami communicantes can be seen spanning the short distance between the intercostal nerves and the sympathetic ganglia in the posterior mediastinum (Fig. 8).

Also present in the posterior mediastinum are the thoracic splanchnic nerves, which leave the sympathetic trunk and run

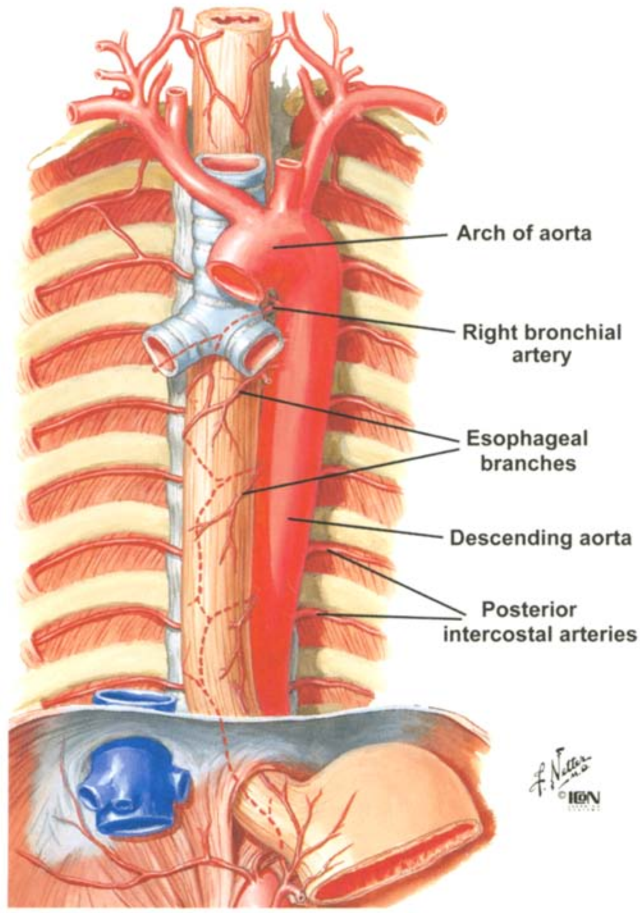


Fig. 19. Course of the descending aorta in the posterior mediastinum with posterior intercostal branches and branches to the esophagus and bronchi.

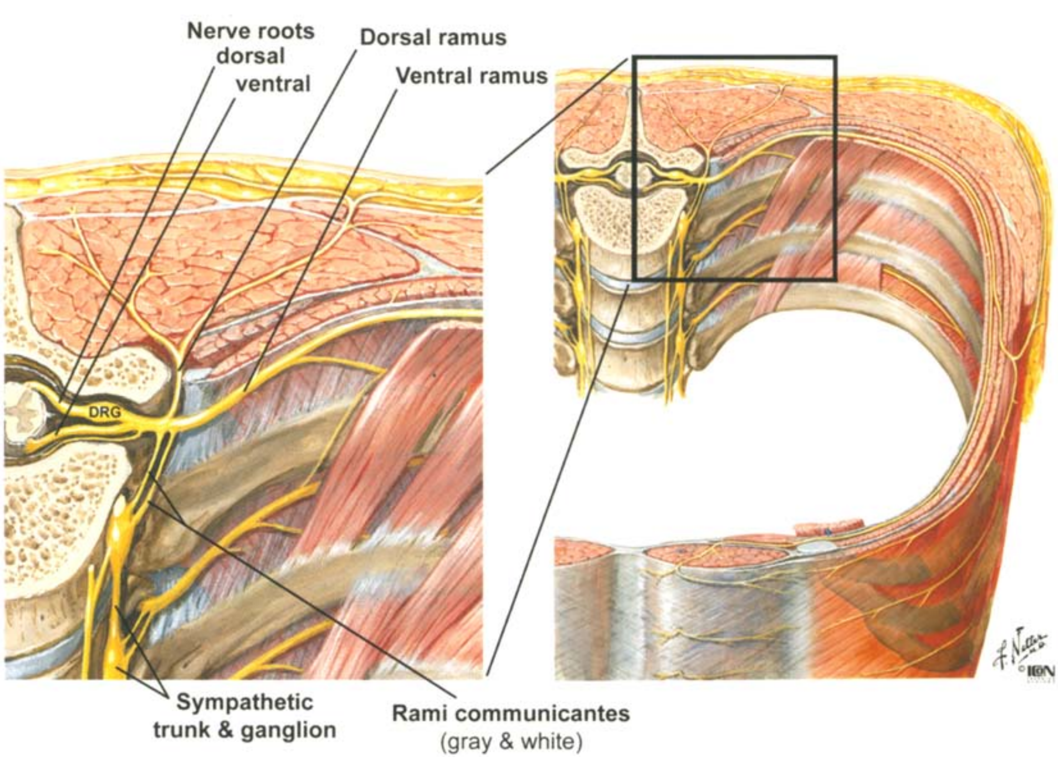


Fig. 20. A typical spinal nerve showing the communication of sympathetic nerves with the chain ganglia via white and gray rami communicantes.

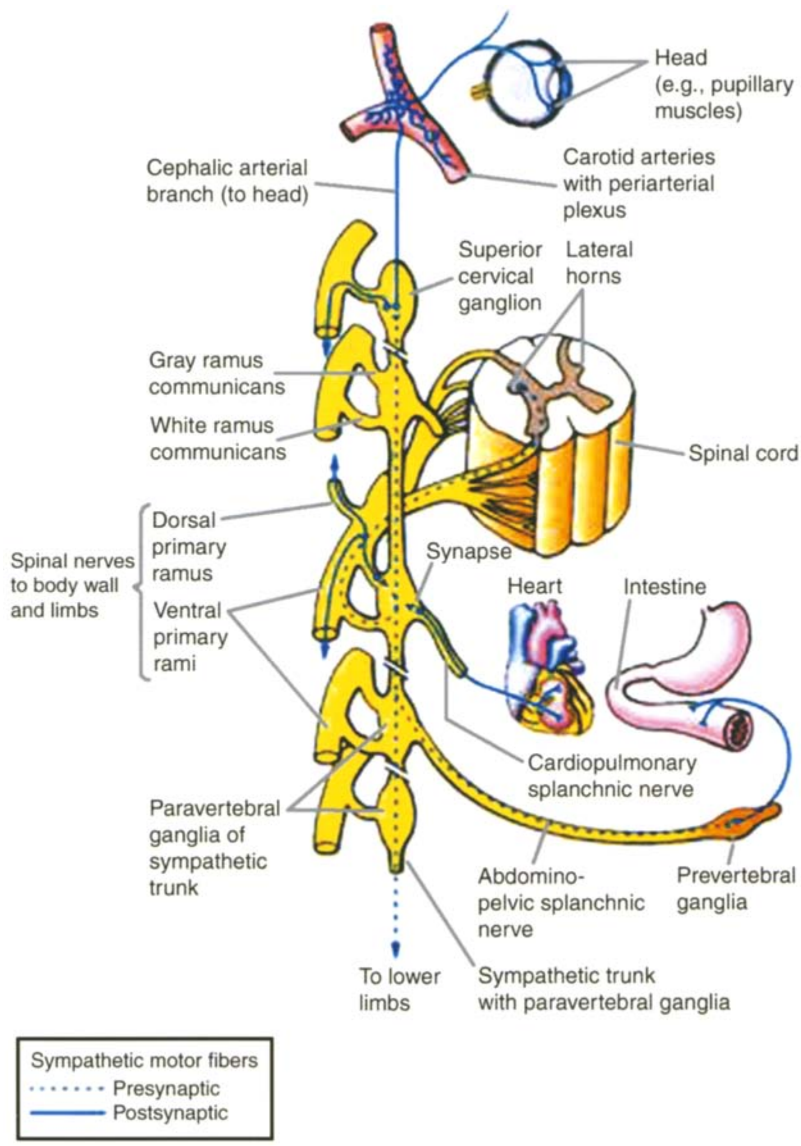


Fig. 21. The three options taken by presynaptic sympathetic fibers are illustrated. All presynaptic nerves enter the sympathetic trunk via white rami communicantes. They can synapse at their level and exit via gray rami communicantes and travel up or down the chain before synapsing, or they can exit before synapsing in the splanchnic nerves. Figure adapted from Figure 1.32 from *Clinically Oriented Anatomy*, 4th Ed., by Keith L. Moore and Arthur F. Dalley. © 1999 Lippincott, Williams, and Wilkins, Philadelphia, PA.

inferiorly toward the midline (Fig. 20). Splanchnic nerves are preganglionic sympathetic neurons that emerge from the spine and pass through the chain ganglion, but do not synapse (Fig. 21). In the thorax these preganglionic splanchnic nerves emerge from spinal cord segments T5–T12 and travel into the abdomen, where they synapse in collateral ganglia, called *prevertebral ganglia*, located along the aorta. The postganglionic fibers then innervate the abdominal organs. There are three splanchnic nerves that emerge in the thorax. The greater splanchnic nerves emerge from spinal cord segments T5–T9, although a few studies reported that they can emerge from T2–T10. The axons of the lesser and splanchnic nerves emerge from segments T10 and T11 and of the least splanchnic nerves emerge from T12.

11. PLEURA AND LUNGS

11.1. The Pleura

The bilateral pulmonary cavities contain the lungs and the pleural membranes (Fig. 1). The pleural membranes are continuous serous membranes that form a closed pleural cavity within each cavity (Fig. 10). The relationship of the lung to this membrane is the same as that of a fist (representing the lung) pushed into an underinflated balloon (representing the pleural membrane). The fist becomes covered by the membrane of the balloon, but it is not "inside" the balloon. In the case of the lung, the pleura in contact with the lung is the visceral pleura, and the outer layer, which is in contact with the inner wall of the thorax and the mediastinum, is the parietal pleura (Fig. 22). The space within the pleural sac is the pleural cavity. Under

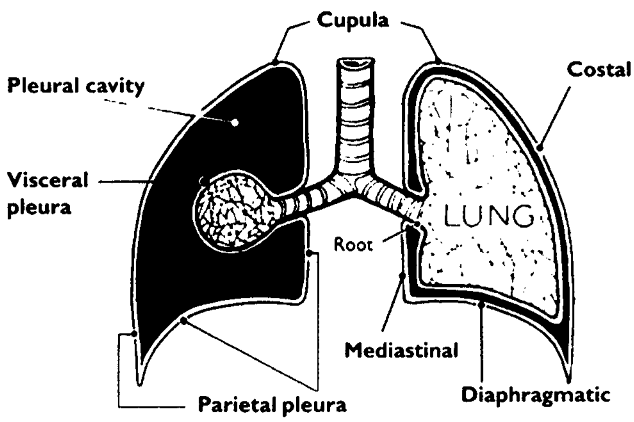


Fig. 22. Relationship of the lungs and walls of the thoracic cavity to the pleural membrane. Adapted from Fig. 1.15 of *Grant's Dissector*, 12th Ed., E. K. Sauerland (ed.). © 1999 Lippincott, Williams, and Wilkins, Philadelphia, PA.

normal conditions, the pleural cavity contains only a small amount of serous fluid and has no functional open space. It is referred to as a "potential space" because a real space can be created if outside material, such as blood, pathologic fluids, or air, is introduced into this space.

The parietal pleura is subdivided into specific parts based on the part of the thorax it contacts (Figs. 10 and 22). Costal pleura overlies the ribs and intercostal spaces. In this region, the pleura is in contact with the endothoracic fascia, the fascial lining of the thoracic cavity. The mediastinal and diaphragmatic pleura are named for their contact with these structures. The cervical pleura extends over the cupola of the lung; above the first rib into the root of the neck, it is strengthened by the suprapleural membrane, an extension of the endothoracic fascia over the cupola of lung.

The lines of pleural reflection are the locations along which the parietal pleura transitions from one region to the next (Fig. 23). The sternal line of reflection is the point at which costal pleura transitions to mediastinal pleura on the anterior side of the thorax. The costal line of pleural reflection lies along the origin of the diaphragm at which the costal pleura transitions to diaphragmatic pleura. Both the costal and sternal lines of reflection are very abrupt. The vertebral line of pleural reflection lies along the line at which costal pleura becomes mediastinal pleura posteriorly. This angle of reflection is shallower than the other two. The surface projections of the parietal pleura are discussed in Section 12.2.

The parietal pleura reflects onto the lung to become the visceral pleura at the root of the lung. A line of reflection descends from the root of the lung, much like the sleeve of a loose robe hangs from the forearm, forming the pulmonary ligament (Fig. 24). The visceral pleura covers the entire surface of each lung, including the surfaces in the fissures, where the visceral pleura on one lobe is in direct contact with the visceral pleura of the other lobe. On the surface of the lung, the visceral pleura is in contact with the parietal pleura.

The pleural cavity is the space inside the pleural membrane (Fig. 22). It is a potential space that under normal conditions contains only a small amount of serous fluid, which lubricates the movement of the visceral pleura against the parietal pleura during respiration. During expiration, the lungs do not entirely fill the most inferior aspect of the pulmonary cavity. This creates a region, along the costal line of reflection, in which the diaphragmatic and costal pleura come into contact with each other with no intervening lung tissue. This space is the costodiaphragmatic recess.

11.2. The Lungs

The primary function of the lungs is to acquire O_2, required for metabolism in tissues, and to release CO_2, a metabolic waste product from tissues. The lungs fill the pulmonary cavities and are separated from each other by structures in the mediastinum. In the living, the lung tissue is soft, light, and elastic, filling the pulmonary cavity and accommodating surrounding structures that impinge on the lungs. In the fixed cadaveric lung, the imprint of structures adjacent to the lungs is easily seen. Blood and air enter and exit the lung at the hilum or root of the lung via the pulmonary vessels and the bronchi.

Each lung is divided into a superior and inferior lobe by an oblique (major) fissure (Fig. 24). The right lung has a second, horizontal (minor) fissure that creates a third lobe called the *middle lobe*. Each lung has three surfaces—costal, mediastinal, and diaphragmatic—and an apex that extends into the cupula at the root of the neck. The costal surface is smooth and convex, and diaphragmatic surfaces are smooth and concave. The mediastinal surface is concave and is the site of the root of the lung, where the primary bronchi and pulmonary vessels enter and exit the lungs.

The mediastinal surface has several impressions created by structures in the mediastinum. The left lung has a deep impression (the *cardiac impression*) that accommodates the apex of the heart. There is also a deep impression of the aortic arch and the descending thoracic aorta behind the root of the lung. At the superior end of the mediastinal surface, there are impressions from the brachiocephalic vein and the subclavian artery and a shallow impression from the esophagus and trachea. On the right side, there are prominent impressions of the esophagus behind the root of the lung and the arch of the azygos vein, extending over the root of the lung. An impression of the superior vena cava and the brachiocephalic vein appears anterior and above the root of the lung. An impression of both the trachea and esophagus is seen close to the apex of the lung. Descending from the root of both lungs, the pulmonary ligament can be seen.

The lungs also have three borders where the three surfaces meet. The posterior border is where the costal and mediastinal surfaces meet posteriorly. The inferior border is where the diaphragmatic and costal surfaces meet. The inferior border of the lung does not extend to the costal pleural reflection. The anterior border is where the costal and mediastinal surfaces meet anteriorly. On the left lung, the cardiac impression creates a visible curvature on the anterior border called the *cardiac notch*. Below the cardiac notch, a segment of lung called the lingula protrudes around the apex of the heart.

The main bronchi are the initial right and left branches from the bifurcation of the trachea and enter the lung at the hilum (Fig. 25). Like the trachea, they are held open by C-shaped

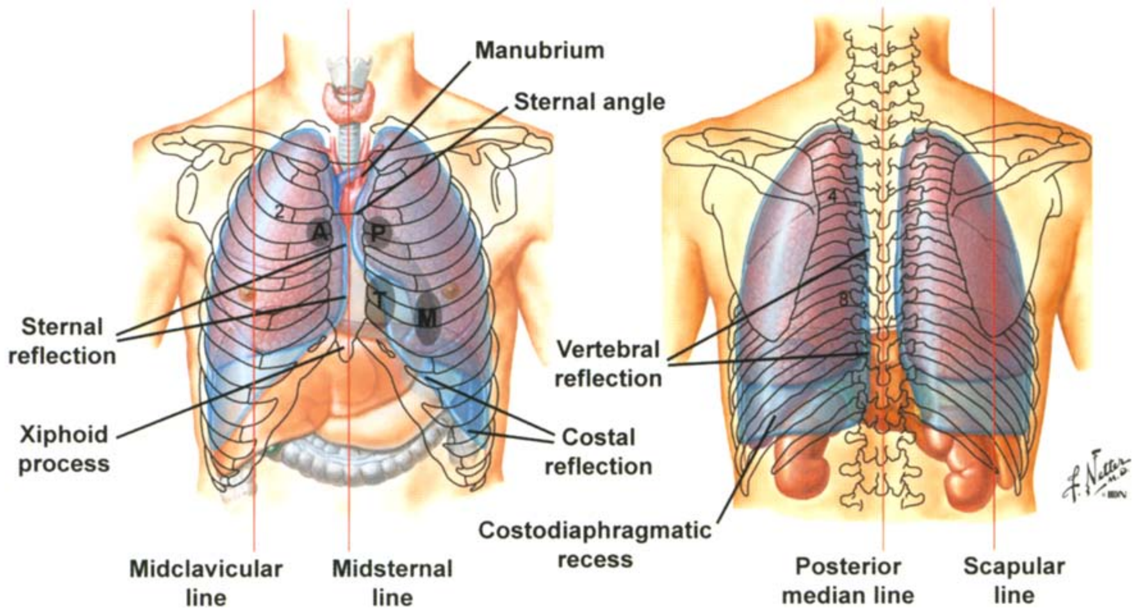


Fig. 23. Surface anatomy and important surface landmarks on the anterior and posterior thorax. The labeled gray areas mark the placement of a stethoscope for listening to heart sounds (auscultation), especially the sounds of the valves. A, aortic valve; P, pulmonary valve; T, tricuspid valve; M, mitral valve.

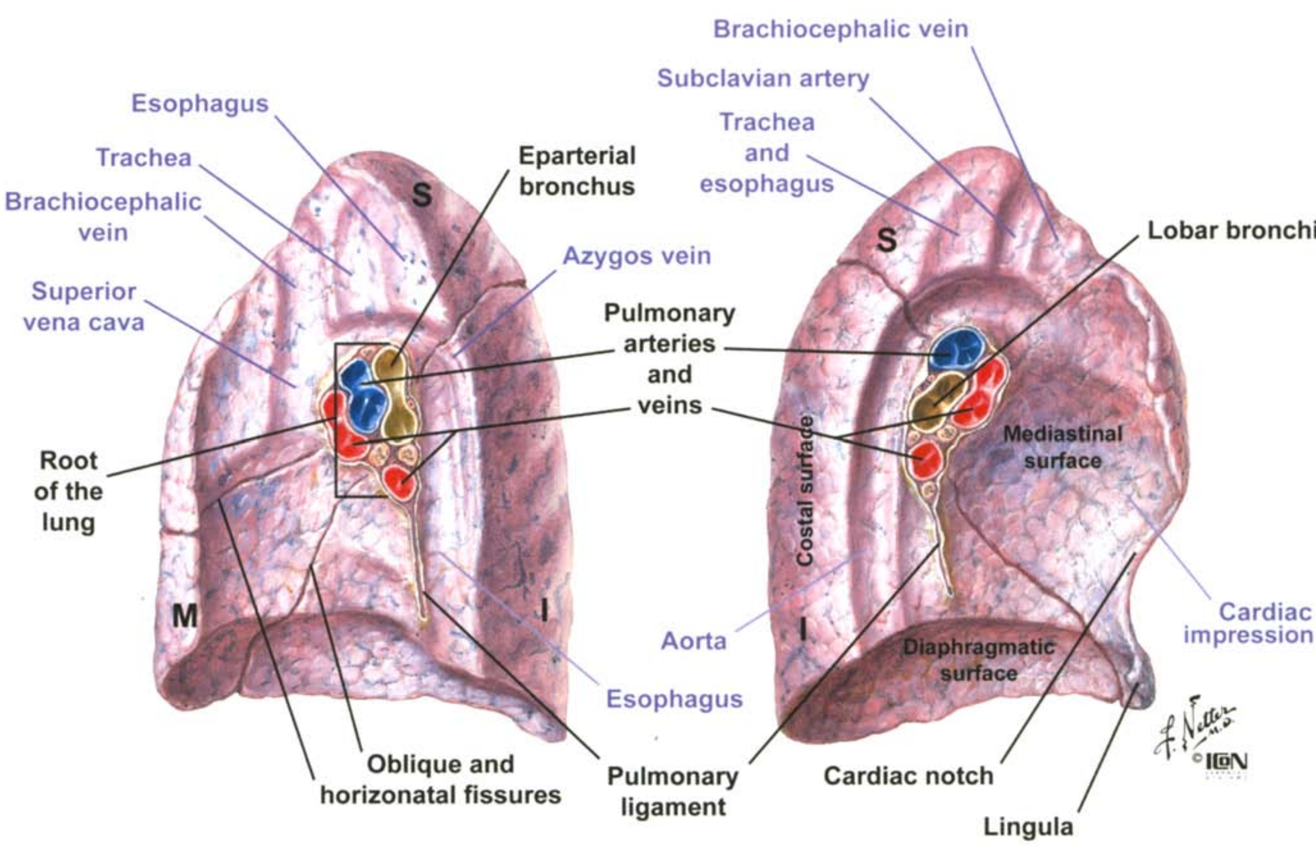


Fig. 24. Surface anatomy of the right (left) and left (right) lungs. S, superior lobe; I, inferior lobe; M, middle lobe.

segments of hyaline cartilage. The right main bronchus is wider and shorter and enters the lung more vertically than the left main bronchus. This is the reason aspirated foreign objects more often enter the right lung than the left. The left main bronchus passes anterior to the esophagus and under the aortic arch to enter the lung.

Once in the lung, the main bronchi branch multiple times to form the bronchial tree (Fig. 25). The first branching supplies

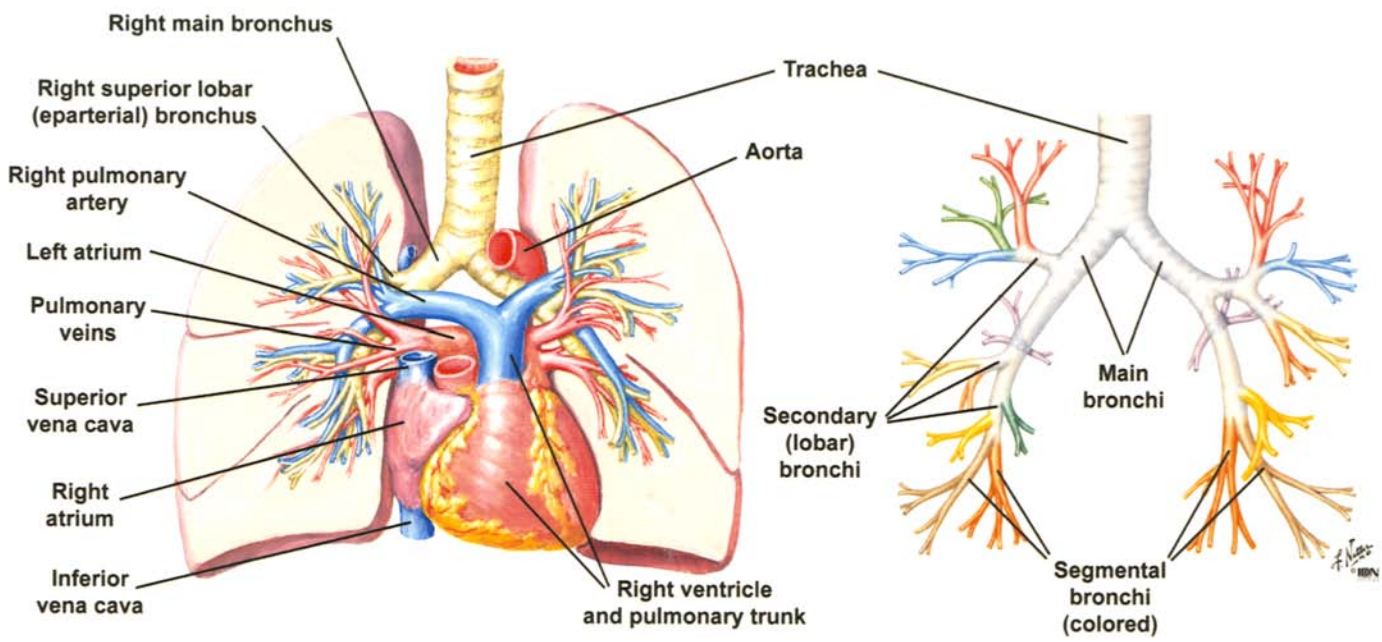


Fig. 25. Pattern of structure entering and leaving the root of the lung (left) and the branching pattern of the bronchi (right).

each lobe of the lung. These are the secondary or lobar bronchi. There are three lobar bronchi on the right and two on the left; these supply their respective lobes. The lobar bronchi branch into several segmental bronchi; each supplies air to a subpart of the lobe called a bronchopulmonary segment. Each bronchopulmonary segment has an independent blood supply and can be resected without impacting the remaining lung. The segmental bronchi then further divide into a series of intersegmental bronchi. The smallest intersegmental bronchi branch to become bronchioles, which can be distinguished from bronchi in that they contain no cartilage in their walls. The terminal bronchioles branch into a series of respiratory bronchioles, each of which contains alveoli. The respiratory bronchioles terminate by branching into alveolar ducts that lead into alveolar sacs, which are clusters of alveoli. It is in the alveoli that gases in the air are exchanged with the blood.

Each lung is supplied by a pulmonary artery that carries deoxygenated blood (thus they are colored blue in anatomical atlases) from the right ventricle of the heart (Fig. 25). Each pulmonary artery enters the hilum of the lung and branches with the bronchial tree to supply blood to the capillary bed surrounding the alveoli. The arterial branches have the same names as the bronchial branches. Oxygenated blood is returned to the left atrium of the heart via the paired pulmonary veins emerging from the hilum of both lungs. The pulmonary veins do not run the same course as the pulmonary arteries within the lung. At the hilum of the lung, the pulmonary artery is typically the most superior structure, with the main bronchus immediately below. On the right, the main bronchus is somewhat higher, and the superior lobar bronchus crosses superior to the pulmonary artery; it is referred to as the *eparterial bronchus*. The pulmonary veins exit the hilum of the lung inferior to both the main bronchus and the pulmonary artery.

Lymphatic drainage of the lungs is to tracheobronchial lymph nodes located at the bifurcation of the trachea (Fig. 26). A subpleural lymphatic plexus lies under the visceral pleura and drains directly to the tracheobronchial nodes. A deep lymphatic plexus drains along the vasculature of the lungs to pulmonary nodes along the bronchi, which communicate with bronchopulmonary nodes at the hilum, and from there to the tracheobronchial nodes. The lymphatic drainage from the lungs may either drain directly to the subclavian veins via the bronchomediastinal trunks, or into the thoracic duct.

The lungs receive innervation from the pulmonary plexus (Fig. 16). The parasympathetic nerves are from the vagus (cranial nerve 10), and they are responsible for constriction of the bronchi and vasodilatation of the pulmonary vessels; they are secretomotor to the glands in the bronchial tree. The sympathetics act opposite the parasympathetics. Pain afferents from the costal pleura and the outer parts of the diaphragmatic pleura are derived from the intercostal nerves. The phrenic nerves contain sensory afferents for the mediastinal pleura and the central part of the diaphragmatic pleura.

11.3. Mechanics of Respiration

Respiration is controlled by the muscles of the thoracic wall, the respiratory diaphragm, the muscles of the abdominal wall, and the natural elasticity of the lungs (Fig. 27). The diaphragm contracts during inspiration, causing the dome of the diaphragm to descend and the vertical dimension of the thoracic cavity to increase. Simultaneously, the ribs are elevated by contractions of external intercostal muscles and the interchondral parts of the internal intercostals. During deep inspiration, the ribs are further elevated by contractions of muscles in the neck. Elevation of the ribs increases the diameter of the thoracic cavity. The net result is the expansion of the pulmonary cavities.

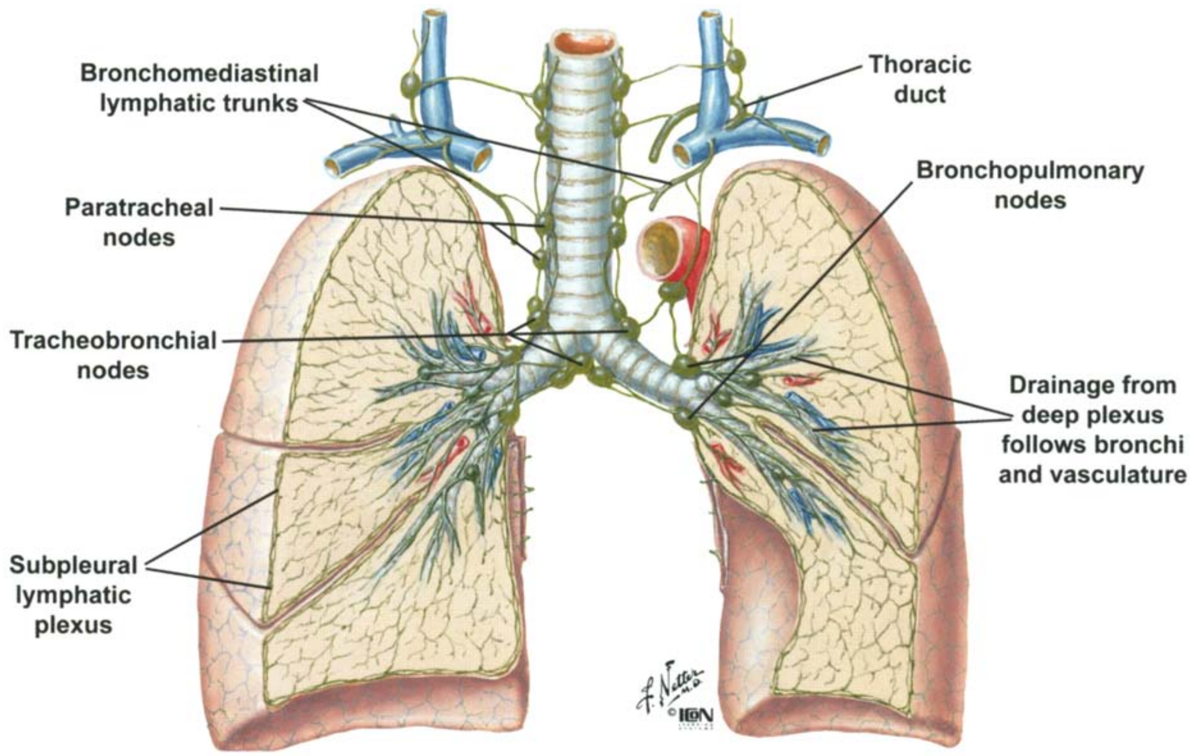


Fig. 26. Pattern of lymphatic drainage from the lungs.

When the walls of the thorax expand, the lungs expand with them because of the negative pressure created in the pleural cavity and the propensity of the visceral pleura to maintain contact with the parietal pleura because of the high surface tension of the liquid between these surfaces (somewhat like two plates of glass sticking together with water in between them). The resultant negative pressure in the lungs forces the subsequent intake of air.

Quiet expiration of air is primarily caused by the elastic recoil of the lungs when the muscles of inspiration are relaxed. Further expiration is achieved by contraction of the lateral internal intercostal muscles, depressing the ribs, and the contraction of abdominal muscles, causing increased abdominal pressure, which pushes up on the diaphragm. At rest, the inward pull of the lungs (in an attempt to deflate further) is at equilibrium with the springlike outward pull of the thoracic wall.

12. SURFACE ANATOMY

12.1. Landmarks of the Thoracic Wall

There are several defined vertical lines that demark regions of the anterior and posterior thoracic wall (Fig. 23). These lines are used to describe the location of surface landmarks and the locations of injuries or lesions on or within the thorax. The anterior median line runs vertically in the midline. It is also referred to as the *midsternal line*. The midclavicular line bisects the clavicle at its midpoint and typically runs through or close to the nipple. Three lines demarcate the axilla. The anterior axillary line runs vertically along the anterior axillary fold, and the posterior axillary line runs parallel to it along the posterior axillary fold. The midaxillary line runs in the midline of the axilla, at its deepest part. The scapular line runs vertically on the posterior thorax, through the inferior angle of the scapula. The posterior median line, also called the *midvertebral* or *midspinal line*, runs vertically in the midline on the posterior thorax.

The sternum lies subcutaneously in the anterior median line and can be palpated throughout its length. The jugular notch is found at the upper margin of the sternum, between the medial ends of the clavicle. The jugular notch is easily palpated and can usually be seen as a depression on the surface. The jugular notch represents the anterior junction of the superior mediastinum and the root of the neck. It lies at the level of the T2 vertebra posteriorly. The manubrium intersects with the body of the sternum about 4 cm inferior to the jugular notch, at the manubriosternal joint; this joint creates the sternal angle, which is normally visible on the surface of the thorax.

The sternal angle demarcates the inferior border of the superior mediastinum and lies at the level of the intervertebral disc between T4 and T5. The second rib articulates with the sternum at the sternal angle, making this site an excellent landmark for determining rib number. Immediately adjacent to the sternal angle is rib 2; the other ribs can be found by counting up or down from rib 2. Intercostal spaces are numbered for the rib above. On the posterior thorax, the fourth rib can be found at the level of the medial end of the spine of the scapula and the eighth rib at the inferior angle.

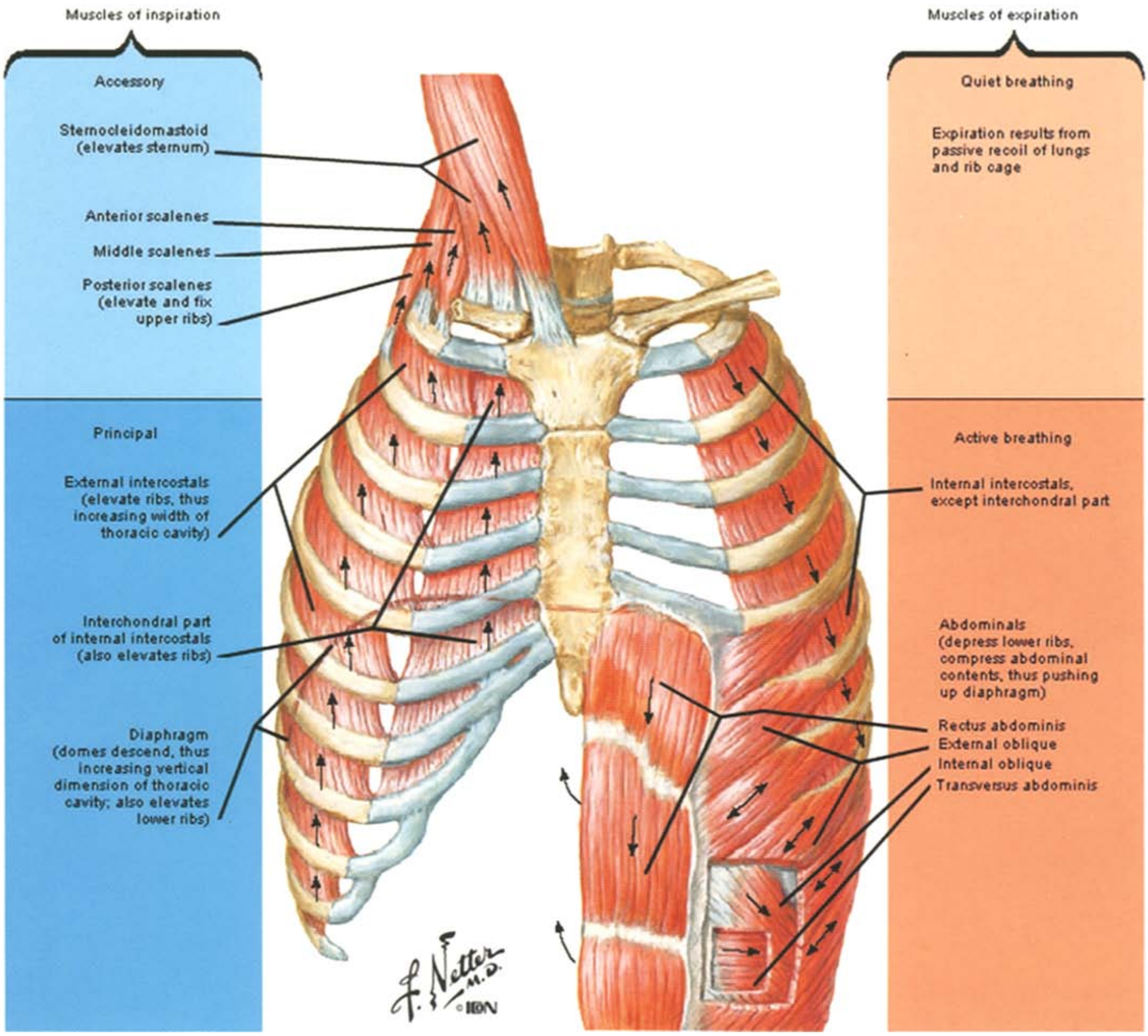


Fig. 27. The participation of muscles in respiration.

The manubrium overlies the junction of the brachiocephalic veins to form the superior vena cava (Fig. 23). The superior vena cava passes at the level of the sternal angle and at, or slightly to the right of, the border of the manubrium. The superior vena cava typically enters the right atrium behind the costal cartilage of the third rib on the right; it is sometimes accessed for various procedures, and knowledge of this surface anatomy is critical for such a procedure.

The xiphoid process is the inferior part of the sternum and lies in a depression, called the *epigastric fossa*, at the apex of the infrasternal angle formed by the convergence of the costal margins at the inferior border of the thorax (Fig. 23). The location of the xiphisternal joint is used as a landmark to determine hand position for cardiopulmonary resuscitation.

The breasts are also surface features of the thoracic wall. In women, the breasts vary greatly in size and conformation, but the base of the breast usually occupies the space between ribs 2 and 6, from the lateral edge of the sternum to the midaxillary line. The nipples, surrounded by an area of darker pigmented skin called the *areola*, are the prominent features of the breast. In men, the nipple is located anterior to the fourth intercostal space in the midclavicular line. Because of the variation in breast anatomy in the female, the location of the nipple is impossible to predict.

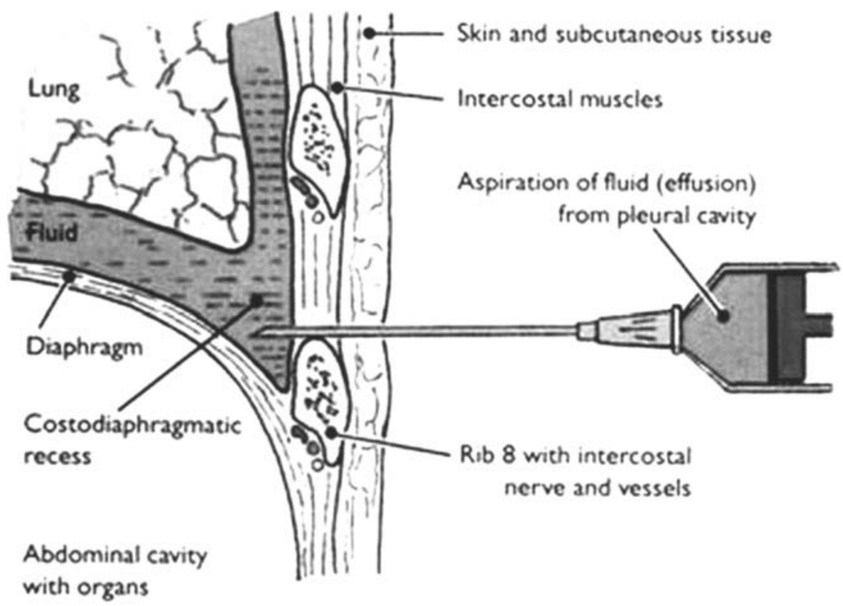


Fig. 28. Illustration of thoracocentesis. Figure adapted from Figure 1.16 from *Grant's Dissector,* 12th Ed., E. K. Sauerland (ed.). © 1999 Lippincott, Williams, and Wilkins, Philadelphia, PA.

12.2. The Lungs and Pleura

The pleural sac is outlined by the parietal pleura as it projects onto the surface of the lungs (Fig. 23). From the root of the neck, these projections follow the lateral edge of the sternum inferiorly. On the left, the border of the parietal pleura moves laterally at the level of fourth costal cartilage to accommodate the cardiac notch within the mediastinum. The pleura follows a line just superior to the costal margin, reaching the level of the tenth rib at the midaxillary line. Posteriorly, the inferior margin of the plural cavity lies at the level of T12, and the medial margin follows the lateral border of the vertebral column to the root of the neck.

In the superior parts of the pleural cavity, the visceral pleura of the lungs is in close contact with the parietal pleura, with the lungs consequently filling the plural cavity. Both lungs and parietal pleura (cervical part) extend above the clavicles into the supraclavicular fossae, at the root of the neck. At the inferior reaches of the pleural cavities, the lungs stop short of filling the plural cavity, reaching only to the level of the 6th rib in the midclavicular line, the eighth rib in the midaxillary line, and the tenth rib posteriorly, creating the costodiaphragmatic recesses. The major (oblique) fissures of the lungs extend along a line from the spinous process of T2 to the costal cartilage of the sixth rib. The minor (horizontal) fissure of the right lung lies under the fourth rib.

Under pathological conditions, fluid can accumulate in the pleural cavity. This fluid normally drains inferiorly and accumulates in the costodiaphragmatic recess. Thoracocentesis refers to the procedure used to drain such fluid (Fig. 28). A needle is inserted into the costodiaphragmatic recess by passing it through the middle of the intercostal space, taking care to avoid the primary intercostal neurovascular bundle immediately below the rib above and collaterals above the rib below.

12.3. The Heart

The heart and great vessels are covered by the sternum and central part of the thoracic cage (Fig. 23). The apex of the heart usually lies in the fifth intercostal space just medial of the midclavicular line. The upper border of the heart follows a line from the inferior border of the left second costal cartilage to the superior border of the right costal cartilage. The inferior border of the heart lies along a line from the right sixth costal cartilage to the fifth intercostal space, at the midclavicular line where the apex of the heart is located. The right and left borders follow lines connecting the right and left ends of the superior and inferior borders.

All four heart valves, the closing of which account for the heart sounds, lie well protected behind the sternum. The sounds of the individual valves closing are best heard at ausculatory sites to which their sounds are transmitted. The bicuspid (mitral) valve is heard at the apex of the heart in the region of the fourth or fifth intercostal space on the left near the midclavicular line. The tricuspid valve can be heard along the left margin of the sternum at the level of the fourth or fifth intercostal space. The pulmonary valve is heard along the left border of the sternum in the second intercostal space. The aortic valve is heard at the second intercostal space on the right sternal border. (For more details on heart sounds, *see* Chapter 14.)

12.4. Vascular Access

An understanding of the surface landmarks relative to the axilla and subclavian region is critical for successful access of the venous system via the subclavian vein. The subclavian vein passes over the first rib and under the clavicle at the junction of its middle and medial thirds; it courses through the base of the neck, where it passes anterior to the apex of the lung and the pleural cavity (Fig. 29). The subclavian vein is immediately

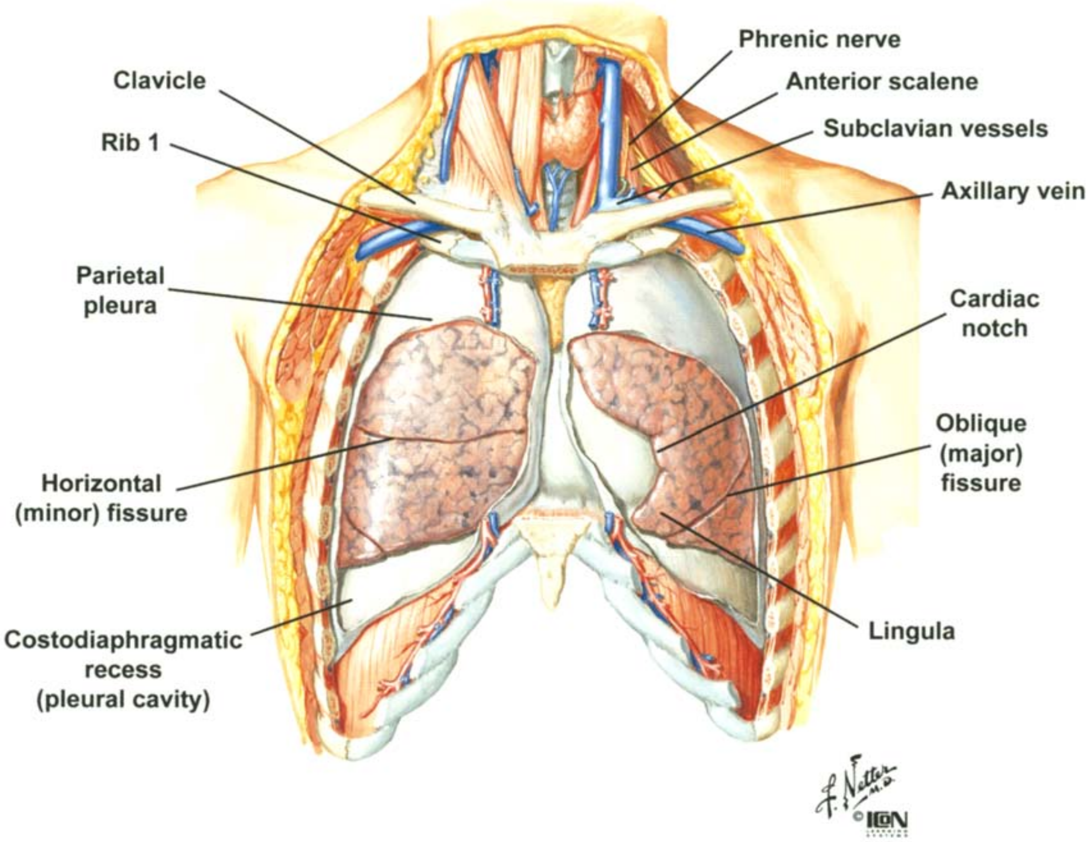


Fig. 29. Anatomy of the subclavian veins and surrounding structures.

anterior to the subclavian artery and is separated from the artery medially by the anterior scalene muscle. To access the subclavian vein, a needle is inserted approx 1 cm inferior to the clavicle at the junction of its medial and middle thirds, and the needle is aimed toward the jugular notch, parallel with the vein to minimize risk of injury to adjacent structures.

The most common complication of subclavian venous access is puncture of the apical pleura, with resulting pneumothorax or hemopneumothorax. In addition, the subclavian artery, lying behind the vein, also has the potential to be injured by this procedure. If subclavian access is attempted on the left, one must also be aware of the junction of the thoracic duct with the subclavian vein. Injury to the thoracic duct can result in chylothorax, the accumulation of lymph in the plural cavity. This is difficult to treat and has an associated high morbidity. When access of the subclavian is attempted for cardiac lead placement, care must be taken to avoid piercing the subclavius muscle or costoclavicular ligament. Passing the lead through these structures tethers it to the highly mobile clavicle, which may cause premature breakage of the lead.

12.5. Summary

Options for accessing, in a minimally invasive fashion, the heart are limited by the vascular anatomy of the superior mediastinum and the axilla. Percutaneous access strategies are limited by the bony anatomy of the thoracic cage. How a device interacts with the thorax and accommodates basic thoracic movements, and movements of the upper extremity and neck, must be understood for design of devices that will endure in the body. Thus, a thorough understanding of the thoracic anatomy surrounding the heart is important to those seeking to design and deploy devices for placement and use in the heart. With an understanding of the important thoracic anatomical relationships presented in this chapter, the engineer should be able to design devices with an intuition for the anatomical challenges that will be faced for proper use and deployment of the device.

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