Avoiding abdominal flank bulge after anterolateral approaches to the thoracolumbar spine: cadaveric study and electrophysiological investigation

Laboratory investigation

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Object. The thoracolumbar junction is frequently accessed through an anterolateral approach with the incision and muscle dissection extending from the lower thoracic region to the lateral border of the rectus abdominis muscle. This approach is frequently associated with the subsequent development of an unsightly and uncomfortable relaxation of the ipsilateral abdominal wall, or flank bulge, caused by denervation injury to the intercostal nerves. However, the etiology of this complication is not widely recognized by spine surgeons. The object of this study was to better define the relevant anatomy and innervation of the anterolateral abdominal wall musculature.

Methods. The authors performed 32 cadaveric dissections and 6 intraoperative electromyography (EMG) evaluations.

Results. The cadaveric dissection studies and intraoperative EMG evaluations provided detailed anatomy of the anterolateral abdominal wall and its innervation. Cadaveric dissections revealed that the most significant intercostal nerve contributions to the anterolateral abdominal wall arise from T11 and T12. Electrophysiological confirmation of these findings was accomplished through intraoperative stimulation in 6 patients undergoing anterolateral retroperitoneal approaches to the thoracolumbar junction. The authors confirmed T11 and T12 innervation of the anterolateral abdominal wall musculature by direct intraoperative EMG recording in all 6 patients.

Conclusions. The authors classified the 3 potential zones of injury that can be affected during an anterolateral approach to the thoracolumbar junction. Modifications to the operative technique are suggested to avoid the complication of flank bulge. The most significant intercostal nerve contributions to the anterolateral abdominal wall arise from T11 and T12. (DOI: 10.3171/2011.7.SPINE10887)

Key Words • postoperative complication • flank bulge • denervation injury • anterior spine surgery • thoracolumbar junction • anterolateral approach

**A**nterolateral access to the thoracolumbar junction is often necessary to perform decompression and instrumented fusion for fractures, tumors, infections, and deformities. The thoracolumbar junction of the spine can be accessed anteriorly through a thoracoabdominal anterolateral retroperitoneal approach.5,12,15,25 However, many complications have been reported with this surgical approach, many of which are directly attributable to the thoracotomy. The most common are respiratory complications including atelectasis, pneumonia, and pneumothorax.8,11 Entering the thoracic cavity invariably impairs normal respiratory mechanics, which can remain abnormal for several months postoperatively.15 Another approach-related complication is postoperative ileus, which affects approximately 2.5% of patients who undergo this approach.16 Even less frequently, postoperative arterial or venous thrombosis can occur as a result of intraoperative injury or excessive prolonged compression of the vessels.26,19

This approach is also associated with a complication that is seldom mentioned in the spine literature despite its substantial impact on patient outcome and quality of life. An unsightly and painful abdominal flank bulge can occur after anterolateral approaches to the thoracolumbar spine (Fig. 1). Postoperatively, patients report abdominal muscle laxity and flank bulge, which results in asymmetrical cosmetic deformity and dissatisfaction with physical appearance. For many patients, this flank bulge can be painful and tender to the touch.

Abdominal flank bulge is largely underrecognized, and its impact is substantially unappreciated by spine surgeons. Although every spine surgeon knows that the T1
Abdominal flank bulge

Fig. 1. Photographs showing postoperative abdominal flank bulge.

and T2 nerve roots should be preserved whenever possible given their important contributions to the lower trunk of the brachial plexus, some mistakenly believe that the other thoracic intercostal nerves can routinely be sacrificed. There is a misconception that ligation of the thoracic intercostal nerves results only in a sensory deficit along the body wall. There is a general lack of awareness among spine surgeons regarding the contributions of the lower thoracic nerves, especially T11 and T12, to the muscles of the anterolateral abdominal wall.

Therefore, it is not surprising that abdominal flank bulge is usually only mentioned in passing when discussing the complications of an anterolateral exposure to the spine, with reference made to the vascular surgery literature. In fact, most of what we know about this complication comes from the literature on vascular surgery, in which a similar incision is used to deal with abnormalities of the abdominal aorta and its branches. The incidence of abdominal flank bulge after these vascular operations is generally reported to be between 8% and 23%, with one outlying series documenting an incidence of 56% at the 1-year follow-up.

Jagannathan and colleagues have been the only authors thus far to evaluate the incidence of abdominal flank bulge specifically in the setting of spine surgery. They observed this complication in 18% of 120 patients who had undergone an anterolateral retroperitoneal approach, a rate in concordance with previously reported rates in the vascular literature. More importantly, however, the patients who experienced an abdominal bulge reported lower scores on self-assessments of wound appearance and overall wound satisfaction. Moreover, this complication was associated with a lower quality of life, as indicated by statistically significant lower scores on the Scoliosis Research Society–30 questionnaire compared with the overall cohort. We have also noted that patients who experience postoperative abdominal flank bulge report increased pain, decreased satisfaction with their operation, and decreased quality of life.

Our objective in the present study was to elucidate the muscular and nervous anatomy of the abdominal wall to highlight the pathophysiology of abdominal flank bulge. To accomplish this task, we performed cadaveric dissections and intraoperative electrophysiological evaluations. We critically examine the currently used operative techniques for anterolateral approaches to the thoracolumbar spine, and we classify the 3 potential zones of denervation injury. Finally, we suggest modifications of the standard operative technique to avoid injury to the T11 and T12 intercostal nerves.

**Methods**

To clearly identify the muscular anatomy and innervation of the anterolateral abdominal wall, we undertook a 2-stage investigation. First, we performed 32 cadaveric dissections to isolate the individual muscle layers and nerve supply. Second, we performed intraoperative electrophysiological evaluations in 6 patients to verify the findings of our anatomical dissections.

**Cadaveric Dissections**

Bilateral dissection of the anterolateral abdominal wall was performed in 16 cadavers, for a total of 32 cadaveric dissections. Eleven of the cadavers were male and 5 were female. The mean age at the time of death was 76.8 ± 4.2 years. The individual muscular layers of the abdominal wall were identified and isolated. The lower thoracic intercostal nerves (T9 through T12) were identified along the undersurface of the corresponding rib and were traced distally to their insertions into the muscle layers of the abdominal wall.

**Electrophysiological Evaluation**

After completing our cadaveric investigations, we performed intraoperative electrophysiological evaluations in 6 patients who were undergoing an anterolateral retroperitoneal approach for the treatment of disease at the thoracolumbar junction. There were 4 men and 2 women, whose mean age was 56.4 ± 8.3 years. Based on the findings of our cadaveric dissections, we only performed electrophysiological stimulation at the T11 and T12 nerves to confirm the data based on our anatomical dissections.

Direct nerve stimulation was begun at an amplitude of 1 mA and was gradually increased until a response was obtained. A response was detected by EMG needle recording from electrodes that had been placed directly in each of the individual muscle layers (external oblique, internal oblique, and transversus abdominis muscles) under direct visualization. The end point of the electrophysiological evaluation was the observation of a muscle action potential on the EMG recording from any of the individual muscles. Intraoperative EMG recordings were obtained from the external oblique, internal oblique, transversus abdominis, and rectus abdominis muscles.

**Results**

**Anatomical Findings**

Our 32 cadaveric dissections confirmed what is already known about the muscular abdominal wall. It is composed of the rectus abdominis muscle medially and 3 overlapping layers of abdominal muscles laterally; from
superficial to deep, these 3 muscle layers are the external oblique, internal oblique, and transversus abdominis muscles (Fig. 2A). All the intercostal nerves initially begin their course along the inferior surface of the corresponding thoracic rib, immediately beneath the vein and artery. As they course laterally around the abdominal wall, they leave the inferior surface of the rib and begin to project into the intercostal space. With regard to the 2 so-called floating ribs, the intercostal nerves are sheltered by their corresponding ribs for an even shorter segment of their course. As they continue around the abdominal wall anteriorly, these nerves continue their downsloping trajectory toward the anterior abdominal wall.

We noted that along the inferior and lateral aspect of the anterolateral abdominal wall, there is a neurovascular plane that runs between the internal oblique and transversus abdominis muscles. This plane was identified in 29 of the 32 cadaveric dissections. In the area corresponding to the more inferior aspect of a dissection to expose the thoracolumbar junction, this plane contains the intercostal nerves (including T11 and T12), as well as the iliohypogastric and ilioinguinal nerves (both branches of the ventral rami of L1). If one were to extend even farther down, as if to expose the lower lumbar spine, the inferior intercostal, subcostal, and lumbar arteries could also be found in this plane, as could the deep circumflex artery (a branch of the external iliac artery). As these structures proceed anteriorly around the abdominal wall, they leave this neurovascular plane, passing through the internal oblique muscle to a more superficial location.

Although it is generally accepted that the ventral rami of the inferior 6 thoracic nerves (T7–T12)—also known as the intercostal or thoracoabdominal nerves—contribute in varying degrees to the innervation of all muscles of the anterolateral abdominal wall, our anatomical dissections revealed very limited insertion of the T9 and T10 nerves into these muscles (Table 1). The T9 nerve root innervated at least one of the muscles of the anterolateral abdominal wall (most commonly the internal oblique muscle) in one-sixth of the dissections. The T10 nerve root innervated one of the abdominal muscle layers (most commonly the transversus abdominis muscle) in one-third of the dissections. In addition, the L1 nerve root was found to only occasionally have significant insertions into the internal oblique (3 dissections [9%]) and transversus abdominis (5 dissections [16%]) muscles, although never into the external oblique or rectus abdominis muscles.

Based on our 32 cadaveric dissections, the most substantial and most frequently identified nerves inserting into the anterolateral abdominal musculature were the 11th and 12th intercostal nerves (Table 1). The T11 innervation of the individual muscle layers ranged from 84% for the rectus abdominis muscle to 94% for both the transversus abdominis and the internal oblique muscles. The T12 innervation of the individual muscle layers ranged from 81% for the transversus abdominis muscle to 97% for the external oblique muscle. Our explorations showed that the subcostal nerve (T12) is the largest of the 6 intercostal nerves and appeared to be especially prominent in its insertions into the external oblique muscle (31 [94%] of 32 dissections).

**Intraoperative EMG Results**

Our cadaveric dissections revealed that the most significant intercostal nerve contributions to the anterolateral abdominal wall arise from T11 and T12. We pursued electrophysiological confirmation of these findings through intraoperative stimulation in 6 patients undergoing anterolateral retroperitoneal approaches to the thoracolumbar junction. We confirmed T11 and T12 innervation of the anterolateral abdominal wall musculature by direct intraoperative recording in all 6 patients (Fig. 3).

The T10 nerve was accessible in 2 of the patients without any alteration of the operative plan, and in both of these cases stimulation of the T10 nerve root produced weak EMG responses only in the external oblique muscle layer. In 1 of the patients the L1 nerve was easily accessible, and stimulation of this nerve produced EMG responses only in the transversus abdominis muscle recordings.

**Standard Operative Technique**

We have observed and performed the widely accepted technique for anterolateral exposure of the thoracolumbar spine, which generally proceeds as follows. Traditionally, the incision begins at the tip of the 11th rib and courses anteriorly and inferiorly around the abdomen, extending medially to the lateral aspect of the rectus sheath (Fig. 2B). The 3 underlying muscle layers are then divided with electrocautery to enter the retroperitoneum. The peritoneal cavity and its contents are retracted anteriorly until the anterior border of the psoas muscle can be visualized. After completing the spine operation, the wound is closed in layers.

**Classification of Potential Zones of T11 and T12 Intercostal Nerve Injury**

The occurrence of postoperative abdominal flank bulge is most likely attributable to muscle denervation caused by injury to the T11 and T12 intercostal nerves. Based on our cadaveric dissections and electrophysiological investigations, we have classified the potential areas of nerve injury into 3 distinct anatomical locations (Fig. 2B).

**Zone I Injuries.** Each intercostal nerve travels within the costal groove along the inner border of the inferior aspect of the corresponding rib. We define Zone I as the segment of intercostal nerve along the body of the rib immediately proximal to the last few centimeters of the rib (Fig. 2B). Generally, the rib provides the intercostal nerve with some protection from injury. However, during anterior approaches to the spine, there are 3 ways in which the intercostal nerve can be injured within Zone I.

First, the nerve can be injured during so-called minimally invasive, or less-invasive, exposures. Some of these exposures involve resecting a portion of the rib with a rib cutter to provide a window through which the spine can be accessed. This procedure involves a periosteal dissection to strip the intercostal muscles and the intercostal neurovascular bundle off the posterior aspect of the rib. During this process a Bovie instrument or bipolar forceps is frequently used to control bleeding from the intercostal
vascular bundle, which may inadvertently result in thermal injury to the intercostal nerve.

Second, during exposure, the lower thoracic intercostal nerves can be injured with a rib dissector, electrocautery, or a rib spreader. When a rib spreader is placed to expand the intercostal space, 1 side of the retractor is placed along the inferior border of the more rostral of the 2 ribs that are being spread apart. Since the intercostal nerve is the most inferior structure among the neurovascular bundle that travels within the costal groove along

**Fig. 2.** A: Illustration showing the 3 muscular layers of the abdominal wall (external oblique, internal oblique, and transversus abdominis muscle layers) and the path of the intercostal nerve as it travels in the neurovascular bundle between the internal oblique and transversus abdominis muscle layers. A more superficial cutaneous branch of the intercostal nerve is depicted, and this nerve can be injured during exposure. **B:** Illustration depicting the 3 potential zones of T11 nerve injury along a thoracoabdominal retroperitoneal incision. Zone I, segment of intercostal nerve along the body of the rib immediately proximal to the last few centimeters of rib; Zone II, segment of intercostal nerve as it leaves the costal groove at the distal end of the floating rib; and Zone III, segment of intercostal nerve as it travels along the neurovascular plane between the internal oblique and transversus abdominis muscle layers. Printed with permission of Daniel H. Kim, 2011.
the inferior border of the rib, it is susceptible to crush or stretch injury during the use of this technique. Third, the ribs that were previously spread apart to allow for adequate exposure are routinely reapproximated during closure. This process frequently involves using a large suture to bring the 2 adjacent ribs together, which may cause direct injury to the intercostal nerve of the more caudal rib in the pair by crushing the nerve between the rib and the suture.

**Zone II Injuries.** The second anatomically defined zone of potential injury to the nerve involves the most distal few centimeters of a floating rib (Fig. 2B). Zone II involves the costochondral junction between T12 and the retroperitoneum. Several operative techniques unique to Zone II can damage the intercostal nerve.

Spine surgeons routinely dissect just distal to the tip of the T12 floating rib, at the costochondral junction, to enter the retroperitoneum. This process can result in injury to the passing intercostal nerve just as it leaves the rib. Additionally, Bovie electrocautery is frequently used to begin detachning the diaphragm in this region, which may cause direct or indirect injury to the intercostal nerve.

One particular technique used to increase exposure during anterolateral approaches to the spine involves fracturing the distal-most portion of the rib and splaying it posteriorly and inferiorly. This technique may lead to inadvertent injury to the intercostal nerve, which can occur through direct trauma from the fractured rib. More commonly, however, this manipulation induces a stretch injury by pushing the nerve posteriorly and inferiorly while it remains relatively tethered in the soft tissues distally.

The distal-most portion of the rib is also frequently resected for use as a bone graft. A rib cutter is frequently used to divide the rib. If underlying tissues, including the neurovascular bundle within the costal groove, are not carefully dissected away from the rib before cutting, transection of the nerve can occur. Even if the nerve is carefully dissected from the portion where the rib cutter will be applied but not distal to that, it can suffer a traction injury while being inadvertently pulled during removal of the resected rib.

**Zone III Injuries.** We define Zone III as anywhere along the course of the intercostal nerve distal to the tip of the rib (Fig. 2B). There are at least 2 ways in which the intercostal nerves can be injured in this zone. They can be directly transected with monopolar electrocautery during division of the anterior abdominal wall musculature, or they can be indirectly damaged by heat injury if they are close to the Bovie instrument during opening.

Zone III injuries can also occur during closure. When the muscle layer of the abdominal wall is closed, an intercostal nerve that is not visualized can be directly damaged by a passing needle. Even more likely, however, is suture tightening, which can cause strangulation of the nerve as it is inadvertently included in the suture line.

**Discussion**

Having observed abdominal flank bulge with the standard thoracoabdominal approach to the spine, we have modified our operative techniques to minimize denervation injury of the abdominal wall musculature. Our intention in this study was to increase awareness among spine surgeons regarding ways to preserve the T11 and T12 intercostal nerves along their course given that they innervate the musculature of the abdominal wall. Suggestions for technique modifications related to each potential cause of injury are discussed below. Technique modifications during opening, manipulation of the rib, and closing are also presented as they relate to each potential zone of injury (Table 2).
Technique for Rib Spreading and Retraction

The use of a rib spreader is very helpful for attaining adequate exposure of the anterior thoracolumbar spine. Although its use can result in Zone I or II injuries, a rib spreader can be used safely while minimizing the potential for injuring the intercostal nerve of the rostral rib to be retracted. Two simple techniques, when used in tandem, can help to avoid injury to the underlying nerve. The intercostal nerves are carefully dissected and mobilized, and then they are covered and protected to prevent any nerve injury. Prior to applying the rib spreader, a moistened laparotomy sponge can be used to pad the inferior surface of the rostral rib to protect the nerve from the retractor blade. These precautions can prevent crush injury to the nerve during rib retraction.

Technique for Rib Dissection

Rib dissection along the body of the rib can potentially result in a Zone I injury. Similarly, resection of the most distal portion of the rib for use as an autograft can be associated with a Zone II injury through a similar mechanism. These injuries can be avoided by meticulous and thorough subperiosteal dissection of the underlying neurovascular bundle. If bleeding is encountered, precise bipolar electrocautery while protecting the nerve with a moistened cottonoid may prevent inadvertent thermal injury. Furthermore, the rib cutter should approach the rib from below, and one of its blades should be placed between the rib and the underlying neurovascular bundle under direct visualization while the other blade goes above the rib. This strategy prevents inadvertent transection of the nerve, which can occur when the rib cutter approaches from above.

Technique for Partial Rib Osteotomy

Partial-thickness osteotomy of the tip of the 12th rib with subsequent inferior and posterior splaying of the rib for the purpose of increasing the operative corridor can cause a Zone II stretch injury. The only way that this procedure can be safely performed is by dissecting and mobilizing the intercostal nerve within the neurovascular bundle distal to the rib so that it does not remain tethered within the soft tissues with resultant stretch injury or possible transection when the rib is subjected to a partial-thickness osteotomy and is splayed inferiorly and posteriorly.

Technique for Rib Reapproximation

At the end of the case, reapproximation of the ribs using sutures can lead to a Zone I or II crush injury to the intercostal nerve along the more caudal rib. Reapproximation can be safely performed only if the intercostal nerve can be dissected out of the costal groove along the inner inferior border of the more caudal rib and excluded from the suture line of the ribs.

Technique for Avoiding Zone III Injuries

Zone III injuries are unique in that they do not involve manipulation of the ribs, as the intercostal nerves have left the relative shelter of the costal groove. Without awareness of the anatomy or meticulous attention to the operative technique, Zone III injuries can occur during opening or closure.

The use of Bovie electrocautery to cut through all 3 layers of the abdominal musculature can produce Zone III injuries by direct or indirect (heat) damage. It is best to minimize the use of electrocautery while dissecting through these muscle layers. A combination of blunt and sharp dissection can be used to open the external oblique muscle. The internal oblique muscle should then be elevated to separate this layer from the underlying transversus abdominis muscle. Blunt dissection using the spreading motion of a Kelly clamp can be performed along the neurovascular plane that contains the intercostal nerves and the vasculature of the abdominal wall to separate the

**TABLE 2: Recommendations for avoidance of intercostal nerve injury**

<table>
<thead>
<tr>
<th>Time</th>
<th>Zone I</th>
<th>Zone II</th>
<th>Zone III</th>
</tr>
</thead>
<tbody>
<tr>
<td>during opening</td>
<td>protect intercostal nerve w/ moistened cottonoid while coagulating intercostal artery or vein</td>
<td>identify intercostal nerve as it leaves intercostal groove &amp; enters neurovascular plane before using Bovie instrument at tip of floating rib</td>
<td>use blunt dissection w/ Kelly clamp to spread &amp; identify each muscle layer &amp; neurovascular bundle following intercostal nerve distally as it departs from intercostal groove aids in identifying neurovascular plane to prevent inadvertent injury of nerve</td>
</tr>
<tr>
<td>during manipulation of rib</td>
<td>when placing rib spreader, protect intercostal nerve of rostral rib w/ opened moistened laparotomy sponge</td>
<td>dissect intercostal nerve off caudal rib before “down-fracturing” rib; when obtaining a portion of rib for autograft, place rib cutter from below w/ deeper blade btwn rib &amp; intercostal nerve</td>
<td>recommendations for both Zones I &amp; III apply to intercostal nerve preservation in Zone II</td>
</tr>
<tr>
<td>during closure</td>
<td>dissect intercostal nerve out of caudal rib’s intercostal groove before suture reapproximation of ribs</td>
<td>recommendations for both Zones I &amp; III apply to intercostal nerve preservation in Zone II</td>
<td>each muscle layer should be closed separately to prevent inadvertent strangulation of nerve in suture line</td>
</tr>
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**Abdominal flank bulge**

Partial-thickness osteotomy of the tip of the 12th rib with subsequent inferior and posterior splaying of the rib for the purpose of increasing the operative corridor
individual muscle layers. The internal oblique muscle can then be sharply divided with Metzenbaum scissors while being elevated off of the underlying structures. On occasion, even the individual arteries and nerves within this neurovascular plane can be visualized.

After identifying these structures whenever possible, great care is taken to preserve any nerve large enough to be seen after this careful dissection. Blood vessels that cross the desired surgical route can be cauterized with bipolar electrocautery. Once the intercostal nerves have been visualized they can be preserved, and sharp dissection can be used to divide the final layer of the abdominal wall, that is, the transversus abdominis muscle. If necessary, the nerve can be dissected out along a portion of its course to allow its mobilization and transposition out of the path of the desired surgical route.

On occasion, no nerves or blood vessels can be visualized after completing the intermuscular dissection described above. When this occurs, it indicates that the intercostal nerves or blood vessels are either superior or inferior to the dissection. In this scenario we do not recommend continuing the dissection to search for these nerves. These cases are representative of the many patients who do not experience an abdominal flank bulge after this approach, since the intercostal nerves are not encountered along the incision line. We generally only dissect up to 1 or 2 cm above and below the line of the incision to search for and preserve any passing intercostal nerves.

Visualization of the intercostal vein, artery, and nerve along the undersurface of the rib is frequently easier than identifying the intercostal nerve in the neurovascular plane as described above. In fact, following the intercostal nerve as it leaves the edge of the rib can aid in accurately identifying the neurovascular plane. This strategy has been helpful on multiple occasions when the intercostal nerve could not be visualized during the initial interscalene dissection.

Another cause of Zone III injuries is inadvertent inclusion of an intercostal nerve in the suture line during closure. Once the nerves have been exposed during the opening, they are carefully avoided in the closure and are never incorporated into the suture line. Each muscular layer should be closed separately to improve visualization and avoid inclusion of the intercostal nerve within the suture line.

Use of Intraoperative Electrophysiological Monitoring

It is possible to directly stimulate the intercostal nerve intraoperatively and record motor action potentials by EMG needle recording from the individual muscle layers. Stimulation of the nerve can be performed at various stages of the operation (for example, after placement of the retractors) to ensure that there has been no change in the motor action potential recordings. However, this technique is time consuming and impractical and requires limiting the use of paralytics intraoperatively. An awareness of the potential zones of injury as well as the institution of appropriate modifications to the surgical technique should suffice in preventing this complication.

Complication Avoidance During Less-Invasive Anterolateral Approaches

Minimally invasive or less-invasive anterolateral approaches are increasingly used to access the thoracolumbar spine. Unfortunately, these less-invasive approaches do not necessarily protect against the development of postoperative abdominal flank bulge. Many of the techniques suggested above can be applied to minimally invasive transpsoas approaches to the upper lumbar spine and thoracolumbar junction. Specifically, Zone II and III injuries can be avoided during the initial opening by using blunt and sharp dissection through each individual muscle layer, as discussed above, instead of Bovie electrocautery. During less-invasive approaches that involve cutting a window through the rib, a meticulous subperiosteal dissection of the intercostal neurovascular bundle should be performed. Any cauterizing of the intercostal artery or vein should be undertaken only while protecting the intercostal nerve with a moistened cottonoid. There is essentially no risk of injury to the intercostal nerves with minimally invasive lateral approaches to the lower lumbar spine.

Postoperative Abdominal Flank Bulge

Postoperative abdominal flank bulging is an unsightly and painful complication of anterolateral approaches to the thoracolumbar spine. Authors of earlier studies involving a similar approach for vascular or urological procedures suggested that this bulging is a mechanical process attributable to patient-related factors such as diabetes, obesity, or postoperative pulmonary complications.1,22,23,26 However, these characteristics are more likely to represent risk factors for the development of a true hernia of the abdominal wall as opposed to a denervation injury that causes generalized bulging of the flank.

It is extremely important to distinguish between a true hernia and a denervation injury of the anterolateral abdominal musculature, because the former requires a reoperation for repair, whereas the latter is essentially an irreversible injury. True hernias involve one or more fascial defects, whereas a denervation injury involves thinning of the musculature but an intact fascial plane.24 The diagnostic distinction is best made with CT studies of the abdomen.1,24 The development of true hernias in the postoperative setting is attributed to regional compromise of the vascular supply, which is not likely to occur in anterolateral approaches to the spine because the abdominal wall has abundant vascular anastomoses.7,28 Therefore, it is more likely that abdominal flank bulging after anterolateral approaches to the spine is attributable to a denervation injury.

Multiple authors have hypothesized that denervation injury in this type of flank incision results from damage to the intercostal nerve due to extension of the incision into the intercostal space between the 11th and 12th ribs.7,9,13 However, subsequent investigators have not found extension into this space to be a risk factor for developing this complication.29 More recently, authors have found an association between longer incisions and abdominal flank bulging.16,18,20 However, this association is confounded by a related finding attributing this complication to an
Abdominal flank bulge

...increased body mass index, which is inextricably associated with an increased incision length. Perhaps the association between longer incision length and postoperative abdominal flank bulging can be attributed to a higher risk of nerve injury associated with a longer incision and not to the direct mechanical result of a longer incision.

It has been proposed by some that postoperative abdominal flank bulging is partially a mechanical process caused by direct muscular injury, scarring, or disruption of the blood supply. However, there is abundant evidence that implicates denervation injury as the more likely etiology. For example, multiple studies have shown substantial thinning of the abdominal wall musculature after similar flank incisions. The pattern of muscular atrophy has even been documented as following an oblique pattern, mimicking a dermatomal distribution. One study in the vascular literature included the neurophysiological evaluation of patients with abdominal flank bulge, which revealed iterative discharges, polyphasia, fibrillation potentials, and altered recruitment patterns, indicating a denervation injury.

Multiple authors have suggested that abdominal flank bulging after retroperitoneal approaches may be a result of denervation injury. However, these authors have varied substantially in their recommendations on how to avoid this injury. Some advocate avoiding extension of the incision into the intercostal space between the 11th and 12th ribs. Others suggest minimizing the length of the incision. Several mention the importance of not crossing dermatomes with the incision while simultaneously conceding the difficulty of performing this task.

Our proposed strategies for avoiding this unsightly and painful complication incorporate some of these recommendations while further expanding them. Entry into the intercostal space is not forbidden, especially if it is done to identify the intercostal nerve within the costal groove and to follow the nerve distally. Avoiding the crossing of dermatomes is advisable, although it is not as important or as helpful as visualizing and preserving the nerves themselves, realizing that they travel in a neurovascular bundle between the internal oblique and transversus abdominis muscles.

By clarifying the anatomical course and function of the intercostal nerves, we hope to increase awareness of their importance. By classifying the 3 potential zones of injury and identifying the techniques that can lead to nerve injury within each zone, we have elucidated the potential causes of this bothersome complication. The suggested modifications of traditional techniques for rib resection, spreading, fracturing, and reapproximation can prevent Zone I and II injuries. Zone III injuries can be avoided by using a layer-by-layer technique for opening, including meticulous sharp dissection of each muscular layer with identification of the intercostal nerve whenever possible.

Conclusions

Abdominal flank bulge is an unsightly and painful complication that can occur after anterolateral retroperitoneal approaches to the thoracolumbar spine. Based on cadaveric dissections and intraoperative electrophysiological investigations, we believe that this complication results from denervation of the abdominal musculature, caused by injury of the T11 and T12 intercostal nerves. Awareness of the anatomical course of the intercostal nerve, the 3 zones of injury, and the potential causes of injury within each zone is the first step in preventing this complication. The suggested technique modifications may decrease the risk of denervation injury with resultant abdominal flank bulge.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: DH Kim, Fahim. Acquisition of data: Fahim, SD Kim. Analysis and interpretation of data: DH Kim, Fahim, SD Kim. Drafting the article: Fahim, SD Kim, Cho, Lee. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: DH Kim. Administrative/technical/material support: DH Kim. Study supervision: DH Kim. Illustration supervision: Cho, Lee.

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