Surgical Anatomy of the Diaphragm in the Anterolateral Approach to the Spine

A Cadaveric Study

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Study Design: Laboratory cadaveric study.

Objective: To delineate the pertinent surgical anatomy of the diaphragm during access to the anterolateral thoracolumbar junction.

Summary of Background Data: The general anatomy of the thoracic diaphragm is well described. The specific surgical anatomy as it pertains to the lateral and thoracoabdominal approaches to the thoracolumbar junction is not well described.

Methods: Dissections were performed on adult fresh cadaveric specimens. Special attention was paid to the diaphragmatic attachments to the lower rib cage and to the spinal thoracolumbar junction.

Results: The pertinent diaphragmatic attachments to the rib cage are at the 11th and 12th ribs. Whether the diaphragm is incised or mobilized ventrally, the pertinent spinal attachments are the lateral and medial arcuate ligaments. Identifying and sectioning these structures allows for direct access to the thoracolumbar junction, particularly the L1 vertebral body.

Conclusions: An understanding of the diaphragmatic-costal and diaphragmatic-spinal attachments is key for the safe and effective implementation of diaphragm mobilization during the lateral and thoracoabdominal approaches to the spine.

Key Words: diaphragm, thoracolumbar junction, thoracoabdominal approach

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The anterolateral or thoracoabdominal approach is an effective, if not definitive, route for decompression and stabilization in cases of trauma, tumors, and infections at the thoracolumbar junction. The goals of the operation include decompression of neural elements, restoration of vertebral height and alignment, and stabilization. Both the traditional thoracoabdominal and the minimally invasive lateral approaches necessitate mobilization of the thoracic diaphragm.[1–3] Although vascular or thoracic access surgeons have traditionally assisted with this part of the procedure, it remains paramount for the primary spine surgeon to understand the relevant anatomy and techniques associated with mobilizing the thoracic diaphragm. The goal of this work was to delineate the pertinent surgical anatomy of the diaphragm during access to the anterolateral thoracolumbar junction. Our goal was also to provide clinical pearls based on our experience with the anterolateral thoracoabdominal approach.

METHODS

Fresh adult cadaveric specimens were used in this study. Dissections were performed at the VISTA cadaveric surgical training facility in Baltimore; no external or industry funding was used for this study. Five total sides were examined. Dissections were carried out using the standard flank, thoracoabdominal approach. Special attention was paid to the lower rib cage (ribs 10–12) and the diaphragmatic attachments at this level. The diaphragm was then mobilized ventrally and/or incised to expose the deeper diaphragmatic-spinal attachments. The relationship of the diaphragmatic-costal and diaphragmatic-spinal attachments was recorded and images were obtained.

RESULTS

The diaphragm has several pertinent costal and spinal attachments as the anterolateral corridor to the thoracolumbar junction is developed. The significant diaphragmatic-costal attachments are at the undersurface of the 11th and 12th ribs (Fig. 1). The attachment to the 12th rib in fact provides the lateral-most point of separation between the thoracic and retroperitoneal cavities (Fig. 2). As the diaphragm is detached from these lower ribs and is reflected ventrally, the lateral and medial arcuate ligaments are exposed (Figs. 3, 4). The medial arcuate ligament is a fascial band that arcs over the psoas muscle with a medial insertion at the L1 vertebral body

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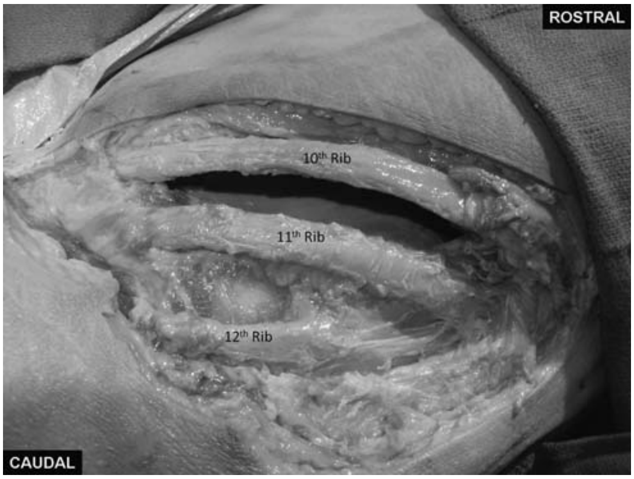

FIGURE 1. Diaphragmatic-costal attachments at the 11th and 12th ribs.

(it interdigitates with the respective crus) and a lateral insertion is the same-level transverse process. The lateral arcuate ligament, in contrast, arcs over the quadratus lumborum muscle. Its medial insertion is the L1 transverse process and its lateral insertion is the 12th rib. Complete access to the entire thoracolumbar junction (T11–L2) requires (1) undermining the deep medial and lateral arcuate ligaments and (2) either incising the diaphragm superficially or deflecting it ventrally after detaching the costal attachments.

DISCUSSION

General Anatomy

The diaphragm is a dome-shaped musculoaponeurotic structure that (1) serves as an important respiratory muscle and (2) separates the thoracic and the abdominal cavities.

FIGURE 2. Diaphragmatic-costal attachment to the 12th rib (cut). Note distinct separation of the chest and abdominal cavities at this level.

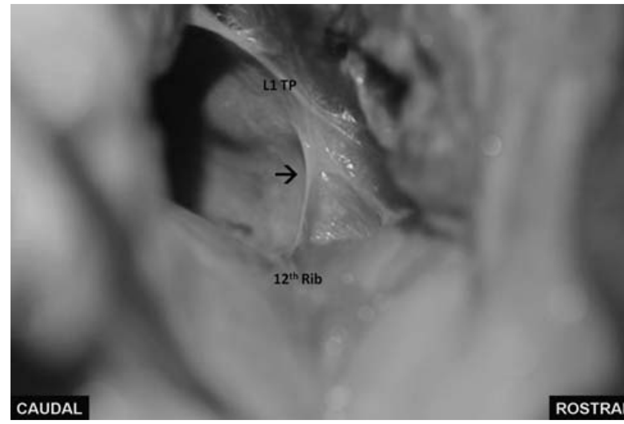

FIGURE 3. The lateral arcuate ligament (arrow) directly medial to the diaphragmatic-costal attachments. Note the attachments to the L1 transverse process medially and the 12th rib laterally. This ligament overlies the quadratus lumborum muscle.

It is comprised of a central, noncontractile fibrous tendon centrally (composed of 3 leaflets: right, left, and middle) and 2 major muscular portions: the costal and crural diaphragm. An additional minor muscular portion is the sternal part of the diaphragm.[4,5] The diaphragm houses 3 apertures: aortic hiatus at T12, the esophageal hiatus at T10, and the caval hiatus at T8 through which the vena cava runs. The aortic hiatus transmits the aorta, the aortic plexus, the thoracic duct, lymphatic vessels that descend from the thorax to the cisterna chili,[6] and usually the azygos vein. The esophageal hiatus transmits the esophagus, the anterior and posterior vagal nerve trunks, and the phrenicoabdominal (sensory) branch of the left phrenic nerve (eventually supplying the pancreas and peritoneum). Ventrally, the esophageal hiatus is walled by muscle fibers that aide in the closure of the caudal end of the esophagus.

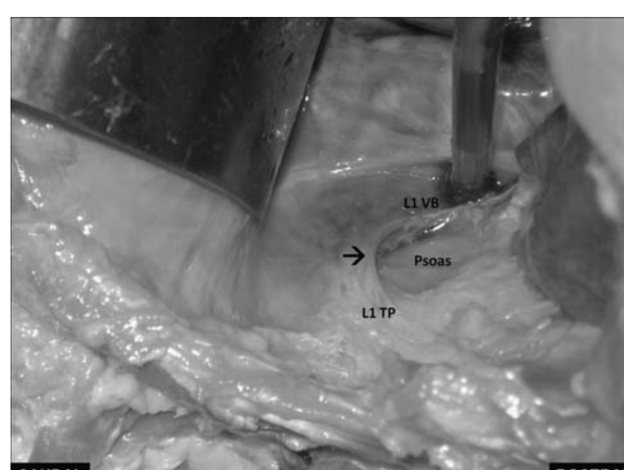

FIGURE 4. The medial arcuate ligament (arrow) directly medial to the lateral arcuate ligament. Note the attachments to the L1 vertebral body medially and the L1 transverse process laterally. This ligament overlies the psoas muscle.

Muscular Parts of the Diaphragm

The diaphragm is a striated skeletal muscle consisting of 2 major parts: the muscular, which is radiating outward, and the central, noncontractile tendinous part. It has 3 components, which originate from the sternum ventrally, lumbar spine dorsally, and ribs laterally (pars lumbaris, pars costalis, and pars stanlis). The lumbar (crural) diaphragm project toward the anterolateral aspect of L1 to L3, whereas muscle fibers of the costal diaphragm project from the central tendon to the upper margins of the lower 6 ribs and the xiphoid process of the sternum.

The lumbar (crural) part of the diaphragm forms the right and the left crura along the lumbar spine, and it is the most powerful part of the diaphragm. The right crus is larger than the left crus, and it overlies the middle part of the central tendon on both sides. The right crus arises from the anterior surface of the lumbar vertebrae (L1–3 on the right and L1–2 on the left). In >60% of individuals, the right crus splits to form the esophageal hiatus.[4] In the rest, the esophageal crura is derived from both crurae. It functions as a sphincter-like opening of the diaphragm. The right crus forms the ligament of Treitz inferiorly, which is attached to the duodenum between its third and fourth part.

The costal part of the diaphragm originates from the inner surface and upper margins of the 6 lower ribs and radiates into the central tendon. The lumbocostal triangle or the Bochdalek gap is found between the lumbar and costal parts of the diaphragm. The sternal part of the diaphragm originates from the posterior layer of the rectus sheath and from the posterior surface of the xiphoid process. All musculature of the diaphragm inserts on the thickened central tendon, which is the highest part of the diaphragm. The superior surface of the tendinous part is attached firmly to the pericardium.

Vascular Supply

The arterial blood supply to the diaphragm is derived from the pericardiophrenic arteries (branch of the internal thoracic artery), the musculophrenic arteries (branched from the internal thoracic arteries), the superior (branched from the thoracic aorta) and inferior phrenic arteries (branched from the abdominal aorta or renal artery), and the intercostal arteries. The right and left inferior phrenic arteries supply the abdominal side of the diaphragm. They are much larger than the other arterial branches and are the main source of arterial blood supply to the diaphragm. The peripheral parts of the costal diaphragm have an additional blood supply from the intercostal arteries and are anastomosed with the superior and inferior phrenic arteries.[7]

The veins of the diaphragm follow the arteries. The venous drainage from the thoracic side of the diaphragm is through the azygos and hemiazygos systems, whereas that of the abdominal side is mainly through the inferior phrenic veins to the inferior vena cava. The peripheral costal and sternal portions of the diaphragm drain through the intercostal and the internal thoracic veins. The thoracic and abdominal surfaces of the diaphragm have a rich lymphatic system accompanying the blood vessels.[8–10]

Innervation

Motor and sensory innervations are supplied by the phrenic nerve and the sixth or seventh intercostal nerves. The right and left phrenic nerves originate in the cervical plexus (mainly the fourth cervical nerve roots, with lesser contributions from the third and fifth roots) and run craniocaudally, passing anterior to the hilum of the lungs, in close proximity to the pericardium along with the pericardiophrenic artery and veins where they provide pericardial branches. Understanding the distribution of the phrenic nerves is important if the diaphragm is to be incised during surgery. Diaphragmatic branches of the phrenic nerves are typically deep and central to the muscle and are not exposed on the undersurface of the diaphragm.[11,12]

Surgical Pearls

Mobilizing the diaphragm is necessary when anterolateral access to the thoracolumbar junction is needed, especially if access to the L1 vertebral body is necessary. Whether the diaphragm is incised as in the traditional open approaches, or whether it is reflected ventrally as in the minimally invasive lateral approach, the pertinent surgical anatomy must be appreciated.[13–16]

How the diaphragm is encountered depends on the point of anterolateral entry. During the 10th or 11th rib approaches, it is possible to stay supradiaphragmatic and entirely within the chest (either retropleural or transpleural). This is often adequate if access caudal to T12 is not needed If complete access to L1 is needed (as in total vertebrectomy and adjacent level instrumentation), then the diaphragm requires mobilization. Once the 11th rib is resected, and the diaphragmatic attachments are dis-inserted, the corridor can either be transthoracic transdiaphragmatic, or retropleural retrodiaphragmatic (Fig. 5). In fact, detaching the diaphragm-pleura from the 11th and 12th ribs will communicate the retropleural to the retroperitoneal space (the so-called "extracelomic space").[3] However, undermining both the lateral and medial (but not median) arcuate ligaments is always necessary to fully expose the anterolateral spine. Once the diaphragm is mobilized, these thin bands are either sharply dissected or cauterized. This will fully expose the quadratus lumborum, the origin of the psoas muscle, and the lateral aspect of the L1 vertebral body. Of note, the crura of the diaphragm drape over the anterolateral aspect of L1–3 bodies (as they interdigitate with the anterior longitudinal ligament) and their lateral edges can be carefully cauterized to increase anterolateral exposure of the vertebral body (Fig. 6).

With respect to the innervation and vascular supply of the diaphragm, both are more ventrally located close to the central tendon and thus should not be compromised during the more dorsal, anterolateral approach to the spine. If the diaphragm is incised, however, incisions

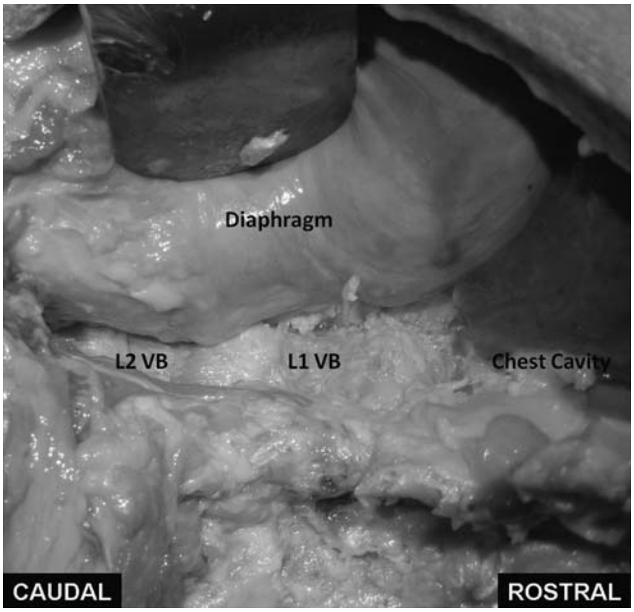

FIGURE 5. Resection of the medial and lateral arcuate ligaments allows mobilization of the diaphragm ventrally. The chest and retroperitoneal space is now communicating, and complete access to the thoracolumbar junction is possible.

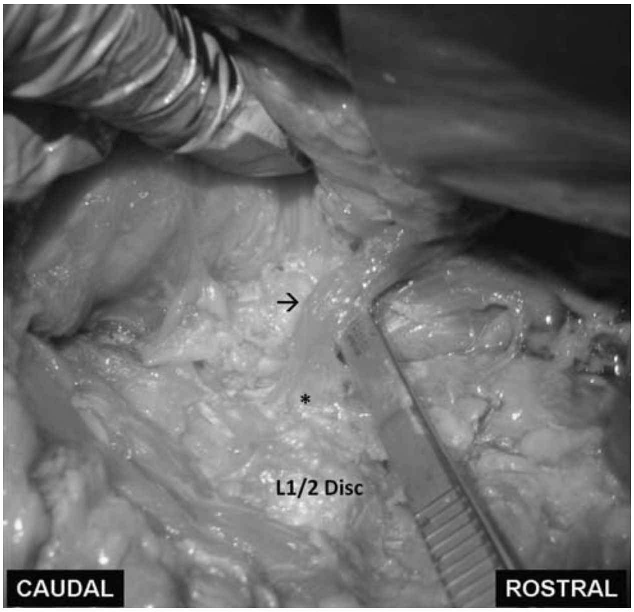

FIGURE 6. Left crus of the diaphragm (arrow) inserting ventrolaterally onto the L1–2 vertebral bodies and interdigitating with the anterior longitudinal ligament (asterisk).

should be made either circumferential (parallel to the edge of the muscle) or radial (from central tendon outward).[3] The diaphragm is reapproximated using a high-caliber nonabsorbable suture.

CONCLUSIONS

Anterolateral access to the thoracolumbar junction is feasible once the diaphragm is either incised or mobilized ventrally. An understanding of the diaphragmatic-costal and diaphragmatic-spinal attachments is paramount to safely and effectively accessing the anterolateral thoracolumbar junction. The key diaphragmatic structures encountered during the thoracoabdominal approach are the 11th and 12th costal attachments and the medial and lateral arcuate ligaments.

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