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The rising psoas sign: an analysis of preoperative imaging characteristics of aborted minimally invasive lateral interbody fusions at L4–5

Report of 3 cases

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Minimally invasive lateral interbody fusion for the treatment of degenerative disc disease, spondylolisthesis, or scoliosis is becoming increasingly popular. The approach at L4–5 carries the highest risk of nerve injury given the proximity of the lumbar plexus and femoral nerve. The authors present 3 cases that were aborted during the approach because of pervasive electromyography responses throughout the L4–5 disc space. Preoperative imaging characteristics of psoas muscle anatomy in all 3 cases are analyzed and discussed. In all cases, the psoas muscle on axial views was rising away from the vertebral column as opposed to its typical location lateral to it. Preoperative evaluation of psoas muscle anatomy is important. A rising psoas muscle at L4–5 on axial imaging may complicate a lateral approach.
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Key Words • **XLIF** • **DLIF** • **psoas** • **L4–5** • **lumbar** • **minimally invasive** • **lateral interbody fusion**

Lumbar interbody fusion is an established technique for the treatment of degenerative disc disease and spondylolisthesis.[9] Lateral interbody fusion (extreme lateral interbody fusion [XLIF], direct lateral interbody fusion [DLIF]) is a minimally invasive alternative to the traditional approaches such as posterior lumbar interbody fusion, transforaminal lumbar interbody fusion (TLIF), and anterior lumbar interbody fusion. Advantages of this technique include the ability to place a large intervertebral graft to facilitate arthrodesis while minimizing disruption of osteoligamentous structures, to avoid retraction of the neural elements within the spinal canal, and to eliminate the need for an access surgeon and associated complications with the anterior approach.[12,14,22] This procedure can be performed with minimal tissue disruption and blood loss, leading to less postoperative pain and shorter hospital stays.[1,6,9,12,14,16,18,20,22]

Disadvantages of the lateral approach are the result of involvement of the psoas muscle and the proximity of the lumbar plexus particularly at L4–5.[2,5,7,10–14,16–19,25] Injury or excessive retraction onto these structures may result in iliopsoas and quadriceps muscle weakness, as well as groin and thigh paresthesias or numbness and chronic dysesthetic pain. According to a number of studies, rates for these complications have ranged from 2% to 30%, with most symptoms resolving within 3 months.[3–6,12,14–16,18,22,26] Several studies have described safe corridors or operative zones during the initial approach to minimize these complications.[2,7,11,17,19,25]

We present 3 cases of aborted minimally invasive lateral approaches to L4–5 in response to robust electromyography (EMG) responses found throughout the L4–5 disc space during the initial docking stage with the first dilator and nerve stimulation. In all cases, the psoas muscle on preoperative axial MRI studies was found to be rising away from the vertebral body as opposed to its typical location lateral to it. This anatomical configuration is typically seen at the lumbosacral junction. One of the patients had 6 lumbar vertebrae. These 3 cases are illustrated, and their preoperative imaging characteristics and intraoperative findings are analyzed.

Case Reports

Case 1

History and Examination. A 63-year-old woman with a history of diabetes and renal insufficiency presented with severe low-back and right leg pain in an L-5 distribution. Her symptoms were refractory to multiple conservative treatment measures. Her physical examination revealed normal strength but decreased sensation along the lateral aspect of the calf on the right. Her gait was antalgic and she ambulated with the assistance of a cane. Magnetic resonance imaging studies revealed a Grade I L4–5 spondylolisthesis with significant lateral recess stenosis and a right paracentral disc protrusion (Fig. 1A and

Abbreviations used in this paper: EMG = electromyography; TLIF = transforaminal lumbar interbody fusion.

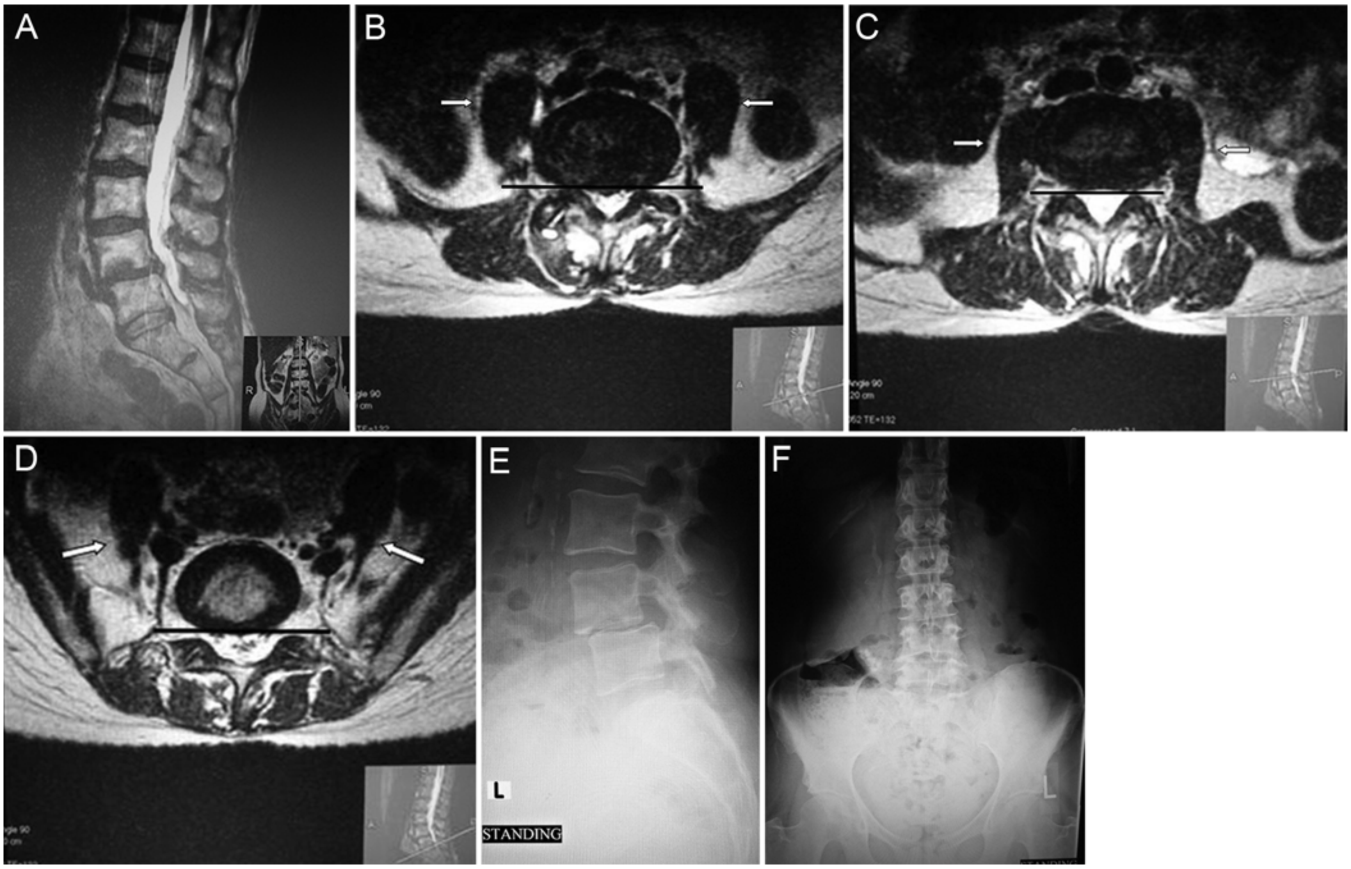

Fig. 1. Case 1. Sagittal T2-weighted MR image **(A)** demonstrating a typical L4–5 spondylolisthesis. Axial view **(B)** at L4–5 showing the psoas muscle rising away ventrally and laterally from the vertebral body bilaterally *(arrows and black line)*, an anatomical position typically at the lumbosacral junction (L5–S1). Axial view **(C)** at L3–4 with a normal psoas position *(arrows and black line)*. Axial view **(D)** at L5–S1 with a completely detached psoas muscle bilaterally *(arrows and black line)*. Standing lateral **(E)** and anteroposterior **(F)** radiographs showing 5 lumbar vertebrae. Twelve ribs were counted on thoracic imaging.

B). A ventral- and lateral-appearing psoas muscle was observed at L4–5 (Fig. 1B). Psoas muscle anatomy at L3–4 and L5–S1 on axial MRI is also depicted (Fig. 1C and D). Standing lateral and dynamic radiographs showed mobility at the L4–5 junction (Fig. 1E). An anteroposterior radiograph showed 5 lumbar vertebrae (Fig. 1F) with thoracic views confirming the presence of 12 ribs.

Operation. The surgical plan was to perform a minimally invasive lateral interbody fusion at L4–5 with the goal of reducing the spondylolisthesis and achieving indirect decompression of the moderate stenosis with subsequent relief of back and leg pain. The patient would then be positioned prone for percutaneous pedicle screw instrumentation. The EMG recordings were planned, and needles were inserted in the usual fashion in all muscle groups of both lower extremities (NeuroVision, NuVasive Inc.). The patient was positioned in the standard true lateral fashion with her left side up. An axillary roll was placed under the right axilla, and all pressure points were padded. The neck was maintained in the neutral position. The left leg was flexed to relax the psoas muscle. The chest and hip areas were taped to the operating table, and the table was broken at the level of the iliac crest to provide greater access and exposure to L4–5. Proper anteroposterior and lateral radiographs were obtained, and a 3-cm left flank incision was marked over the L4–5 disc space. The incision area was prepared and draped in the typical fashion, and the planned incision was infiltrated with a local anesthetic. The incision was made with a 15 blade, and the anterior abdominal wall musculature was exposed. Muscle fibers were split bluntly, and the retroperitoneal space was entered with digital dissection. Retroperitoneal fat and the belly of the psoas muscle were visualized. Complete reversal of short-acting paralytics was confirmed by the NuVasive company representative using NeuroVision and by the anesthesia team using a train-of-four test. A first dilator was placed over the psoas muscle and guided through it with anteroposterior and lateral imaging onto the midpoint of the disc space from a lateral view. Significant EMG activity at a threshold of 3 mA was noted at this point. The dilator was elevated and reinserted through the psoas muscle at multiple points of the disc space involving all 4 quadrants to attempt to map the underlying neural structures. Significant EMG activity was found in all areas at a threshold below 4 mA with the exception of one point 5 mm anterior to the midpoint of the disc space where a threshold of 8 mA was deemed acceptable. A Steinmann pin was inserted into the disc space, and a series of larger dilators were placed, followed by the insertion of the working channel that in turn was affixed to the flexible arm. All these subsequent steps were performed with EMG responses at a threshold ranging from 6 to 8 mA in the posterior and anterior directions. A lateral and anteroposterior radiograph confirmed proper placement of the working channel centered over the midpoint of the disc space. Soft tissue within the working channel was inspected prior to shim placement and retractor expansion. An anticipated small amount of muscle was identified over the disc space, which was swept away with a Kittner instrument. Two flattened white structures coursing diagonally could barely be discerned from the underlying disc space. These were stimulated with the nerve probe, and a robust EMG response was obtained. The working channel was loosened and slightly elevated, and these two structures subsequently expanded, clearly revealing themselves to be nerves of approximately 3–4 mm in diameter. Given the presence of these nerves within the working channel and the intense EMG activity found during stimulation of the entire disc space, the surgery was aborted. The working channel was loosened and slowly elevated, revealing two additional nerves both anterior and posterior to retractor placement. The incision was closed after irrigation, and hemostasis was achieved.

Postoperative Course. The patient's postoperative course was notable for moderately painful left leg dysesthesias along the anterior thigh. These were treated with pregabalin for 4 weeks, after which her symptoms resolved and the medicine was discontinued. She had no weakness.

Six weeks after the aborted lateral approach, she underwent an L4–5 posterior TLIF and laminectomy without complications. She enjoyed complete resolution of her preoperative symptoms.

Case 2

History and Examination. A 64-year-old woman with a history of a lumbar laminectomy in 2000 experienced recurrent back and bilateral leg pain refractory to multiple conservative treatments. Her physical examination revealed no neurological deficits. Preoperative anteroposterior and lateral (Fig. 2A) radiographs demonstrated 6 lumbar vertebrae. Magnetic resonance imaging showed a Grade I L4–5 spondylolisthesis (Fig. 2B). If her lumbarized sacrum was considered, her listhesis was effectively to L5–6.

Operation. The same surgical treatment plan in Case 1 was devised in this case. A left-sided approach to the L5–6 junction was also used. Similar thresholds of 3 mA or lower were noted, with stimulation throughout all 4 quadrants of the disc space. The larger dilators and working channel were not inserted, and the surgery was aborted.

Postoperative Course. The patient's postoperative course was uneventful. She had no neurological deficits and no additional leg pain.

Case 3

History and Examination. A 60-year-old woman presented with severe low-back and right leg pain despite extensive physical therapy, a series of epidural injections, and increasing narcotic consumption. Her physical examination revealed diminished sensation on the right leg in an L-4 and L-5 distribution. Magnetic resonance imaging showed degenerative disc disease at L4–5 with the loss of disc height on the right together with lateral recess and foraminal stenosis (Fig. 3). Anteroposterior and lateral radiographs showed 5 lumbar vertebrae.

Operation. The patient underwent a right-sided lateral approach to L4–5 for interbody fusion. Thresholds of 3 mA or lower were encountered throughout the disc space, as described in the case above. The right-sided approach was aborted, and after obtaining consent from the family, we performed a left-sided approach on the same day. No EMG activity was encountered during stimulation with the initial dilator in the posterior 3 quadrants of the disc space. The procedure was completed without event.

Postoperative Course. The patient's postoperative course was remarkable for iliopsoas and quadriceps muscle weakness (Manual Muscle Test [MMT] 4/5) and painful dysesthesias in an L-4 distribution of the right leg, the side of the aborted approach. She had a diminished quadriceps muscle reflex on the right. Postoperative radiography showed intact placement of the instrumentation and spacer. Her symptoms were treated with pregabalin in addition to her regular narcotic regimen. At the time of her 3-month follow-up, her right leg symptoms had nearly

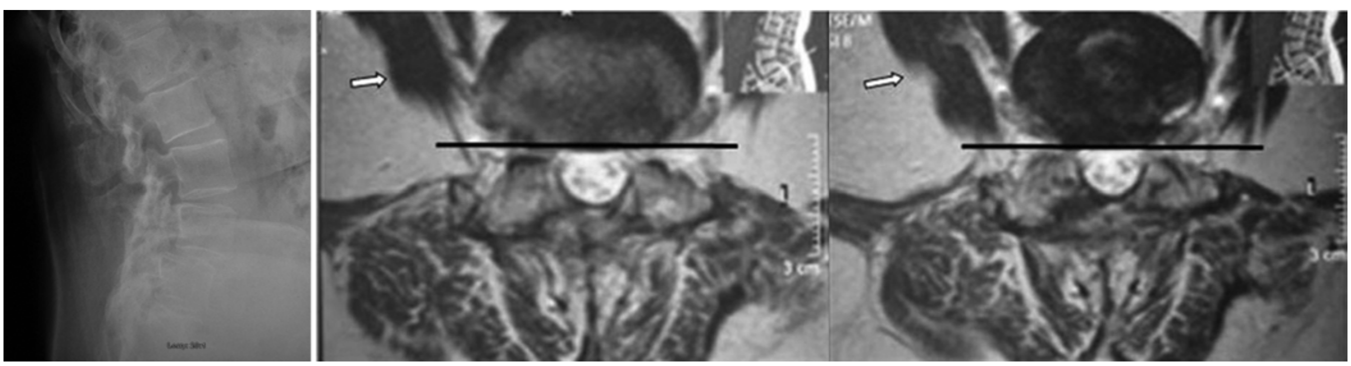

Fig. 2. Case 2. **Left:** Standing lateral radiograph showing an L5–6 spondylolisthesis (functional L4–5). **Right:** Axial T2-weighted MR images obtained at L5–6, demonstrating a rising psoas sign bilaterally *(arrows and black lines)*.

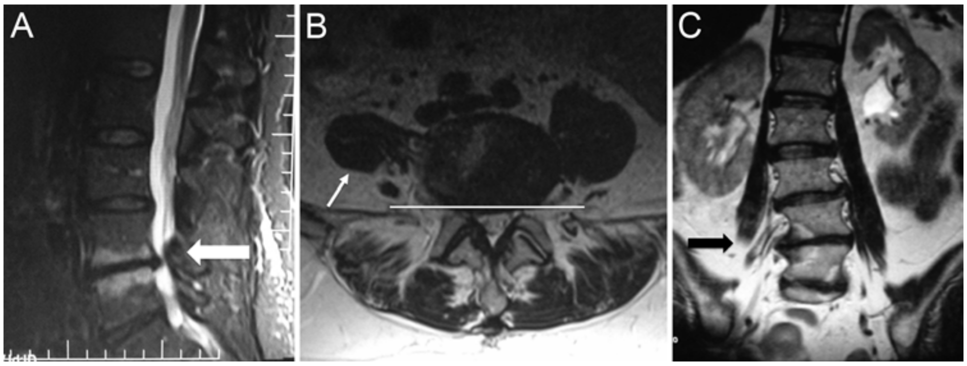

Fig. 3. Case 3. **A:** Sagittal STIR image showing degenerative disc disease at L4–5 with a disc protrusion and endplate changes *(arrow)*. **B:** Axial T2-weighted MR image demonstrating asymmetry of the psoas muscles. On the right, the psoas muscle rises away from the vertebral body *(arrow and white line)*. **C:** Coronal T2-weighted MR image showing a detached psoas muscle on the right *(arrow)* with the lumbar plexus visualized medial to it. The plexus is not visible on the left.

completely resolved and the pregabalin was discontinued. She suffered no left leg symptoms. Retrospective analysis of the psoas muscle anatomy with respect to the L4–5 disc space on axial MRI revealed a psoas muscle rising away from the vertebral column on the right but not on the left (Fig. 3B).

Discussion

Minimally invasive lateral interbody fusion has been performed successfully for the treatment of disc degeneration,[22,26] scoliosis,[12] and low-grade spondylolisthesis.[14] Clinical outcomes and fusion rates are comparable to those following traditional approaches with the advantages of decreased muscle denervation, surgical site infection, incisional pain, narcotic use, hospital stay, and estimated blood loss.[26]

Complications associated with this approach largely result from traversing and retracting the psoas muscle and lumbar plexus. Weakness of the iliopsoas muscle has been attributed to postoperative edema. Quadriceps muscle weakness and leg dysesthesias can occur from a stretch injury to the femoral nerve during insertion of the tubular dilators and placement and use of the retractor.[18,22] Postoperative sensory symptoms range from burning or stabbing dysesthetic pain to numbness or paresthesias. Motor injuries in lateral approaches focus on hip flexor and knee extensor weakness. These injuries are more apt to occur at the L4–5 junction because of the proximity and more ventral presence of the lumbar plexus.[2,13,17,19,21,25] The incidence of postoperative thigh numbness, paresthesias, and weakness has varied widely from 8.3% to 42.4%, 0.7%–30%, and 3.4%–23.7%, respectively,[3,6,14,15,22,23,25] owing to various definitions of postoperative complications.

Suggestions to reduce the risk of nerve injury have included the use of preoperative steroids,[22] dissection of the psoas muscle with a Penfield dissector prior to dilator placement,[16] decreasing the break of the operative table, reducing hip flexion during positioning,[6] and meticulous conscientious dilator placement in relation to the lumbar plexus.[15] We have found, as have others, that the risk of nerve injury declines steadily with greater experience owing to several factors.[15,23] A careful preoperative evaluation of psoas muscle and nerve anatomy is performed in deciding the laterality of the approach. If on axial imaging the lumbar plexus appears more ventral along the vertebral body, a contralateral approach is used. Greater facility with dilator placement with respect to neural anatomy and EMG responses combined with a shortened operative time also contributes to minimizing complication rates. We retrospectively reviewed our experience with 104 cases and 135 levels treated and found 7 nerve-related complications all occurring at L4–5 (our unpublished data, 2014). Postoperatively, 5 patients had persistent leg dysesthesias and 2 patients had profound weakness, all of which resolved within 3 months. Five of these 7 cases occurred within the first 50 surgeries. We believe that these complications were the result of nerve retraction occurring early in our experience.

A number of cadaveric studies have been performed to elucidate the relationship of the psoas muscle, lumbar plexus, and lumbar vertebrae from a lateral perspective.[1,8,13,15,21,25] Uribe et al. defined safe working corridors devoid of neural elements that could be exploited during surgery.[25] Park and colleagues described a gradual decrease in the average distance from the center of the disc to neural elements as one proceeded caudally,[19] findings corroborated by Benglis et al., who noted a ventral migration of the lumbosacral plexus caudally and most prominent at L4–5.[2]

Few radiological studies to date have analyzed the precise 3D relationship of the psoas muscle with the lumbar spine. Gross anatomical illustrations have shown that the psoas muscle typically originates at T-12 or L-1. Its belly is most robust from L-3 to L-5, and it subsequently thins at the lumbosacral junction as it dissociates from the vertebral body and takes a more ventral and lateral course. On cross-sectional imaging studies, the psoas muscle appears to rise away from the vertebral body at L5–S1 as it enters the pelvic cavity and inserts into the femur. Figure 4 features axial T2-weighted MR images obtained at L4–5 and L5–S1 in a patient without sagittal or coronal deformity or sacral lumbarization, demonstrating the typical relationship of the psoas muscle with the vertebral body. Kepler and colleagues studied the anatomy of the psoas muscle and lumbar plexus with respect to the lateral approach by retrospectively reviewing 43

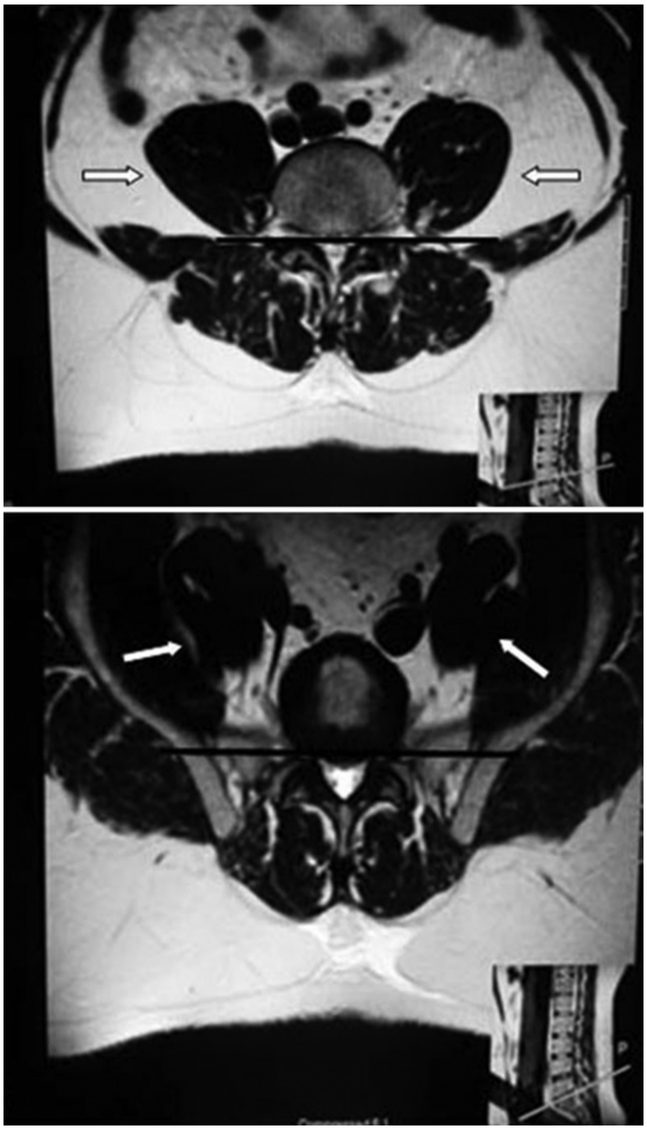

Fig. 4. Axial T2-weighted MR images demonstrating typical psoas anatomy at L4–5 **(upper)** where the psoas muscle lies lateral to the vertebra *(arrows and black line)*. At L5–S1 **(lower)**, the psoas muscle rises away from it *(arrows and black line)*.

lumbosacral spine MR images.[13] They concluded that the L4–5 level presented the highest risk of iatrogenic injury and interestingly observed that a more anterior position of the psoas muscle relative to the vertebral body correlated with a more anterior position of the lumbar plexus as well.

In all 3 cases illustrated herein, the psoas muscle was found to be rising away laterally and ventrally from the vertebral body at the index level on preoperative axial imaging studies. Specifically, the most posterior aspect of the psoas muscle was anterior to a horizontal line defining the most posterior aspect of the disc or vertebral body (Figs. 1B, 2B, and 3B). In addition, the psoas muscle was no longer in contact with the vertebra and appeared detached from it as opposed to its typical location depicted in Fig. 4 upper. In the first case, the patient had 5 lumbar vertebrae; therefore, we are led to conclude that the anatomy of the psoas muscle at L4–5 was aberrant. The second patient had a lumbarized sacrum explaining the course of the psoas muscle effectively at L5–6 rather than at L4–5. The third case revealed asymmetry of psoas muscle anatomy at L4–5 with a rising psoas on the right and not on the left. This finding correlated with robust EMG activity throughout the disc space on the right and minimal activity on the left where the surgery was completed successfully and without complication.

The radiographic finding of a rising psoas muscle in all 3 cases was concomitant with the pervasive EMG responses discovered throughout the disc space during the initial approach. These responses were probably the result of direct stimulation of the lumbosacral plexus splayed throughout the disc space and not easily identified radiographically. This finding is consistent with the trend of progressive ventral migration of the plexus throughout the lumbar spine from cephalad to caudad. No cadaveric or clinical studies have reported on the location and relationship of the lumbar plexus and psoas muscle at L5–S1 because the lateral approach is not performed at this level, but its position has been postulated.[24] In the aforementioned MRI study by Kepler and colleagues, the position of the lumbar plexus, femoral nerve, and psoas muscle was quantified at L5–S1.[13] They observed that the lumbar plexus and femoral nerve were found, on average, less than 1 mm and 6 mm posterior to the anterior-most aspect of the vertebral body, respectively. This correlated with a more anterior position of the psoas muscle.

Smith and colleagues recently reported on the lateral transpsoas approach in the setting of a lumbarized sacrum, as appeared in one of our illustrated cases.[24] Eight of 10 patients with 6 lumbar vertebrae approached at L5–6 (functional L4–5) were converted to another approach due to the inability to find a safe working corridor based on EMG responses. Axial MRI of these failed cases revealed a "teardrop-shaped" and detached psoas muscle, while the two successful interventions had a more typical psoas appearance. We reviewed all other clinical studies on lateral interbody fusions in search for aborted cases. We found 5 cases aborted owing to an inability to find a safe docking zone in Knight and colleagues' publication[14] and 3 aborted cases in Cahill and colleagues' retrospective report, all cases at L4–5.[4] No description of psoas muscle anatomy was offered in either study.

Given this unifying preoperative imaging characteristic that correlated with an inability to safely dock onto the disc space and the aforementioned clinical and radiographic observations, we believe that a rising psoas sign on axial views at L4–5 with or without the presence of a lumbarized sacrum could portend difficulty during the approach. Psoas anatomy and location with respect to the vertebra is easier to appreciate than the lumbar plexus and femoral nerve and may be a stronger predictor of a successful or failed approach. Since our experience with these aborted cases, we routinely study the anatomy of the psoas muscle with respect to the vertebra and disc space on preoperative axial imaging and avoid the lateral approach when a rising psoas muscle is observed at L4–5 (Fig. 5). We have not encountered pervasive EMG responses of the type described, have not aborted any cases, and have observed a reduced incidence of postoperative

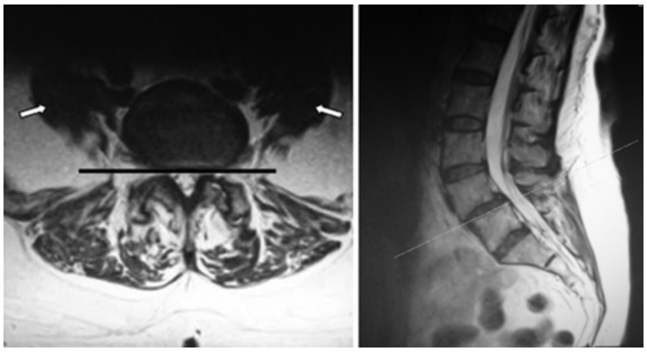

Fig. 5. Axial **(left)** and sagittal **(right)** T2-weighted MR images obtained in a patient with an L4–5 spondylolisthesis believed to be a candidate for a minimally invasive lateral approach. Because of the rising psoas sign seen on axial views *(arrows and black line)*, a posterior approach was used instead. *White line* in the sagittal image indicates the level of the axial image.

neurological complications as discussed above. We retrospectively reviewed all patients who underwent a lateral L4–5 fusion prior to our current practice of preoperative evaluation of psoas muscle anatomy. We obtained imaging studies in the form of preoperative or postoperative MRI or CT on 41 of 47 patients and evaluated the relationship of the psoas muscle to the vertebral bodies. We found only 1 patient of 41 with a rising psoas muscle on axial MRI (Fig. 6) who underwent lateral interbody fusion. Although intraoperative EMG monitoring data were not available from her surgery, she experienced leg paresthesias and mild weakness after surgery that lasted for 6 months.

Conclusions

We present 3 cases in which a minimally invasive lateral interbody fusion at L4–5 was aborted owing to

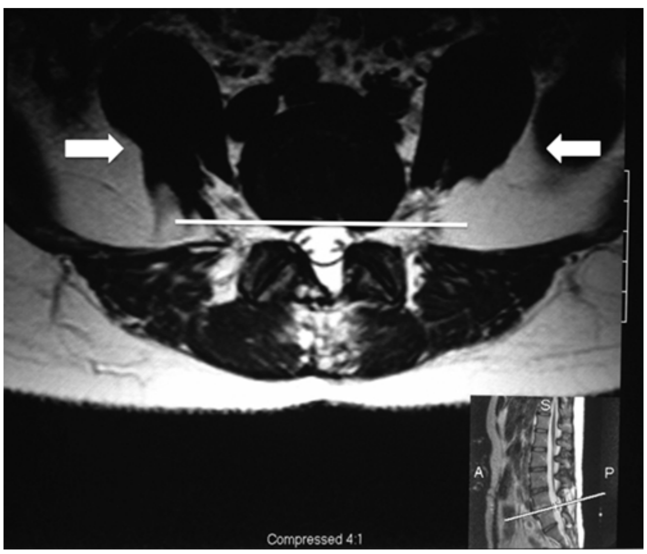

Fig. 6. Axial T2-weighted MR image obtained in a 39-year-old female patient who underwent a lateral interbody fusion at L4–5 for degenerative disc disease. The psoas muscles are located ventral and lateral to the L4–5 disc space. She had persistent paresthesias and leg weakness for 6 months after surgery.

pervasive EMG responses throughout the disc space. On preoperative axial MRI in all cases, the psoas muscle was more anterior and lateral to the vertebral body, resembling an anatomical position commonly seen at L5–S1 where the psoas appears to rise away from the spinal column on axial imaging. One of these patients had 6 lumbar vertebrae or a lumbarized sacrum. When planning a lateral approach, particularly at L4–5, preoperative analysis of psoas muscle anatomy and its relationship to the vertebral body is important. A rising psoas sign on axial imaging at L4–5 with or without a lumbarized sacrum may increase the risk of nerve injury during the procedure and warrant consideration of an alternative approach.

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: all authors. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: all authors. 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: Voyadzis. Statistical analysis: all authors. Administrative/technical/material support: all authors. Study supervision: all authors.

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