The anatomical relationship of the diaphragm to the thoracolumbar junction during the minimally invasive lateral extracoelomic (retropleural/retroperitoneal) approach

Laboratory investigation

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Object. The thoracolumbar junction (T11–L2) poses an anatomical dilemma, given the presence of the lower rib cage and the diaphragm when performing anterolateral approaches. To circumvent dealing with the diaphragm, a minimally invasive lateral extracoelomic approach has been used to approach the thoracolumbar junction by mobilizing the diaphragm anteriorly. No anatomical studies have described the attachments of the diaphragm and their surgical significance during the lateral approach to the thoracolumbar spine. The objective of this study is to describe the anatomical relationship of the diaphragm in reference to the minimally invasive lateral approach to the thoracolumbar spine and its surgical significance.

Methods. Nine adult fresh-frozen cadaveric specimens were dissected and studied (18 sides). All specimens were placed in the lateral decubitus position, similar to the surgical technique, for the dissections. The relationship between the retroperitoneum, retropleural space, diaphragm, and thoracolumbar spine was analyzed in reference to the minimally invasive lateral approach. Special attention was given to the attachments of the diaphragm and their relationship to the ribs during the early stages of the approach.

Results. All 18 sides were successfully dissected, analyzed, and photographed. The diaphragm is a musculotendinous sheet extending between the thoracic and abdominal cavities. Its attachments can be divided into 3 main categories: 1) sternal or anterior, 2) costal or lateral, and 3) lumbar or posterior. These attachments are described in detail, with specific reference to the lateral approach. When performing the minimally invasive lateral extracoelomic approach to the thoracolumbar spine, the lateral and posterior attachments must be identified and dissected to successfully mobilize the diaphragm anteriorly.

Conclusions. The diaphragm has multiple attachments that can be categorized as anterior, lateral, and posterior. In reference to the minimally invasive lateral extracoelomic approach to the thoracolumbar junction, the surgically significant attachments are primarily to the 12th rib and transverse process of L-1.

Key Words • retropleural approach • retroperitoneal approach • thoracolumbar junction • anatomy • lateral access • extracoelomic approach

The thoracolumbar area is a common location for traumatic and nontraumatic pathologies. The thoracolumbar junction (T11–L2) poses an anatomical dilemma to spine surgeons during lateral approaches given the presence of the lower rib cage and the diaphragm, which is sandwiched between the pleura and peritoneum. Multiple surgical approaches have been described to access this area, from conventional open to more minimally invasive techniques, as well as coelomic to extracoelomic approaches. Extracoelomic approaches include both the retropleural and retroperitoneal approaches, whereas coelomic approaches include transthoracic and transperitoneal approaches.

The retropleural and retroperitoneal approaches to the thoracolumbar junction have been described as early as 1925 by Fey. Francioli similarly described an approach for sympathectomies. In 1973, Mirbaha further described the combined retropleural-retroperitoneal approaches to the thoracolumbar spine. Moskovich et al. modified the technique and coined the term “extracelomic approach” (retropleural and retroperitoneal) to the spine. The clinical results of these approaches have also been reported.

With recent advances in minimally invasive technologies, many spinal procedures are being performed with an emphasis on minimizing tissue damage and blood loss. The minimally invasive lateral extracoelomic approach to
the thoracolumbar junction has been described.\textsuperscript{1,15,17} Clinical data describing its safety and efficacy have also been reported.\textsuperscript{15,16,18}

Although the minimally invasive lateral extracelo-
omic approach to the thoracolumbar spine is being increasingly used, there is a paucity of literature on the anatomy of the region. The diaphragm, which is located at the thoracolumbar junction separating the thoracic and abdominal cavities, must be mobilized during the minimally invasive extracelo-
omic approach. An understanding of its anatomy and relationship to nearby structures is critical during the approach. In this study we describe the anatomical relation-
ship of the diaphragm in reference to the minimally invasive lateral approach to the thoracolumbar spine and its surgical significance.

**Methods**

Adult fresh frozen cadaveric specimens without innate or detected abnormalities were used in this study. They were each systematically evaluated for evidence of prev-
ous retroperitoneal, abdominal, or spinal surgery. A total of 9 adult fresh-frozen cadaveric specimens were dissected and studied. Bilateral dissections were performed, yielding a total of 18 dissections. Dissections were performed at the University of South Florida biomechanical spine labora-
tory and at the cadaveric laboratory at NuVasive, Inc. All specimens were placed in the lateral decubitus position, which is consistent with the surgical technique, for the dis-
sections. The relationship between the retroperitoneum, retropleural space, diaphragm, and thoracolumbar spine was analyzed in reference to the minimally invasive lateral approach. Special attention was given to the attachments of the diaphragm and their relationship to the ribs during the minimally invasive lateral approach.

**Results**

Our findings are consistent with previous anatomical descrip-
tions.\textsuperscript{11,19} No anomalies, pathological lesions, or prev-
ious incisions were noted for any side, excluding minor degenerative changes to the spine in these adult cadavers. All 18 sides were successfully dissected, analyzed, and photographed.

**Chest/Abdominal Wall**

The muscles of the chest and abdominal wall involved at the thoracolumbar area when approaching the spine from the lateral aspect include the latissimus dorsi, intercostal, transversus abdominis, and external and internal oblique muscles. The origins and insertions of these muscles are described below.

The latissimus dorsi originates from the lower 6 tho-
racic and all the lumbar and sacral spinous processes, as well as a posterior portion of the iliac crest. The fibers converge to a tendon that inserts into the medial lip of the intertubercular groove of the humerus. The muscles that pass between 2 adjacent ribs are called intercostal muscles and are arranged into 2 layers, external and internal. The external and internal intercostal muscles originate from the lower border of a rib and insert into the upper border of the rib below. The external intercostal fibers slant downward and forward, whereas the internal intercostal fibers slant downward and backward. The external oblique muscle originates from the lower 6 ribs, runs downward and medi-
ally, and inserts on the anterior part of the iliac crest, pu-
bis, and linea alba. The internal oblique muscle originates from the iliopsoas fascia, anterior part of the iliac crest, and thoracolumbar fascia. It travels upward and medially inserting into the lower borders of the lower 3 ribs and linea alba. The transversus abdominis, found deep to the external and internal oblique muscles, originates from the thoracolumbar fascia (between the iliac crest and the 12th rib), iliopsoas fascia, anterior part of the iliac crest, and the internal aspects of the lower 6 costal cartilages where it interdigitates with the diaphragm. It shares a common insertion with the oblique muscles into the linea alba.

**Diaphragm**

The diaphragm is a musculotendinous sheet extending between the thoracic and abdominal cavities (Fig. 1). Its su-
perior surface is covered by parietal pleura and pericard-
um, and its inferior surface is covered by the diaphragmat-
ic fascia, an extension of the transversalis fascia, and the peritoneum. The peritoneum separates from the posterior aspect of the diaphragm because of the intervening fat and the superior aspects of the kidneys and related structures.

The attachments of the diaphragm can be divided into 3 main categories: 1) sternal or anterior, 2) costal or lat-
eral, and 3) lumbar and posterior (Table 1). The sternal at-
tachments arise from the back of the xiphoid process and aponeurosis of the transversus abdominis. The costal at-
tachments arise from the medial aspects of the seventh and eighth ribs anteriorly, the ninth and 10th laterally, and the 11th and 12th ribs posterolaterally (Figs. 2 and 3). When comparing the right and left sides, there is no difference in the sternal or costal attachments, despite the presence of the liver. Posteriorly, the diaphragm forms 2 arcuate liga-
ments on each side and 2 crura. The lateral arcuate lig-
ament spans the quadratus lumborum, whereas the medial...
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TABLE 1: Summary of attachments of the diaphragm

<table>
<thead>
<tr>
<th>Location</th>
<th>Attachments</th>
</tr>
</thead>
<tbody>
<tr>
<td>anterior (sternal)</td>
<td>xiphoid process, aponeurosis of the transversus abdominis</td>
</tr>
<tr>
<td>lateral (costal)</td>
<td>medial aspects of the 7th &amp; 8th ribs anteriorly, 9th &amp; 10th ribs laterally, &amp; 11th &amp; 12th ribs posterolaterally</td>
</tr>
<tr>
<td>posterior (lumbar)</td>
<td>medial &amp; lateral arcuate ligaments, lt &amp; rt crura</td>
</tr>
</tbody>
</table>

arcuate ligament spans the psoas muscles. The lateral arcuate ligament attaches medially to the transverse process of L-1 and laterally to the inferior edge of the 12th rib. The medial arcuate ligament attaches laterally to the transverse process of L-1 and medially to the corresponding crus. The intervening point of attachment is on the transverse process of L-1 (Fig. 4). The attachments of the lateral arcuate ligament are the same on the left and right sides. The crura of the diaphragm extend along the anterolateral lumbar spine on their respective sides. The only major difference in the attachments of the diaphragm when comparing the left and right sides can be seen with the crura. The left crus typically extends to L-2, whereas the wider right-sided crus extends to the level of L-3.

Coelomic Cavities

The 2 pertinent coelomic cavities separated by the diaphragm include the pleural and peritoneal cavities (Fig. 5). The pleura, composed of 2 layers, is the membrane that surrounds the lungs and forms the lining of the pleural cavity. The outer pleura (parietal pleura) is attached to the chest wall. The inner pleura (visceral pleura) covers the lungs and adjoining structures. The potential space between them is the pleural cavity. The peritoneum, also composed of 2 layers, is a membrane that forms the lining of the abdominal cavity. It covers most of the intraabdominal (or coelomic) organs. The outer layer, called the parietal peritoneum, is attached to the abdominal wall. The inner layer, or visceral peritoneum, is wrapped around the internal organs that are located inside the intraperitoneal cavity. The potential space between these 2 layers is the peritoneal cavity.

Surgical Approach

The surgical approach has been described previously. The patient is placed in a true lateral decubitus position, and under fluoroscopic guidance, a 6-cm-long oblique incision (following the trajectory of the rib at the index level) is made at the midaxillary line. In all cases, the side of the approach is chosen according to the vertebral level and the location of the abnormality. To facilitate this surgical approach, a portion of rib is removed. The rib removed is the one overlying the affected level, which may vary slightly. This is usually the 10th rib for T-12, 11th rib for L-1, and the 12th rib for the L-2 level. Using monopolar cautery, the muscles overlying the rib are transected. The periosteum over the selected rib is incised and elevated. Further separation of the periosteum is performed with the aid of an Alexander or Cobb elevator. A segment of the rib (ap-
proximately 5–6 cm) is excised. The portion of resected rib may be set aside for use as autograft. From the lateral approach in the midaxillary line, the portion of the 10th or 11th rib resected lies over the endothoracic fascia and pleura. If this is the case, then the plane between the endothoracic fascia and the parietal pleura is developed bluntly with the aid of a finger (Fig. 6). However, due to the insertion of the diaphragm, when removing the 12th rib, one is in effect disinserting the costal attachments of the diaphragm. The pleura is then mobilized anteriorly along with the diaphragm bluntly with a finger or a sponge stick until the lateral side of the vertebral body and adjacent discs are exposed. If the target levels include L-1, then the lumbar or posterior attachments of the diaphragm must be sharply transected off the transverse process of L-1. This intervening attachment between the medial and lateral arcuate ligaments must be cut to fully expose the lateral vertebral body. When disinserting the diaphragm from its costal and lumbar attachments, one is able to connect the retropleural and retroperitoneal spaces. If more anterior exposure of the vertebral body is required, then the ipsilateral crus may be transected as well. At this point an expandable tube retractor system may be inserted, and the goals of the surgery may be carried out in the standard fashion (Fig. 7). When using this extracoelomic approach, there is no need for repair of the diaphragm. Since we are not making an incision in the diaphragm and we remain in the retroperitoneal/retropleural spaces, we have seen no long-term sequelae or complications from this approach.

**Discussion**

The relationship between the diaphragm, ribs, pleura, and peritoneum poses a challenge during surgical approaches to the lower thoracic and upper lumbar vertebrae. Due to the transitional anatomy, the approach to the spine becomes more complex. When approaching the thoracolumbar spine using the lateral corridor, this area can be accessed using a coelomic (transpleural) or extracoelomic (retropleural, retroperitoneal, or combined retropleural/retroperitoneal) approach. Since the first description of the extracoelomic approach in 1925, it has been further modified and described in detail numerous times.1–3,8–10,15,17

The diaphragm muscle is the most relevant structure in this area, and it separates the thoracic cavity from the abdominal cavity. When developing the extracoelomic approach, it is necessary to mobilize the diaphragm. Knowledge of the regional anatomy, with special attention to the attachments of the diaphragm, is essential to successfully use the extracoelomic corridor. To fully un-
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derstand the anatomy, we will begin by first reviewing the embryological development of this area.

Embryology

At the end of the 3rd week in development, embryos form 2 cavities: the intraembryonic (body cavity or coelom) and the extraembryonic coelom (or chorionic cavity). The intraembryonic coelom is lined by somatic and splanchnic lateral plate mesoderm. The somatic mesoderm will go on to form the parietal layer of the serous membranes that line the outside of the pleural and peritoneal cavities. The splanchnic mesoderm forms the visceral layer of the serous membranes that cover the abdominal organs and lungs. The embryological development of the pleural and peritoneal cavities provides the basis for the extracoelomic surgical approach both to the thoracic and to the thoracolumbar spine.

The development of the diaphragm begins in the 7th week of gestation and is complete by the 10th week. The diaphragm divides the coelomic cavity into the pleural and peritoneal cavities and develops from the following 4 components: 1) the anteromedial portion (central tendon) from the transverse septum, 2) the posterolateral portions from the pleuropertoneal membranes, 3) the lumbar portions (or crura) from the dorsal mesentery of the esophagus, and 4) the muscular portions from myoblasts of the lateral and dorsal body walls.

Surgical Significance

When approaching the thoracolumbar spine using the lateral extracoelomic approach, the diaphragm is the most critical structure. This muscle is intimately related to the approach during all stages. The 2 most relevant attachments of the diaphragm are the costal and lumbar portions. During the early stages of the exposure, the costal or lateral portion is exposed. The subperiosteal dissection and excision of the rib overlaying the target mobilizes the diaphragm from its costal attachments. The challenge of dissecting the costal attachments is the delineation of tissue planes. The transversus abdominis interdigitates with the muscle of the diaphragm with no clear plane of dissection. By excising a portion of the rib, an extracoelomic plane is identified.

The lumbar portion (arcuate ligaments and crura) is exposed after disinserting the costal portion as described above and by bluntly mobilizing the diaphragm anteriorly with the pleural and peritoneal contents. The next attachment visualized is the medial attachment of the lateral arcuate ligament and the lateral attachment of the medial arcuate ligament to the L-1 transverse process. This attachment must be sharply cut. In addition to this attachment, the arcuate ligaments also fuse posteriorly to the thoracolumbar fascia. This is the last structure that should be disinserted before finishing the surgical corridor, exposing the thoracolumbar spine from the lateral access. If further anterior exposure of the vertebral body is required, then the ipsilateral crus may also be sectioned and mobilized. When all the costal and lumbar attachments of the diaphragm are mobilized, the retropleural and retroperitoneal spaces are communicated into 1 plane.

Since this approach remains in the retroperitoneal/retropleural space, it can be performed from the right or left side depending on surgeon preference or location of the pathology. The liver, spleen, or other peritoneal structures do not interfere with the approach. Because the approach remains in the extracoelomic space and the diaphragm is not incised, there is no need for any repair of the diaphragm. Mobilizing the diaphragm anteriorly has no long-term clinical sequela.

Conclusions

The retropleural and retroperitoneal cavities are extracoelomic spaces that provide anatomical corridors to the thoracolumbar spine. The diaphragm, which separates the thoracic and abdominal cavities, has multiple attachments that can be categorized as anterior, lateral, and posterior. In reference to the minimally invasive lateral extracoelomic approach to the thoracolumbar junction, the surgically significant attachments are primarily to the 12th rib and transverse process of L-1.

Disclosure

Dr. Uribe is a consultant for NuVasive, Inc.

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