Chapter 13
Lumbar Retroperitoneal Transpsoas Corpectomy

Gabriel Tender, Durga R. Sure, Yasser Badr, Anthony Digiorgio, and Clifford Crutcher

Introduction

The standard surgical treatment for lumbar corpectomy is usually performed by the spine surgeon with the assistance of the general surgeon and involves extensive abdominal wall dissection and psoas muscle mobilization. Thoracic and lumbar corpectomies can be performed via a posterior or postero-lateral approach [1–3] or an antero-lateral (transthoracic/retroperitoneal) approach [4, 5]. The minimally invasive surgery (MIS) option for the lateral approach has been successfully used in the thoracic spine (T5–L1) with good results [4, 5], since the dissection for exposing these levels is extrapleural. However, this approach becomes more difficult in the lower lumbar spine, and particularly at L4, due to the presence of the psoas muscle and the enclosed lumbar plexus. We describe the minimally invasive lateral retroperitoneal technique, in which the psoas muscle is dissected rather than mobilized.

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G. Tender (✉)
Louisiana State University, New Orleans, LA, USA

D.R. Sure
Essentia Health, Duluth, MN, USA

Y. Badr
Badr Brain and Spine, Los Angeles, CA, USA

A. Digiorgio • C. Crutcher
Department of Neurosurgery, Louisiana State University Health Sciences Center, New Orleans, LA, USA
e-mail: Adigi2@lsuhsc.edu; ccrutc@lsuhsc.edu

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Indications

The minimally invasive lateral retroperitoneal approach can be performed for L1 through L4 corpectomy. The lesions affecting the vertebral body that needs to be resected can be traumatic, tumoral, or infectious.

Trauma

The classification and indications for surgical treatment in thoracolumbar fractures have evolved over the past 50 years along with the diagnostic capabilities. Currently, the thoracolumbar injury classification and severity (TLICS) system takes into account fracture morphology, posterior ligamentous complex (PLC) integrity, and neurological status [6, 7]. In patients with comminuted vertebral body fractures and posterior ligamentous complex disruption, a circumferential (anterior and posterior) fixation is recommended.

Tumors

Primary or metastatic tumors can affect the lumbar vertebral bodies and may result in either loss of vertebral body height with kyphotic deformity and/or anterior cauda equina and/or conus medullaris compression. These tumors can be successfully approached via the minimally invasive lateral retroperitoneal approach. However, if the tumor extends into the pedicles and/or has a significant component in the lateral or posterior spinal canal, the postero-lateral approach may provide better circumferential decompression of the canal.

Infection

In cases of discitis, the minimally invasive lateral retroperitoneal approach offers an excellent route to perform an extensive disc debridement and possibly decompression of an anterior epidural abscess compressing the spinal sac. We prefer not to use instrumentation in these cases until the infection is controlled. However, occasionally, there is extensive destruction of the adjacent vertebral bodies and major neurological deficits due to compression of the cauda equina and/or conus medullaris. Almost invariably, these patients also present with significant kyphotic deformity. In this situation, a 2-level corpectomy with decompression of the spinal canal and reconstruction with an expandable cage may become mandatory.

Contraindications

The L5 vertebral body and the L5–S1 disc cannot be accessed via the transpsoas approach.

The L4 corpectomy feasibility depends on the L4–5 disc level anatomy. If the femoral nerve is anteriorly located (as seen on the T2-weighted axial MRI) or if the iliac crests project above the L4 mid-body on the lateral X-ray, then a different approach may be indicated.

Retroperitoneal scarring represents a relative contraindication.

Preoperative Planning

Preoperative imaging includes:

1. MRI: shows the position of the femoral nerve (on the T2-weighted axial images) and the status of the posterior ligamentous complex (on STIR images);
2. Lateral and AP X-rays: show the relative height of the iliac crests and the local deformity;
3. CT: shows the morphology of the fracture and possibly abnormal bony anatomy.

Surgical Technique

Shallow Docking

The patient is placed in lateral decubitus (preferably right, but it depends on whether there is coronal deformity) and taped to the operating table in a fashion similar to the lateral transpsoas discectomy technique, previously described in Chap. 7 as well as the literature [8]. Patients' true lateral position is verified by fluoroscopy [9]. The targeted vertebral body is marked on the skin, based on the lateral fluoroscopic image, and a 6–8 cm skin incision is centered on the targeted segment, parallel to the iliac crest (for L3 and L4) or over the corresponding rib (for L1 and L2). The incision is carried down through the superficial muscle fascia and then the underlying muscles (major oblique, minor oblique, and transversalis) are bluntly dissected until the retroperitoneal fat is accessed. The opening in the lateral abdominal wall muscles is enlarged enough to accommodate a retractor spanning the space between the discs above and below the targeted vertebral body. We recommend bluntly dissecting each muscle layer separately and over a distance of about 8–10 cm (retracting the skin in both directions to do it), with care to protect any nerve encountered (the ilioinguinal and iliohypogastric nerves run parallel to the iliac crest in between the muscle layers). The exposed retroperitoneal fat is gently separated from the posterior wall under direct visualization (the lateral femoral cutaneous nerve runs on the anterior aspect of the transversalis fascia) until the transverse processes and the psoas muscle anterior to them is encountered. A superficial retractor is then placed on the surface of the psoas and attached to the side of the table with the appropriate rigid arm. The rest of the technique is different for each level and will be described individually.

L4

The L4 corpectomy is the most challenging one, because the femoral nerve can occasionally be located more anteriorly at the L4–5 disc level and the iliac crest can make the access to the L4–5 disc more difficult, particularly in males.

The L4–5 discectomy is performed first, using the transpsoas technique previously described in Chap. 7 as well as the literature [8]. If the discectomy cannot be done safely, the procedure can be aborted without having destabilized the L3–4 level. We prefer the direct visualization technique, but the EMG-based technique can also be used. The location of the discectomy is chosen keeping in mind that the exposed L5 endplate will be supporting the caudal footplate of the expandable cage; thus, if more lordosis is desired, a more anterior position for the discectomy is selected. Then, the retractor is removed and re-inserted at the L3–4 level, and the procedure is repeated for the L3–4 discectomy (Video 13.1). The final repositioning is started with the retractor inserted through the psoas at L4–5 and then gently opened cranially, while holding downward pressure, to separate the muscle fibers longitudinally, until the L3–4 discectomy site is encountered. The cranial and caudal blades of the retractor are centered at the previously performed discectomy sites, whereas the posterior blade is placed about 1 cm anterior to the dorsal border of L4 on the lateral fluoroscopic image, in order to protect the dorsal-running femoral nerve. A fourth, fan-like retractor is added anteriorly to keep the retroperitoneal organs and the anterior psoas fibers separated from the operative field.

An alternative to this part of the procedure is to start the psoas dissection at the level of the L4 mid-vertebral body and continue cranially and caudally until the L3–4 and L4–5 discs, respectively, are encountered (Video 13.2). The obvious advantage of this variant is that the retractor does not have to be repositioned twice. The disadvantages are: (1) The psoas dissection has to be well planned, in order for the exposed L4–5 and L3–4 discs to provide optimal position for the discectomy; (2) A special self-retaining retractor is necessary, with blades that are wide enough to span the distance between the L3 inferior endplate to the L5 superior endplate (this retractor is not part of the routine instrumentation set).

At this time, a neuromonitoring ball-tip probe, as well as direct operative microscope visualization, can be used to confirm that the femoral nerve is not exposed in the operative field. After coagulating and cutting the segmental vessels, an L4 corpectomy is then performed between the two discectomy sites, with enough bone removal to easily accommodate the expandable cage, in order to minimize the risk of cage insertion pushing any bone fragments posteriorly into the spinal canal. The corpectomy has to be done relatively fast, since the exposed cancellous bone can result in significant blood loss, particularly if the corpectomy is done for a metastasis from a vascular tumor (e.g., renal cell carcinoma). Therefore, we often use osteotomes for this part of the procedure, with the posterior cut placed roughly at the junction between the anterior two thirds and the posterior third of the vertebral body (this eliminates the risk of spinal canal violation). Once the height of the cage is determined, Floseal or analogues can be placed to decrease cancellous bone bleeding. The contralateral annulus fibrosus at L3–4 and L4–5 is penetrated with a sharp Cobb. Trials mimicking the cage's footplates are used to determine the appropriate length as well as to make sure the footplate will not be blocked by residual disc material near the contralateral annulus. The cage is then inserted between two sliding blades, in order to protect the endplates, and expanded under frequent AP fluoroscopic guidance. A tactile feel, as well as direct visualization, also guide the amount of expansion needed.

The next step, necessary in patients with posteriorly displaced fracture fragments or tumor, is to decompress the spinal canal. The retractor is slightly angled into an oblique anterior to posterior direction (20–30°), holding downward pressure not to lose contact between the tip of the posterior blade and the L4 vertebral body. The high-speed drill is used to thin out the fragments protruding in the spinal canal and a long, bayoneted, small-cup, straight curette is used to separate the posterior longitudinal ligament from the lumbar dura mater and push the ligament along with the remainder of the fractured fragments anteriorly, away from the spinal canal. It is important to custom order this instrument (the long, bayoneted, small-cup, straight curette) since it does not come in any of the regular sets. Copious bleeding from the lumbar epidural venous plexus usually occurs and can be controlled with gelatin thrombin hemostatic sealants and gentle pressure. The decompression is continued in the cranial and caudal direction until the respective discs are encountered, as well as towards the contralateral side, until the level of the contralateral pedicle is reached, on the AP fluoroscopic image. Once the decompression is completed, the dura mater of the spinal sac typically expands into the operative field, back into its' normal anatomic position. After careful hemostasis, the retractor is removed and the wound is closed in layers over a Jackson-Pratt drain.

L3

The L3 corpectomy is usually easier than L4, since the iliac crest height is almost never an issue and the femoral nerve is typically posteriorly located (Video 13.4). Moreover, the exposure is below the rib cage and therefore no rib resection is necessary. The kidney may appear to be in the way on MRI axial images, but typically it mobilizes easily anteriorly. At this level, the psoas muscle is thinner and allows for easier dissection compared to L4.

L2

The L2 corpectomy is still retroperitoneal, although the diaphragm insertion on the underside of the rib is often encountered. After partially removing the overlying rib (the tip of the eleventh rib, typically), we recommend penetrating the diaphragm superficially, under the rib, rather than in the depth, next to the vertebral body. The psoas muscle is thin and easy to dissect.

L1

The L1 corpectomy is actually approached in a retropleural, rather than retroperitoneal, fashion (Video 13.3). After partially removing the overlying rib (the tenth rib, typically), the parietal pleura is encountered. Blunt finger dissection allows detachment of the parietal pleura from the remainder of the tenth rib, as well as the ninth and eleventh intact ribs. Following the ribs proximally, the finger (or a Kittner dissector) eventually encounters the junction with the vertebral body. We try to protect the parietal pleura integrity as much as possible, as it serves as a barrier between the retractor blades and the lung; however, in the depth, the parietal pleura is often adherent to the vertebral body and, upon placement of the retractor, the intrapleural space is exposed, with the tip of the lung often seen coming in and out of the field with each breath (there is no need for dual-lumen intubation and lung deflation). The retractor is placed over the fractured vertebral body (on lateral fluoroscopy), which requires some anterior and downward pressure against the diaphragm. Once the retractor is locked in place, the microscope is brought into the operative field.

The first structure exposed is the diaphragm's insertion on the L1 vertebral body. This can be sharply transected and then closed at the end of the operation, although we have left it open numerous times without any postoperative complications. The next layer is the very thin psoas muscle, which can be detached with the Bovie cautery, but with care to preserve the segmental vessels (the artery must be tested, before transection, to make sure Adamkiewicz artery does not originate at this level).

Pearls and Pitfalls

Positioning

Taping the patient to the table is similar to the LLIF technique. For a perfect lateral image, we usually place the patient in slight Trendelenburg.

After taping, we first get an AP image, to confirm that the patient is in perfect lateral decubitus. The table, not the C-arm, is tilted left or right until the spinous process of the level of interest is perfectly centered between the pedicles on the AP image. The C-arm is then used to draw on the skin the projection of the vertebral body of interest.

Exposure

As mentioned, the muscle layers must be divided bluntly over about 10 cm, as they have different directions and must accommodate a wider exposure than the one for a simple lateral discectomy. At L1 and L2, part of the overlying rib must be resected to achieve the exposure.

While the psoas muscle runs obliquely in a cranial to caudal and posterior to anterior direction, the muscle fibers direction is not exactly parallel to the desired cage direction. Since it is easier to retract the muscle fibers anteriorly, we prefer to dissect the muscle fibers more posterior over the caudal disc, if possible, and retract the psoas fibers anteriorly over the cranial disc.

Discectomy and Endplate Preparation

Since the discs have a bi-convex shape (unless severely degenerated, in which case they become flat), endplate preparation must be done respecting its' concave shape. The best preparation, in our opinion, is done with a wide Cobb (20 or 22 mm) that follows the dissection plane between the disc and the endplate. As the Cobb follows the concave surface of the endplate, the direction of the shaft changes from cranially angled (initially) to straight (as the tip of the Cobb passes the midpoint of the disc). If this direction is not changed, there is a risk of endplate and vertebral body violation in the deep (contralateral) half of the vertebral body.

Corpectomy

The corpectomy has to be wide enough to easily accommodate the core of the cage, so that no fragments get pushed posteriorly in the spinal canal. We typically leave a thin layer of bone in the contralateral aspect of the resected vertebral body, since that will not interfere with cage placement and at the same time will minimize morbidity from the contralateral psoas muscle.

The corpectomy also has to be done fast, since the cancellous bone (or tumoral bone) can bleed briskly at this time. For that reason, we use osteotomes to remove most of the bone, safely away from the spinal canal, and only use the high-speed drill for the second part of the osteotomy, when decompressing the spinal canal (if necessary), *after* cage insertion.

Bleeding from the cancellous (or tumoral) bone can be controlled with Floseal, which can be left in place while the endplates undergo the final preparation and the footplates are sized.

Complications

Neuro-Vascular Injury

The nerves and vessels at risk are the same as for the lateral lumbar interbody fusion technique, described in Chap. 7.

Additionally, care must be exercised before transecting the segmental vessels, particularly at the higher levels, in order to ensure that the Adamkiewicz artery does not originate from that segmental artery. We recommend temporary soft occlusion of the exposed segmental artery (e.g., with a Kittner), for about 10′; if no MEP changes are reported by neuromonitoring, than it should be safe to transect the vessel. It is important to use MEP, since SSEPs will not be changed in case of Adamkiewicz artery occlusion.

Dural Tears

Occasionally, a sharp fracture fragment can penetrate the posterior longitudinal ligament and the dura and, upon removal, can lead to CSF extravasation. More commonly, the surgeon inadvertently injures the dura at the time of fracture fragment removal. In either case, the dural tear is usually not amenable to direct repair. Instead, we recommend gentle tamponade with Gelfoam followed by DuraSeal, and placement of a lumbar drain for 5–7 days.

Inadequate Placement of the Cage

This should be recognized intraoperatively. Typically, the cage is either placed to far posteriorly, especially if the canal decompression is performed before cage insertion, or is placed at an oblique angle against the endplates. Either way, when recognized on the lateral fluoroscopic image, the cage can be repositioned more anteriorly or at the correct angle, respectively.

Case Examples

Patient 1

A 28-year-old man was brought to the emergency room after a 48-foot fall with multiple injuries, including brain contusions, facial and extremity fractures, and an L4 fracture. The neurological examination included right thigh and knee pain and mild knee extension weakness. The computed tomography (CT) scan showed a 3-column fracture with focal sagittal and coronal deformity (Fig. 13.1a–c), but no significant spinal canal compromise. Magnetic resonance imaging (MRI) confirmed PLC disruption (Fig. 13.1d). The TLICS score for the L4 fracture was 7 (morphology 2, PLC integrity 3, neurological status 2) with operative indication for a circumferential fixation. Preoperative planning included MRI analysis of the femoral nerve position between the L3–4 and L4–5 discs (Fig. 13.1e, f). A lateral X-ray showed the projection of the iliac crest at the level of the L4–5 disc space (Fig. 13.1g). A minimally invasive transpsoas L4 corpectomy was performed via a right-sided approach, with deformity correction and indirect right-sided decompression by usage of an expandable cage (Fig. 13.1h–j). Posterior pedicle screw/rod fixation was performed subsequently. A postoperative CT confirmed the adequate placement of the instrumentation and correction of deformity (Fig. 13.1k, l).

Patient 2

A 65-year-old man with schizophrenia was brought to the emergency room after a 32-foot fall with multiple rib, spine, and extremity fractures. The patient showed poor cooperation with the neurological examination, but complained of pain in the right leg and was able to move both legs spontaneously against gravity. The CT showed a 3-column fracture and retropulsion of the fracture fragments with an approximately 70% canal compromise (Fig. 13.2a–c). The MRI confirmed PLC disruption. The TLICS score for the L4 fracture was 7 (morphology 2, PLC integrity 3, neurological status 2) with operative indication for a circumferential fixation. Preoperative CT reconstruction showed the low iliac crest position (Fig. 13.2d) and the MRI showed the posterior femoral nerve location between the L3–4 and L4–5 discs (Fig. 13.2e, f). A minimally invasive transpsoas L4 corpectomy and fusion with expandable cage was performed via a left-sided approach (Fig. 13.2g–j), followed by decompression of the spinal canal. A posterior pedicle screw/rod fixation completed the operation.

The operative time and estimated blood loss were 180 min, 400 ml, and 300 min, 450 ml, respectively. Intraoperatively, the femoral nerve was not exposed in the operative field in either case. Neurostimulation behind the posterior blade in Patient 2 yielded responses between 2 and 5 mA, confirming the close proximity of the femoral nerve, as expected.

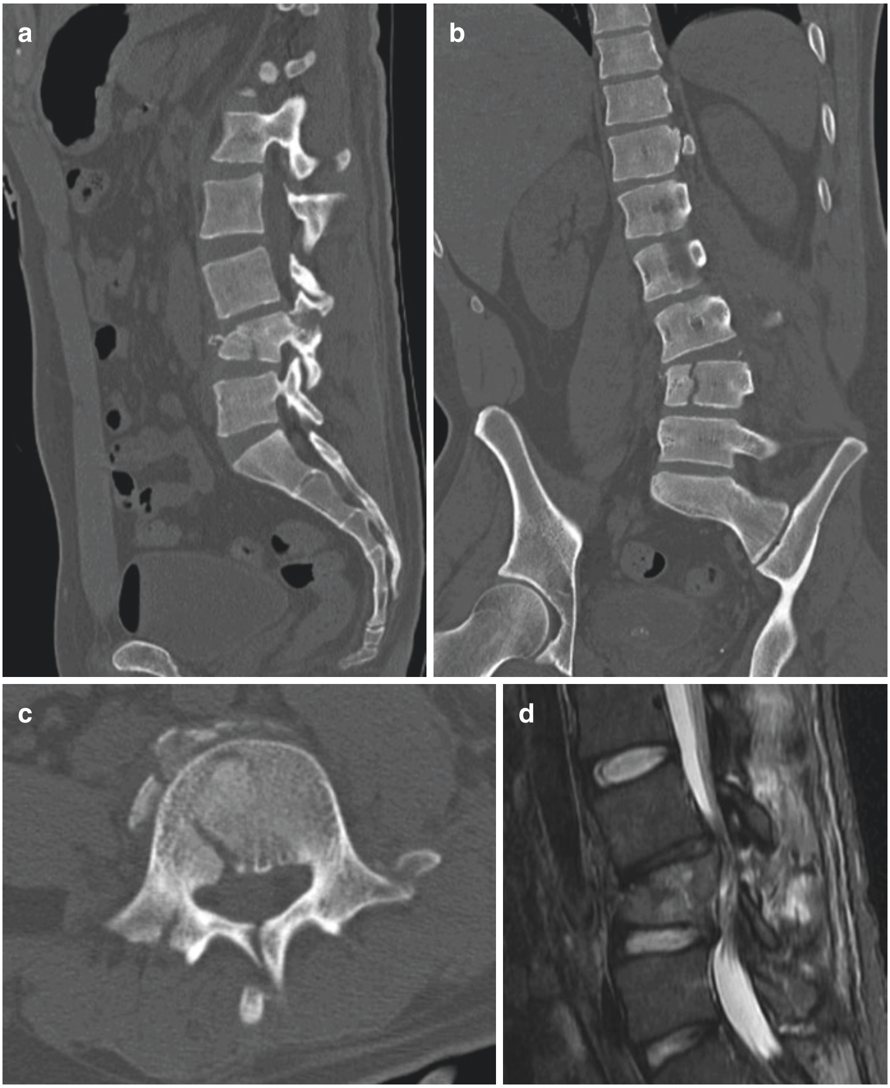


Fig. 13.1 Imaging of Patient 1. (**a**) Sagittal, (**b**) Coronal, and (**c**) Axial computed tomographic (CT) images demonstrating the 3-column L4 fracture without canal compromise; (**d**) Sagittal inversion-recovery magnetic resonance imaging (MRI) demonstrating edema in the posterior ligamentous complex; (**e**) L3–4 and (**f**) L4–5 coronal and axial MRI demonstrating the femoral nerve position in relationship to the vertebral body; (**g**) lateral x-ray demonstrating the iliac crest height at the level of L4–5 disc; (**h**) Lateral intraoperative x-ray demonstrating the cage position, following the sites of L3–4 and L4–5 discectomies and corresponding L4 corpectomy; (**i**) initial and (**j**) expanded cage on antero-posterior (AP) intraoperative x-ray; (**k**) sagittal and (**l**) coronal CT images of the final construct at 1-day postoperatively, showing reasonable correction of deformity

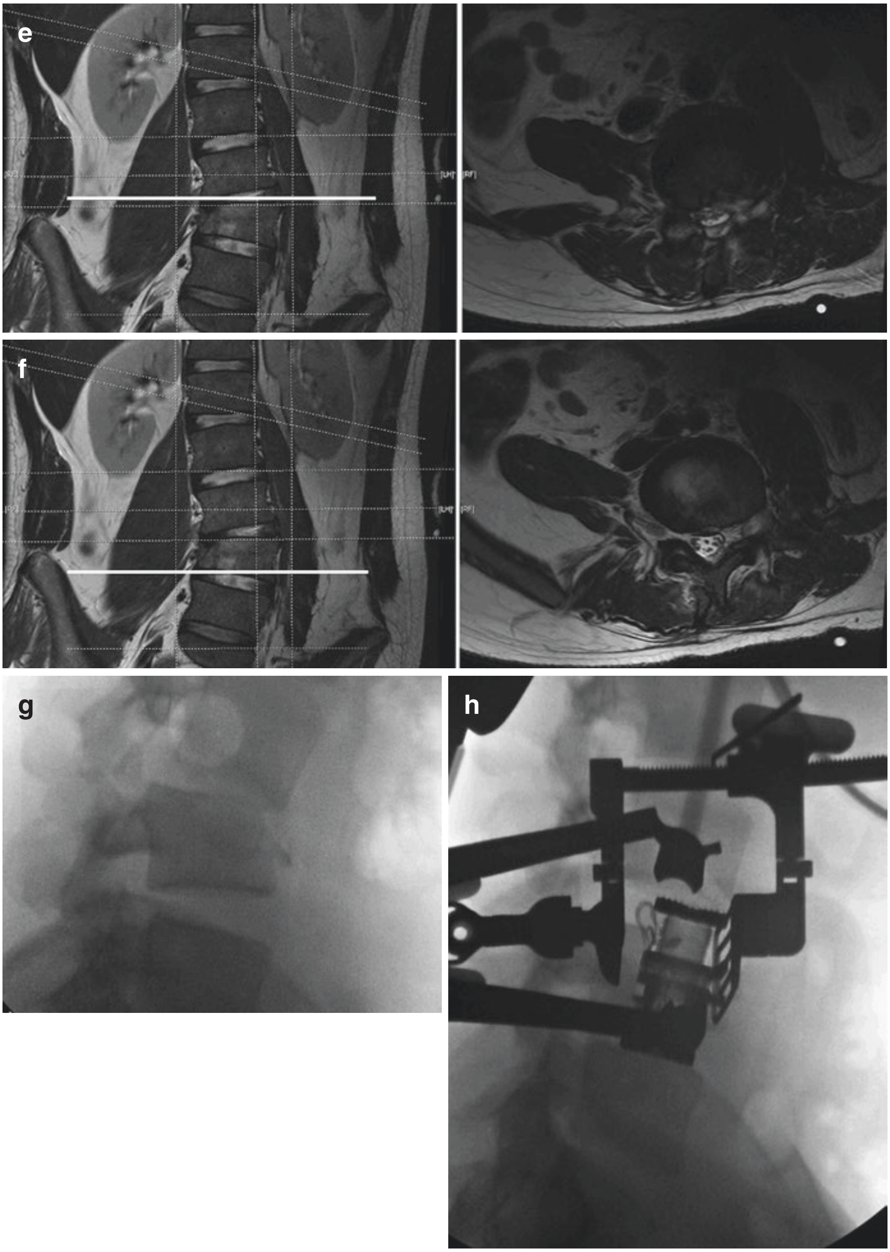
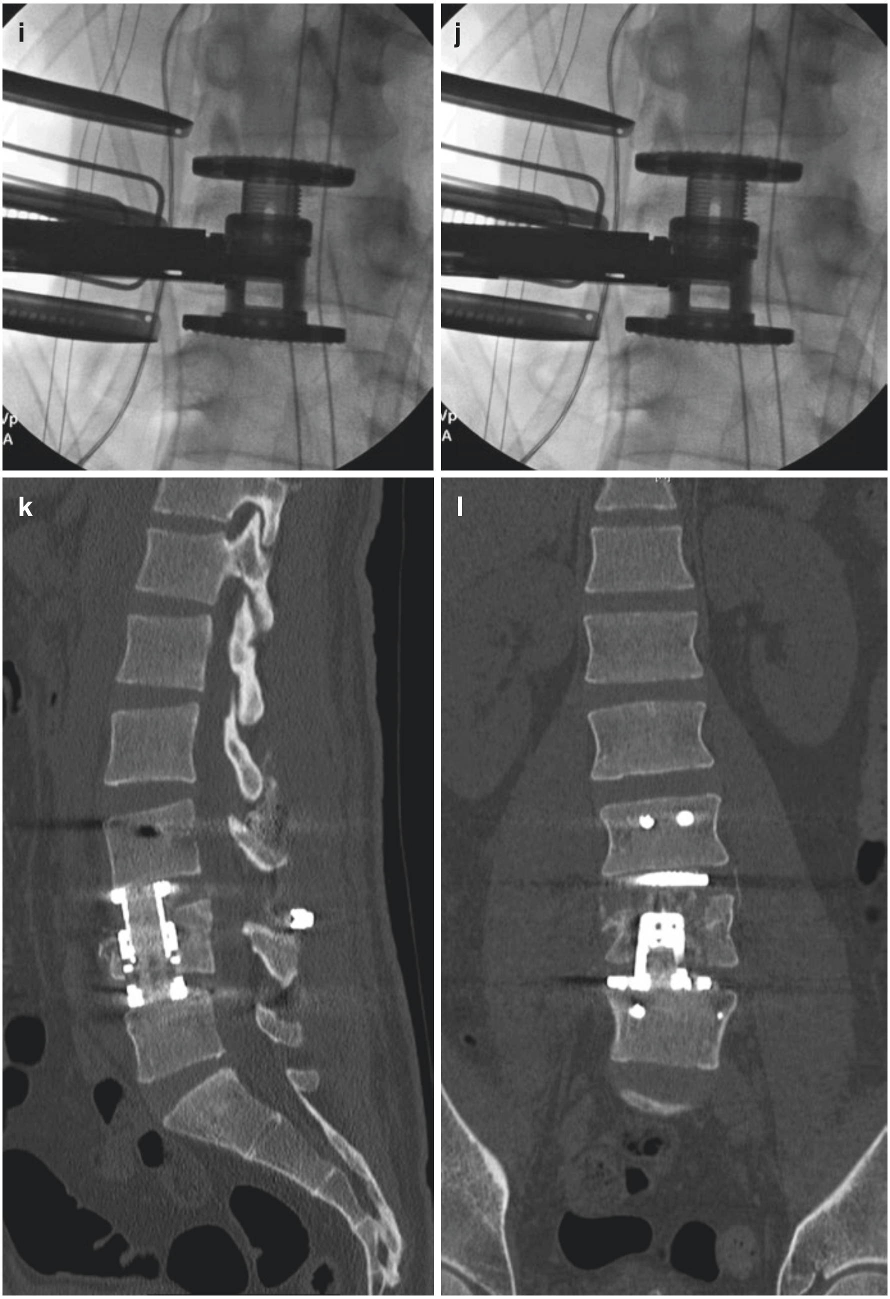


Fig. 13.1 (continued)



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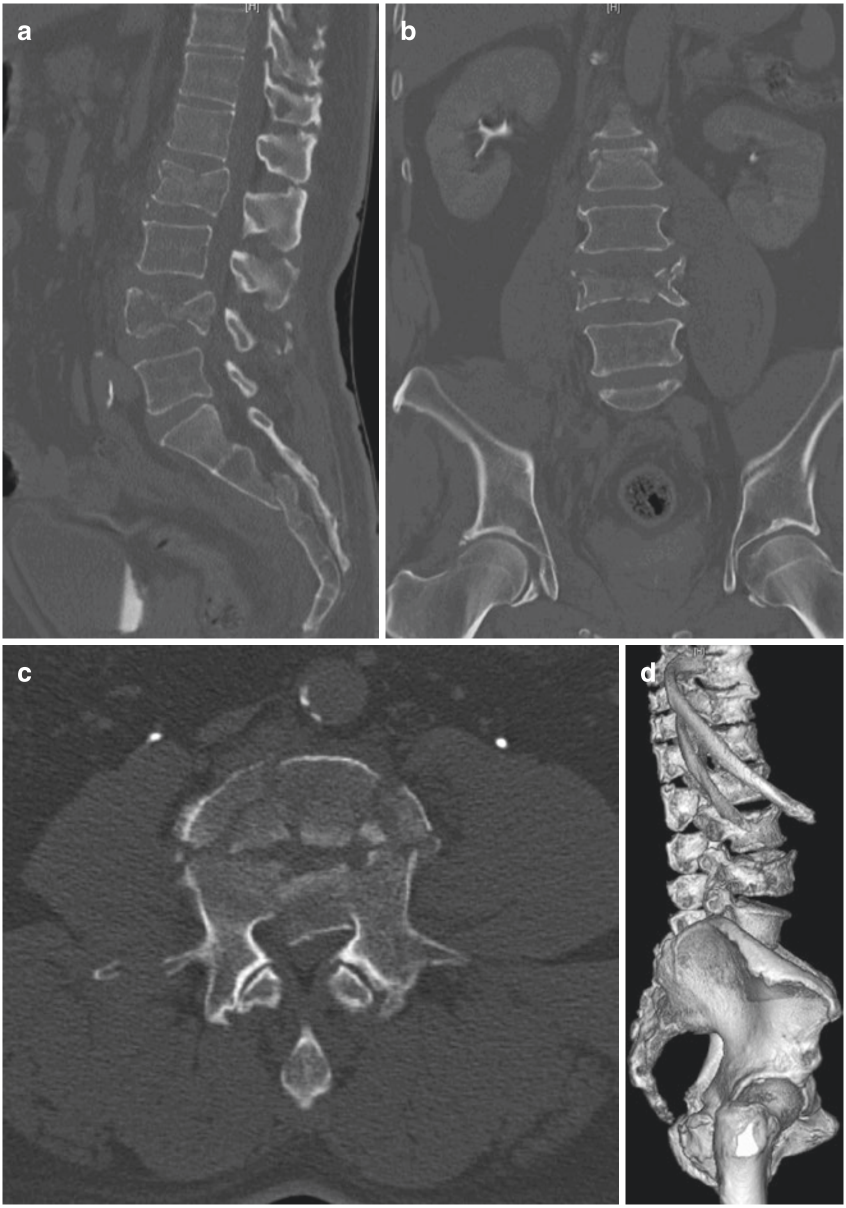
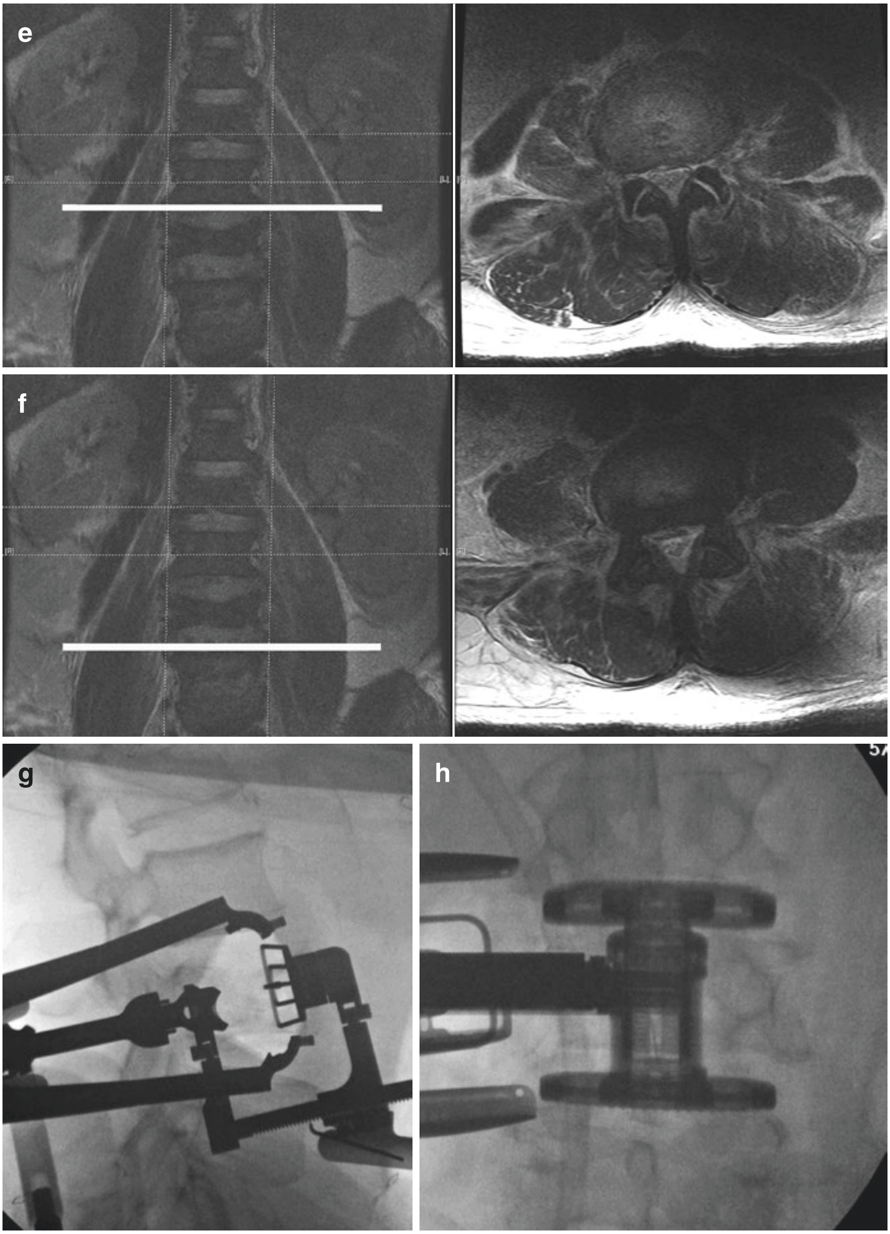


Fig. 13.2 Imaging of Patient 2. (**a**) Sagittal, (**b**) Coronal, and (**c**) Axial computed tomographic (CT) images demonstrating the 3-column L4 fracture with canal compromise; (**d**) CT reconstruction demonstrating the iliac crest height below the level of L4–5 disc; (**e**) L3–4 and (**f**) L4–5 coronal and axial magnetic resonance imaging (MRI) demonstrating the femoral nerve position in relationship to the vertebral body; (**g**) Lateral intraoperative x-ray demonstrating the retractor position, with the cranial and caudal blades following the sites of L3–4 and L4–5 discectomies, respectively, the posterior blade about 1 cm anterior to the posterior L4 vertebral body border, and the anterior fan-like retractor close to the anterior L4 border; (**h**) initial and (**i**) expanded cage on antero-posterior (AP) intraoperative x-ray; (**j**) lateral intraoperative x-ray demonstrating cage position and posterior decompression (the view is slightly oblique, to follow the direction of the posterior retractor blade)



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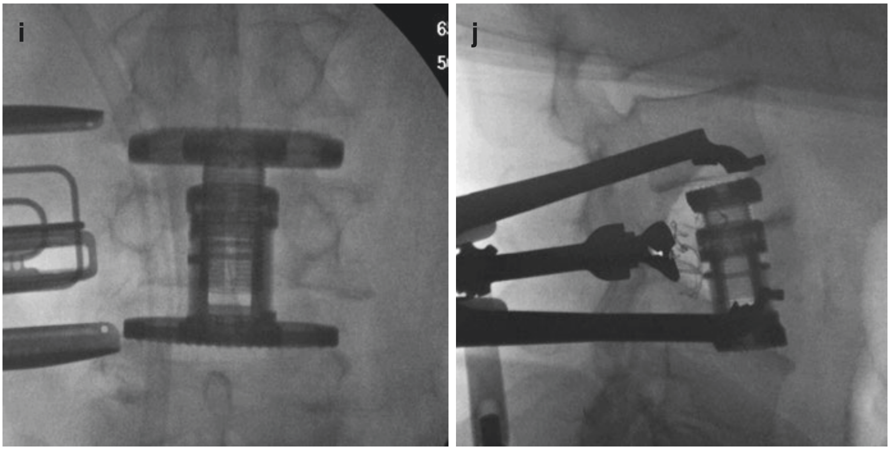

Fig. 13.2 (continued)

There were no complications related to this operation in either patient. Patient 1 exhibited pain relief in the right lower extremity at 2 weeks postoperatively and complete resolution by 6 months. Patient 2 was also mobilized immediately in a TLSO brace (due to the coexisting L2 fracture) and had no residual radicular pain. At the 6-month follow-up visit, both patients were ambulatory and with no complaints related to their lumbar fractures.

Literature Review

The lateral approach offers certain advantages compared to the posterior approaches, such as less paraspinous muscle trauma and better access angle for the spinal canal decompression, particularly with centrally located fragments [5]. The minimally invasive retropleural approach for the thoracic and upper lumbar spine has been recently described [5] and we have also used it with good results. However, in the mid-lumbar spine, and particularly at L4, the presence of the psoas muscle and the lumbar plexus has tempered the usage of a minimally invasive approach for corpectomy.

The standard open approach for L4 corpectomy is typically performed by the general surgeon and involves detachment of the psoas muscle from anterior to posterior. After psoas mobilization and corpectomy, a straight lateral exposure is required for cage insertion, especially if a wide footplate cage is desired [10]. Therefore, this type of operative technique requires a long skin incision and significant retraction of both the abdominal viscera (anteriorly) and the psoas muscle (posteriorly) (Fig. 13.3, left). The idea of a minimally invasive approach stemmed from the realization that, anatomically, the femoral nerve usually runs along the posterior

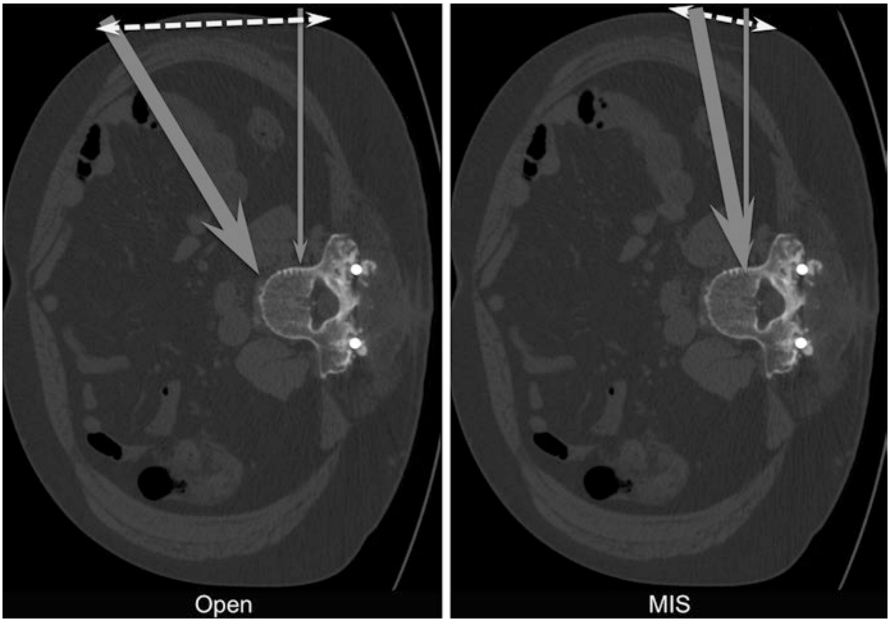

Fig. 13.3 Illustration of psoas dissection (thick arrow) and cage insertion (thin arrow) directions in open (Left) versus minimally invasive (Right) techniques. The skin incision and lateral abdominal wall dissection (dashed arrow) are decreased in the latter approach

quadrant of L4, and it only rarely crosses the L4 vertebral body from posterior to anterior [9, 11]. Conceptually, the minimally invasive technique allows for both psoas dissection and cage insertion through the same pathway, thus requiring a shorter skin incision and less muscle disruption (Fig. 13.3, right). If spinal canal decompression is necessary, the transpsoas approach permits a relatively easy access, due to the small amount of posterior psoas fibers (that also contain the femoral nerve) located behind the posterior retractor blade. Moreover, this approach offers the major advantage of direct visualization of both the posteriorly displaced fragments and the dura mater to be decompressed [5].

Another advantage of the lateral transpsoas approach is the usage of a cage with wide footplate that can span the entire vertebral body and rest on the outer cortical ring, thus minimizing the risk of subsidence [10]. This, in turn, allows for a safer expansion of the cage, with better correction of the coronal and/or sagittal deformity [12].

The feasibility of this technique, particularly at L4, is determined by the position of the femoral nerve in the psoas muscle. Fortunately, the understanding of local anatomy and preoperative planning have improved with the increasing popularity of the lateral approach for degenerative pathology [11, 13–19]. If the femoral nerve is identified in the posterior quadrant at the L4–5 disc level [19] on the axial T2-weighted MRI images and the iliac crest height does not extend above the mid-vertebral body of L4 on lateral x-rays, the L4 minimally invasive corpectomy can be safely accomplished.

We prefer to perform the corpectomy first (including cage insertion), followed (or not) by decompression of the spinal canal. The first advantage is adequate cage placement. At the time of insertion, the cage will follow the path of least resistance: if the decompression is done first, the cage will tend to end up in a suboptimal posterior position, where the discectomy has been performed. The second advantage is that, if the PLL maintains some integrity, the posteriorly displaced fragments may be pulled anteriorly at the time of cage expansion, thus facilitating later removal. Finally, the cranial and caudal adjacent endplates are clearly defined by the cage footplates, thus minimizing the need for fluoroscopy to validate the extent of cranio-caudal decompression. The only potential disadvantage of pushing fracture fragments further in the canal can be avoided by removing enough bone during the corpectomy for the cage to insert easily.

The left side is typically used for most lateral approaches. We chose a right-sided approach in Patient 1 because the psoas muscle was relaxed (secondary to the coronal deformity) and the cage expansion would yield a better coronal correction.

The current surgical technique involves two discectomies by individual exposures, followed by corpectomy, with or without canal decompression. The challenge of the transpsoas dissection consists in opening the retractor from the inferior to the superior discectomy exposures in the direction of the psoas fibers. A potentially better retractor might involve two individual parts, one with three blades to expose the psoas and protect the retroperitoneum, and another to maintain the transpsoas exposure at and in-between the two discectomy sites.

Conclusion

The minimally invasive lateral transpsoas approach for lumbar corpectomy may offer a safe and less morbid alternative in patients with favorable anatomy.

References

1. Chou D, Lu DC. Mini-open transpedicular corpectomies with expandable cage reconstruction. Technical note. J Neurosurg Spine. 2011;14:71–7. https://doi.org/10.3171/2010.10.spine091009.
2. Lu DC, Lau D, Lee JG, Chou D. The transpedicular approach compared with the anterior approach: an analysis of 80 thoracolumbar corpectomies. J Neurosurgery Spine. 2010;12:583–91. https://doi.org/10.3171/2010.1.spine09292.
3. Smith ZA, Li Z, Chen NF, Raphael D, Khoo LT. Minimally invasive lateral extracavitary corpectomy: cadaveric evaluation model and report of 3 clinical cases. J Neurosurgery Spine. 2012;16:463–70. https://doi.org/10.3171/2012.2.SPINE11128.
4. Baaj AA, et al. Complications of the mini-open anterolateral approach to the thoracolumbar spine. J Clini Neurosci. 2012;19:1265–7. https://doi.org/10.1016/j.jocn.2012.01.026.
5. Uribe JS, Dakwar E, Cardona RF, Vale FL. Minimally invasive lateral retropleural thoracolumbar approach: cadaveric feasibility study and report of 4 clinical cases. Neurosurgery. 2011;68:32–9; discussion 39. https://doi.org/10.1227/NEU.0b013e318207b6cb.

6. Rihn JA, et al. A review of the TLICS system: a novel, user-friendly thoracolumbar trauma classification system. Acta Orthop. 2008;79:461–6. https://doi.org/10.1080/17453670710015436.
7. Vaccaro AR, et al. The thoracolumbar injury severity score: a proposed treatment algorithm. J Spinal Disord Tech. 2005;18:209–15.
8. Ozgur BM, Aryan HE, Pimenta L, Taylor WR. Extreme lateral interbody fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. Spine J. 2006;6:435–43. https://doi.org/10.1016/j.spinee.2005.08.012.
9. Tender GC, Serban D. Genitofemoral nerve protection during the lateral retroperitoneal transpsoas approach. Neurosurgery. 2013;73:192–6; discussion 196-197. https://doi.org/10.1227/01.neu.0000431473.49042.95.
10. Pekmezci M, et al. Can a novel rectangular footplate provide higher resistance to subsidence than circular footplates? An ex vivo biomechanical study. Spine. 2012;37:E1177–81. https://doi.org/10.1097/BRS.0b013e3182647c0b.
11. Guerin P, et al. The lumbosacral plexus: anatomic considerations for minimally invasive retroperitoneal transpsoas approach. Surg Radiol Anat. 2012;34:151–7. https://doi.org/10.1007/s00276-011-0881-z.
12. Pekmezci M, et al. Comparison of expandable and fixed interbody cages in a human cadaver corpectomy model, part I: endplate force characteristics. J Neurosurg Spine. 2012;17:321–6. https://doi.org/10.3171/2012.7.spine12171.
13. Ahmadian A, Deukmedjian AR, Abel N, Dakwar E, Uribe JS. Analysis of lumbar plexopathies and nerve injury after lateral retroperitoneal transpsoas approach: diagnostic standardization. J Neurosurg Spine. 2012. https://doi.org/10.3171/2012.11.SPINE12755.
14. Banagan K, Gelb D, Poelstra K, Ludwig S. Anatomic mapping of lumbar nerve roots during a direct lateral transpsoas approach to the spine: a cadaveric study. Spine. 2011;36:E687–91. https://doi.org/10.1097/BRS.0b013e3181ec5911.
15. Benglis DM, Vanni S, Levi AD. An anatomical study of the lumbosacral plexus as related to the minimally invasive transpsoas approach to the lumbar spine. J Neurosurg Spine. 2009;10:139–44. https://doi.org/10.3171/2008.10.SPI08479.
16. Dakwar E, Ahmadian A, Uribe JS. The anatomical relationship of the diaphragm to the thoracolumbar junction during the minimally invasive lateral extracoelomic (retropleural/retroperitoneal) approach. J Neurosurg Spine. 2012;16:359–64. https://doi.org/10.3171/2011.12.SPINE11626.
17. Kepler CK, Bogner EA, Herzog RJ, Huang RC. Anatomy of the psoas muscle and lumbar plexus with respect to the surgical approach for lateral transpsoas interbody fusion. Eur Spine J. 2011;20:550–6. https://doi.org/10.1007/s00586-010-1593-5.
18. Lu S, et al. Clinical anatomy and 3D virtual reconstruction of the lumbar plexus with respect to lumbar surgery. BMC Musculoskelet Disord. 2011;12:76. https://doi.org/10.1186/1471-2474-12-76.
19. Uribe JS, Arredondo N, Dakwar E, Vale FL. Defining the safe working zones using the minimally invasive lateral retroperitoneal transpsoas approach: an anatomical study. J Neurosurg Spine. 2010;13:260–6. https://doi.org/10.3171/2010.3.SPINE09766.