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Relevant Surgical Anatomy of the Chest Wall

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Synopsis

The chest wall like other regional anatomy is a wondrous fusion of form and function. Principle functions are the protection of internal viscera and an expandable ‘cylinder’ facilitating variable gas flow into the lungs.

Knowledge of the anatomy of the ‘whole’ cylinder (ribs, sternum, vertebra, diaphragm, intercostal spaces and extrathoracic muscles) is therefore not only important in the local environment of a specific chest wall resection but its relation to overall function. An understanding of chest wall kinematics might help define the loss of function after resection and the effects of various chest wall substitutes. Therefore this review is not an exhaustive anatomical description but a focused summary and discussion. (1)

Skeletal Structures

Ribs

The ribs and costal cartilages form the lateral aspects of the ‘thoracic cylinder’. Ribs have a head, a neck, a tubercle, an articular facet, and a shaft. (figure1) The first seven are ‘‘true ribs’’ because they articulate posteriorly with the vertebrae and anteriorly with the sternum by means of a costal cartilage and a true synovial joint. The very flat short broad first rib and the little larger second rib because of their size and their limited range of motion, do not contribute in a major fashion to thoracic volume increase in enhanced ventilation.

The last five are ‘‘false ribs,’’ either because they articulate anteriorly with the seventh costal cartilage (ribs 8–10) or because their anterior extremity ends freely in the posterolateral abdominal wall (‘‘floating ribs,’’ 11 and 12).(figure2) The posterior rib head presents an articular surface with two facets per, divided by a crest, for articulation with its two adjacent vertebrae. The lower facet articulates with the superior articular facet of the numerically corresponding vertebral body.(figure1) Exceptions are the first, eleventh, and twelfth rib where there is a single articular facet.

The neck of the rib spans between the head and the tubercle. The tubercle is the posterior bulging of the rib that articulates with the transverse process of the similarly numbered vertebra. (figure 1) The inferior costal groove of the rib forms just beyond the tubercle and protects the intercostal neurovascular bundle. Intercostal spaces breadth is greater anteriorly than posteriorly and greater between the upper ribs than the lower ribs.

Sternum

The sternum consists of three bony parts connected by two joints. The wide cephalad manubrium is relatively fixed because it articulates with the first rib and the clavicle. The large flat body of the sternum articulates with ribs 2 through 7. (figure 3) The joint between the manubrium and the body moves allowing the body to move anteriorly and cephalad. In the process, it draws the ribs, which articulate with it, upward and outward, increasing the transverse diameter of the chest. The xiphoid process is small and is of little consequence

Thoracic vertebrae

On the posterolateral aspect of each thoracic vertebral body are found two articular surfaces, the superior and inferior costal articular facets of the thoracic vertebra.(figure 4) The superior costal articular facet lies just anterior to the arch pedicle.

The transverse process projects posterolateral and slightly upward from the area where the arch pedicle joins the lamina. The transverse process articular facet sits on its anterolateral aspect, near its distal tip. The eleventh and twelfth thoracic vertebrae usually have a single superior costal and no transverse process articular facet.

From the capacious thoracic intervertebral foramen, the spinal ganglion and nerve root and branches of the spinal arterial and venous systems emerge. The foramen limited above and below by the pedicles of the two adjacent vertebrae lying directly in front and below is the base of each transverse process which is a useful surgical landmark.

The ribs are joined to the vertebral bodies by two articulations: one linking the head of the rib with its adjoining vertebral bodies (the costovertebral joint) and one in between the rib tubercle and the transverse process of the vertebra (the costotransverse joint).

As mentioned before costovertebral joint cavity (ribs 2-10) contains the upper facet of the rib head that is in contact with the inferior costal facet of the vertebral body above and the lower head facet that articulates with the superior costal facet of the numerically corresponding vertebra and is partially divided by an interarticular ligament that attaches a crest situated in between the two joint facets of the head and with intervertebral disk. The capsule gains much support comes from the radiate ligament or anterior costovertebral ligament which attaches to the rib head anteriorly and to the sides of the articulating vertebral bodies and the intervertebral disk.(figure 5) A smaller ligament, the posterior costovertebral ligament, unites the rib to the anterior aspect of the corresponding intervertebral foramen above and the external aspect of the arch pedicle below. The costotransverse joint a small synovial cavity held together by ligaments principally superior and posterior ones that extend from the inferior aspect of the transverse process above to the superior aspect of the rib tubercle below. The dorsal ramus of the intercostal nerve root and posterior branch of the segmental artery (which gives off a branch to supply the cord) runs medial to this ligament to the paraspinal muscle mass.

Muscular structures

Intercostal Muscles

Between 12 ribs are 11 intercostal spaces which comprise intercostal muscles and membranes and supplying neurovascular structures.(figure 3) External intercostal muscles extend from the rib tubercles dorsally to the costal cartilages anteriorly arising from the lower border of the rib above, fibers run obliquely downward, forward and insert into the upper border of the rib below. In the upper two spaces they do not reach the anterior end of the ribs and in the lower two they become continuous with the external oblique muscles at the end of the costal cartilages. The internal intercostal muscles run further anterior to the sternum but extend only as far as the angle of the rib arising from the inferior border on the inner surface of the rib that lies superiorly, and from the corresponding costal cartilage, fibers run obliquely inferiorly and posteriorly and insert into the upper border of the rib below. A third layer is interposed between the two planes of muscular fibers and is more developed where the muscular fibers are deficient.

The innermost intercostals are variable, incomplete and fibers run in direction of those of the internal intercostals but they lie deep to intercostal neurovascular bundle. The subcostalis (or infracostal) muscles which could be considered part of this third group of muscles vary in size and number and lie on the internal surface of the lower ribs usually in the lower part of the thorax, arising from the inner surface of one rib near its angle, and are inserted into the inner surface of the second or third rib below.

Diaphragm

The diaphragm is an elliptical cylindroid structure, capped by a dome; it arches over the abdomen, with the right hemidiaphragm higher than the left. (figure 6) The concave, dome-shaped part allows the liver and the spleen, situated underneath the diaphragm, to be protected by the lower ribs and the chest wall. The diaphragm is a striated skeletal muscle consisting of two major parts: the muscular part radiating outward and the central, noncontractile tendinous part.

The tri part muscular diaphragm originates from the lumbar spine (L1-3) dorsally, lower six ribs laterally, and xiphisternum ventrally and have different embryologic origins, segmental innervation, and functional properties.

The lumbocostal triangles/trigones (Bochdalek's gap) exist between the lumbar and costal parts of the diaphragm, more commonly on the left side than on the right side usually closed only by fascia, peritoneum, and pleura. Anteriorly, there are bilateral triangular gaps between the sternal and costal parts (named after Morgagni and Larrey, or the sternocostal triangles) through which pass the internal thoracic/superior epigastric vessels.

The highest part of the diaphragm, the central tendon, where all the musculature of the diaphragm inserts, has a cloverleaf-like shape, lies anteriorly attached firmly to the pericardium. Laterally, the right and left diaphragmatic dome parts are mobile, and their position is dependent on the extent of ventilation.

The diaphragm has an enormously rich blood supply hence necrosis is rare. The arterial blood supply to the diaphragm is derived from (1) the pericardiophrenic arteries running with the phrenic nerves, (2) the musculophrenic arteries, (3) the superior and inferior phrenic (main source) arteries, and (4) the intercostal arteries (peripheral). The veins of the diaphragm follow the arteries and are accompanied by lymphatic vessels. The diaphragmatic blood flow is respiratory phase dependent: it increases during the diaphragmatic relaxation and decreases during inspiration. During resistance breathing, diaphragmatic blood flow increases more than 20-fold. Diaphragmatic contractility is dependent on appropriate oxygen supply and so it is important that it returns to its constant resting position. (2)

Motor and sensory innervations are supplied by the phrenic nerve and the sixth and/or seventh intercostals nerves, the latter distributed to the costal part of the diaphragm. The muscular part of the diaphragm receives its main motor innervation via the phrenic nerves originating in the cervical plexus running craniocaudally passing anterior to the hilum of the lungs, attaching to the pericardium and on the right side pierces the central tendon anterolaterally to the vena caval opening and on the left lateral to the border of the heart and anterior to the central tendon. The phrenic nerves gives branches on the thoracic side of the diaphragm: anteromedially to the sternum, anterolaterally to the costal diaphragm, and posteromedially to the crural diaphragm in a radial fashion. The diaphragm has three anatomic openings: the aortic, the esophageal, and the inferior vena cava orifices.

Breathing is endurance work, like that of the heart, as the diaphragm must contract in repetitive fashion for life. Hence it contains 55% type I, slow-twitch, fatigue resistant muscle fibers the remaining type II, fast-twitch are recruited when the breathing rate increases (3)

Extrathoracic Muscles

Knowledge of function and anatomy of extrathoracic chest wall muscles are essential to understand the effects of resection and appropriate use as muscle flaps (4) (figure 7). An overview is given in the table 1.

Neurovascular structures

The intercostal neurovascular bundle lies between the internal and innermost intercostals muscles or parietal pleura where the intercostal vein is most cephalad followed by the artery and nerve caudally. In each intercostal space, there are two sets of arteries, posterior and anterior, that anastomose with each other. In each space, the single posterior intercostals arteries originate from ventral branches of segmental arteries from the descending thoracic aorta and the smaller twin anterior (coursing above and below each rib) are branches of the internal thoracic artery or its terminal branch, the musculophrenic artery. Except the first two intercostal spaces which originate from the superior intercostals artery posteriorly (costocervical trunk) and the supreme thoracic artery (axillary artery) anteriorly. This twin blood supply has obvious advantages to proximal and distal perfusion of the chest wall after resection. The intercostal veins have a similar distribution to that of the arteries; posteriorly draining into the azgous and accessory /hemi azgous systems (except the uppermost into the brachiocephalic vein) and anteriorly into the internal thoracic veins.

After exiting the intervertebral foramen, the spinal root gives off two branches: the dorsal or posterior ramus supplies the muscles, bones, and joints of the posterior thoracic wall, and the ventral or anterior ramus, which becomes the intercostal nerve running in the subcostal grove of the rib except the twelfth which lies below the rib and is called the subcostal nerve.

The first two nerves supply fibers to the upper extremities in addition to their thoracic branches; the next four are limited to the thorax and the lower five supply thorax and upper abdomen. This accounts for the distribution of pain due from chest wall infiltration. They pass forward in the intercostal spaces below the intercostals vessels initially lying between the pleura and the intercostal membranes but soon piercing the latter and running between the two planes of intercostal muscles as far as the middle of the rib. They then enter the substance of the internal intercostals, running amid their fibers as far as the costal cartilages, where they reach the inner surfaces of the muscles and lie between them and the pleura. Near the sternum, they cross in front of the internal mammary artery and pierce the internal intercostals, the anterior intercostals membranes, and pectoralis major, and supply the integument of the front of the thorax and over the breast, forming the anterior cutaneous branches of the thorax. At the front of the thorax some of these branches cross the costal cartilages from one intercostal space to another. Lateral cutaneous branches derived from the intercostal nerves midway, pierce the external intercostals and serratus anterior, and divide into anterior and posterior branches. The anterior branches run forward to the side and the forepart of the chest, supplying the skin and the mamma; those of the fifth and sixth nerves supply the upper digitations of the external oblique abdominis. The posterior branches run backward, and supply the skin over the scapula and latissimus dorsi. The lower thoracic nerves (seventh to eleventh) continue anteriorly from the intercostal spaces into the abdominal wall; between the internal oblique and transversus abdominis, to the sheath of the rectus abdominis, which they perforate. The lower intercostal nerves supply the intercostals and abdominal muscles; the last three send branches to the serratus posterior inferior.

The intercostal lymphatic vessels

At the anterior ends of the intercostal spaces are the sternal glands, by the side of the internal mammary artery and the posterior parts of the intercostal spaces are occupied by the intercostal glands, in relation to the vessels unite and form a trunk and drain in the case of lower 5 spaces into the cisterna chyli and upper spaces of the left side end in the thoracic duct and upper right side in the right lymphatic duct.

Sympathetic nerves

The sympathetic chain courses vertically over the heads of the ribs, just lateral to the radiate ligaments. The T-1 sympathetic ganglia fuses with C-7 and C-8 to form the stellate ganglion, slightly above the first rib lying transversely and medially.

Chest wall movement

The easiest model to express the mechanics of quiet respiration a cylinder (the sternum, ribs, cartilages and vertebrae) with the diaphragm piston is simplistic.(figure 6) There are three inspiratory actions of the diaphragm related to the cranial-caudal orientation of the muscle fibers and the existence of the zone of opposition (the area of contact between the diaphragm and the rib cage). First, as the diaphragm contracts it pulls the central tendon in a caudal direction, thus expanding chest volumes (piston-like action). At the same, it pushes the abdominal organs down and increases the intra-abdominal pressure which is transmitted across the apposition zone, pushing the lower ribs outward, resulting in expansion of the rib cage. Finally, the relationship of the contracting, descending diaphragm to the opposing effect of the abdominal contents serves as a fulcrum. The net effect is force exerted on the lower ribs cranially, resulting in their upward and outward movement all because of its unique elliptical cylinder capped by a dome shape.(5)

The lungs, which are in direct contact with the chest wall via the pleural surfaces, follow the generated negative extrathoracic pressure and expand. Once inspiration is complete, the diaphragm relaxes, and the intrinsic elastic component of the lungs causes them to contract toward their original volume, causing exhalation.

Motion of the skeletal components of the chest wall facilitate the changes in the dimensions of the cylinder (the chest).(figure 8) The ribs and costal cartilages act as ‘bucket handles’ that move up and down on the spine. Anteriorly, the ribs are connected to the sternum, which can be viewed as a mechanical ‘pump handle’. The joint between the manubrium and the body of the sternum allows the body to have a greater anterior and cephalad excursion, which causes the lower ribs to move more cephalad and anterior than the upper ribs, resulting in a greater increase in diameter in the lower chest.

The volume shifts of the cylinder can be increased greatly during times of need. The accessory muscles of respiration by the above mechanism respond to increase the diameter of the chest on inspiration (sternocleidomastoid muscle, the scalene muscles, and the external intercostals). The accessory muscles of expiration (internal intercostal, rectus abdominis, external and internal oblique and transverse abdominis muscles) function to decrease the internal thoracic diameters and decrease the volume of the cylinder, hence forcing the chest to exhale air. These muscles cause the ribs and the sternum to move downward. The abdominal muscles force the viscera cephalad pushing the diaphragm upward. These changes, along with increased respiratory rate, allow a tremendous increase in respiratory gas exchange to deal with the increased demand.

Because of their fiber orientations and the distances between their costal insertions and the center of rotation of the ribs, the conventional view is that the external intercostal muscles elevate the ribs and have an inspiratory action, whereas the internal intercostals lower the ribs and so have an expiratory action. This may not be completely accurate as animal studies suggest that the position (both craniocaudally and dorsoventrally), lung volume and interaction with other spaces can effect their action. (6)

The exact contribution and interaction of the thoracic rib cage (principally intercostals), abdominal rib cage (principally diaphragm) and abdominal muscles were difficult to study non invasively and dynamically. But more recently there is sound data on the interaction and contributions of these compartments at rest and after different forms of exercise.(7) Significant abnormal patterns at rest, after exercise and asynchronies between compartments have been recognized in disease states.(8) However the local and global changes following chest wall resection and reconstruction are yet to be studied in such detail. Early evidence from pectus excavatum patients suggest that patterns of disordered chest wall motion are present in subgroups of patients but whether surgical correction improves this is uncertain.(9)

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