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Morphometric Analysis of the Ventral Nerve Roots and Retroperitoneal Vessels With Respect to the Minimally Invasive Lateral Approach in Normal and Deformed Spines

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Study Design. A morphometric analysis, using magnetic resonance imaging (MRI) studies of the lumbar spine.

Objective. To identify the anatomic position of the ventral root and the retroperitoneal vessels in relation to the vertebral body in normally aligned and deformed spines.

Summary of Background Data. The lateral approach to the lumbar spine is a relatively new method for performing interbody fusions. In contrast to the standard open anterior approach with direct vision of the operative field, the lateral approach uses expandable retractors that are positioned under fluoroscopic guidance. Risks of this technique include injury to the exiting nerve root and retroperitoneal vessels.

Methods. One hundred lumbar spine MRI studies were reviewed from patients treated for various spinal pathologies. The measured intervertebral segments were divided into 3 groups: group 1 ($n = 247$), normally aligned vertebrae and disc spaces; group 2 ($n = 18$), degenerative spondylolisthetic segments; and group 3 ($n = 19$), segments from the apex of degenerative lumbar scoliosis. Axial MR images were used to measure: the vertebral endplate anterior-posterior (AP) diameter, the overlap between the ventral root and the posterior margin of the vertebra, and the overlap between the retroperitoneal large vessels and the anterior edge of the vertebra.

Results. The overlap between the adjacent neuro-vascular structures and the vertebral body endplate gradually increased from L1–L2 to L4–L5. The maximal overlap, at the L4–L5 level reached 87% resulting in a relatively narrow corridor for performing the operative procedure. Alteration in the anatomic location of the nerve root and the retroperitoneal vessels, in Group 3 (scoliosis) further decreased the safe corridor.

Conclusion. The safe corridor for performing the discectomy and inserting the intervertebral cage narrows from L1–L2 to the L4–L5 level. This corridor is further narrowed with rotatory deformity of the spine. Using the preoperative MRI to assess the relative position of the adjacent neuro-vascular structures in relation to the lower vertebra's endplate at each level is recommended.

Key words: lateral approach, minimally invasive spinal fusion, surgical safe zone. **Spine 2009;34:1330–1335**

Spinal fusion is one of the most common procedures performed by spine surgeons today for the treatment of degenerative problems such as recurrent disc herniation, segmental instability, and deformity. Traditional approaches include anterior and posterior approaches to the spine.

The anterior approach to the spine is associated with risk of injury to the abdominal organs, the large retroperitoneal vessels and the sympathetic plexus.[1–3] The posterior approach carries the risk of devitalizing paraspinal musculature and direct damage to the dural tube and the exiting nerve root.[4,5]

The lateral approach to the lumbar spine is a relatively novel method for performing minimally invasive lateral interbody fusions (XLIF-NuVasive, Inc., San Diego, CA, or DLIF-Medtronic Sofamor Danek Inc.).[6–8] This approach allows for a large graft to be placed at the apophyseal ring where the bone is strongest.[9,10] This facilitates disc height restoration and deformity correction. In addition to the advantage of avoiding manipulation of the large retroperitoneal vessels, this technique uses a small 3-cm incision that avoids significant abdominal wall muscle injury. However, the limited visualization of the surgical field during this procedure exposes the surgeon to difficulties and dangers that do not exist when doing similar procedures in an open technique. The surgeon must rely on intraoperative fluoroscopic images and electromyography monitoring during most of the procedure. Specific risks include injury to the exiting nerve root and laceration of the retroperitoneal vessels during the deployment of the surgical retractors and the discectomy procedure.

Anatomic understanding of the relationship between the ventral nerve roots, the retroperitoneal vessels, and the vertebral body is crucial for minimizing the risk for these complications. Little data has been published in the literature regarding the morphometric measurements of these structures. Some of these studies used young cadaveric specimens without addressing the

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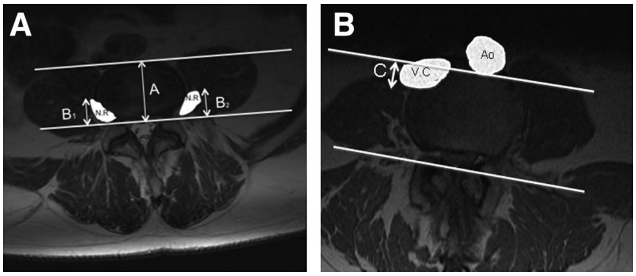

Figure 1. **A,** T2-weighted axial MR image at the level of the superior L4 endplate, the nerve roots are highlighted in white. Distance A is the AP diameter of the vertebral body. B1 and B2 are the distances between the ventral edge of the nerve root and the posterior edge of the vertebra. **B,** T1-weighted axial MR image at the level of the superior L3 endplate. Both the aorta (Ao) and *vena cava* (V.C) are highlighted. Distance C is the overlap between the ventral border of the vertebra and the *vena cava* posterior border.

anatomic alterations that may result from degeneration and deformity of the spine. This study aims to determine the anatomic relationship between the vertebral body and the adjacent vessels and nerves to determine the surgical safe zone for performing the lateral approach procedures. These data are obtained from a larger population of patients with clinically symptomatic degenerative disc disease to assess the effect of degenerative spondylolisthesis and scoliosis on the anatomic position of the nerve root and retroperitoneal vessels.

Methods

Following approval from the institutional review board, lumbar magnetic resonance imaging (MRI) studies from 100 spine patients were selected from the PACS archive of our institution. Measurements were determined using the PACS software computer digitizer (IMPAX 6.3 Agfa Healthcare NV, Mortsel, Belgium).

Radiographic evaluations of standing anterior-posterior (AP) and lateral plain radiographs were used to categorize patients into 3 groups: group 1 consisted of degenerative but normally aligned segments; group 2 consisted of segments with degenerative spondylolisthesis; and group 3 consisted of patients with degenerative scoliosis. The scoliosis group was further divided into right or left convexity. Inclusion criteria for the scoliosis group included a lumbar only curvature with a Cobb angle greater than 20°. Changes in the relative locations of the nerve root and retroperitoneal vessels were correlated to the degree of both the vertebral rotation and apical Cobb angles.

Two independent observers, a musculoskeletal radiologist and a spine surgeon, obtained 2 separate sets of measurements. Axial T1 and T2 images were used to identify the location of the ventral root and adjacent large vessels. Axial images that were not parallel to the plane of the vertebral endplate were excluded to ensure the accuracy of the measurements.

Measurements were obtained either from the posterior or the anterior margin of the lower endplate at each disc level. This reference point is readily identifiable in the operating room setting from the lateral fluoroscopy images. The position of the ventral roots was measured from their ventral edge to the dorsal edge of the vertebral body (Figure 1A). In addition, the extent of the overlap of the retroperitoneal blood vessels with the vertebral body was measured from both sides of the spine (Figure 1B).

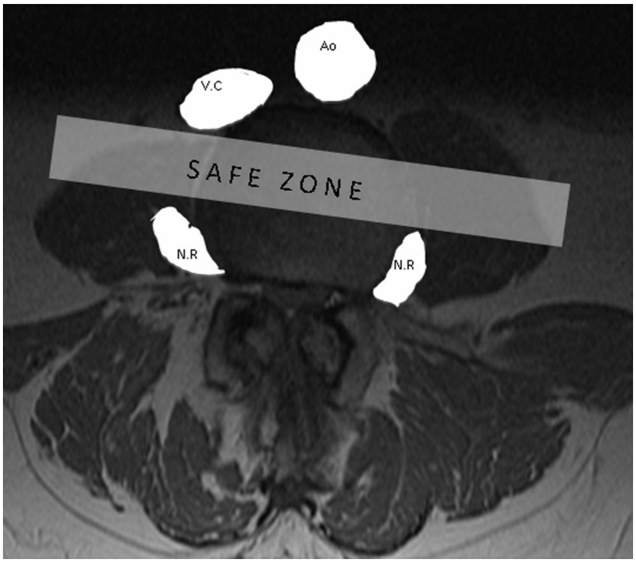

Figure 2. An anatomic illustration of the surgical safe zone (white area), between the nerve roots and the right retroperitoneal vessel (*vena cava*).

To determine the surgical safe zone from either side of the vertebral body, the relative vertebral body diameter that is anterior to the nerve root and is posterior to the retroperitoneal vessels was calculated (Figure 2). The surgical safe zone was calculated with both 95% and 100% confidence, using both the upper limit values of the calculated 95% confidence interval (CI) and the maximal measured values for the nerves and vessels at each level.

Statistical Analysis

Nerve root and blood vessels measurements are reported as 95% CIs, while the vertebral body AP and width diameter are reported as means with standard error. Statistical tests were made using SPSS (version 15.0, Chicago, IL) with α-values set to 0.05. One-way repeated analysis of variance was used to compare difference between the different levels within the normal group. Univariate analysis of variance was used to measure the difference between groups 1, 2, and 3. Interobserver reliability was evaluated with use of the interclass correlation coefficient.

Results

Two hundred ninety-four intervertebral segments from 52 females and 48 males were measured using radiographs and MRI images. The age of the patients ranged from 17 to 87 years (mean 57). The average interclass correlation coefficient between the 2 sets of measurements was 0.73 indicating excellent interobserver reliability.

Position of the Nerve Roots in the Normally Aligned Spine

Two hundred forty-seven normally aligned segments were analyzed from the L1–L2 to L5–S1 level. The nerve root vertebral ratios were calculated using both the high 95% CI and the maximal values of the nerve root position for each level (Table 1). These values were used to further define the 95% and 100% confidence margins of

Table 1. Position of the Nerve Roots and Retroperitoneal Vessels in Group 1 (Normally Aligned Segments)*

	Level	95% CI (mm) Low	95% CI (mm) High	Maximal (mm)	95% CI % High	Maximal %
Nerve root	L1–L2	2.9	3.9	6.5	10.6	17.6
	L2–L3	5.3	6.0	10.5	15.5	26.9
	L3–L4	5.5	6.4	9.7	16.4	25.0
	L4–L5	8.3	10.0	19.5	25.9	50.3
	L5–S1	15.4	18.8	26.5	49.0	69.2
Left vessels	L1–L2	0.0	0.8	5.0	2.2	13.5
	L2–L3	0.1	0.4	3.0	1.1	7.7
	L3–L4	0.2	0.6	4.0	1.5	10.3
	L4–L5	1.7	3.5	11.3	9.0	29.0
	L5–S1	9.2	12.5	23.8	32.7	62.2
Right vessels	L1–L2	1.7	3.7	12.8	10.1	34.5
	L2–L3	3.4	5.0	11.9	12.9	30.4
	L3–L4	3.9	5.4	12.0	13.9	31.0
	L4–L5	6.5	8.2	14.2	21.2	36.5
	L5–S1	7.2	10.4	17.0	27.2	44.4

*Measurements are presented both in millimeters and as a percentage of the AP diameter of the vertebral body.

Table 2. Safe Zone for Group 1 (Normally Aligned Segments)*

	95% Confidence	100% Confidence
L1–L2	79.4	47.9
L2–L3	71.6	42.7
L3–L4	69.7	44.0
L4–L5	53.0	13.1
L5–S1	18.3	0.0

*The surgical safe zone is the relative vertebral body diameter that is anterior to the nerve root and posterior to the retroperitoneal vessel. The 95% confidence zone was calculated using the upper limit values of the 95% CI. The 100% confidence zone was calculated using the maximal measured values.

the surgical safe corridor from either side of the spine. Both ratios increased significantly from L1–L2 to L5–S1, as the position of the nerve root shifted ventrally in relation to the vertebral body ($P < 0.05$). With 95% CI, the nerve root vertebral ratios were between 11% and 16% at the L1–L2 and L3–L4 levels and reached values of 26% and 49% at the L4–L5 and L5–S1 levels, respectively. When using the maximal measured values of the nerve root positions, the corresponding ratios reached 50% at the L4–L5 and 69% at the L5–S1 levels (Table 1).

From the L1–L2 to the L5–S1 level, the degree of overlap between the retroperitoneal blood vessels and the vertebra increased progressively as the vessels moved posterior and lateral with respect to the vertebral body. As a result, the relative right side overlap increased from 10% at the L1–L2 level to 21% at the L4–L5 and to 27% at the L5–S1 levels. On the left side of the vertebral body, the relative overlap increased from 2% at the L1–L2 level to 9% at the L4–L5 level and 33% at the L5–S1 level ($P < 0.05$). When calculating these ratios using the maximal measured values, the right and left overlaps reached 37% and 29% at the L4–L5 level and 44% and 62% at the L5–S1 level (Table 1).

The Surgical Safe Zone in the Degenerative Normally Aligned Spine

As both the nerve root position shifted progressively anterior and the overlap between the anterior aspect of the vertebral body, and the retroperitoneal vessels increased, the calculated surgical safe zone becomes smaller from the L1–L2 to the L4–L5 level (Figure 3). The use of the maximal position values instead of the upper limit values of the CI reduced the safe zone by approximately 40% at the L1–L2 to L3–L4 levels and by 75% at the L4–L5 level (Table 2).

Position of the Nerve Roots and Retroperitoneal Blood Vessels in the Spondylolisthesis Group

Group 2 (n = 18) consisted of degenerative spondylolisthetic segments from the L4–L5 level only. Thirteen of the segments showed a grade 1 listhesis and the remaining 5 segments showed grade 2 anterolisthesis. There were no significant differences in the position of the nerve roots, or retroperitoneal vessels, between group 1 and group 2 patients.

Position of the Nerve Roots and Retroperitoneal Blood Vessels in the Scoliosis Group

Group 3 consisted of segments from spines with degenerative lumbar scoliosis (n = 19). Both right (n = 9) and left (n = 10) convexities were included. The apex of the convexity was at L2–L3 in 10 patients, at

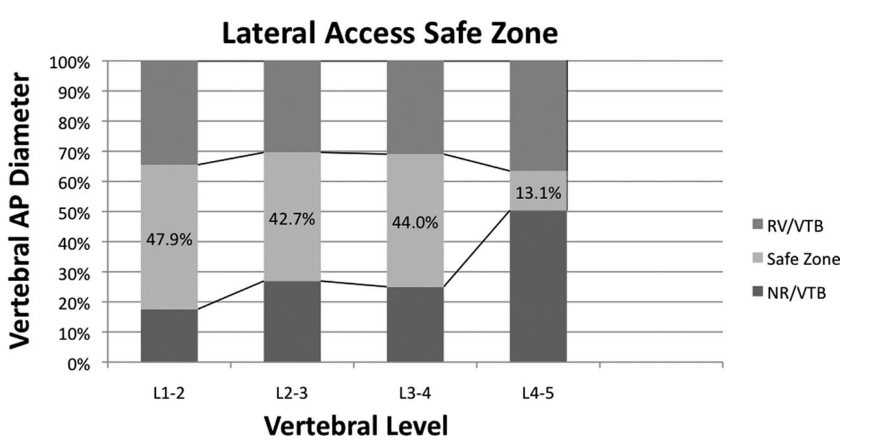

Figure 3. Schematic chart of the relative overlap of the vertebral body with the nerve root (NR/VTB) and the right vessels (RV/VTB). The lateral access safe zone between the right retroperitoneal vessels and the nerve roots is presented at each level. Notice the abrupt reduction of the safe zone at the L4–L5 level.

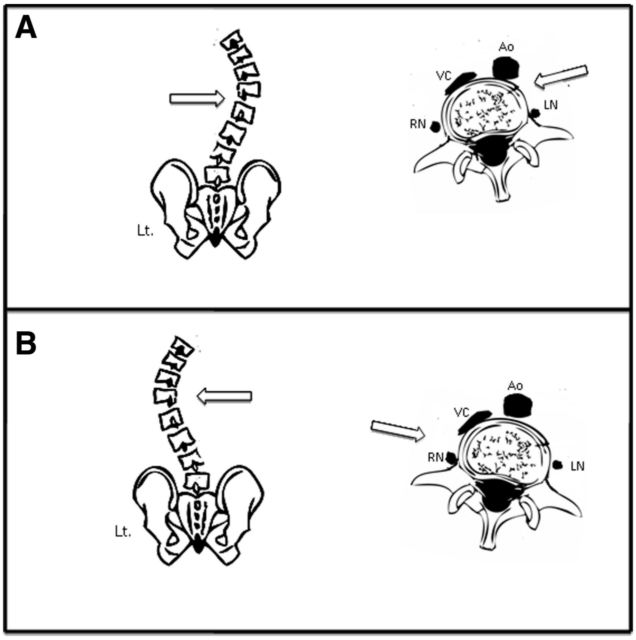

Figure 4. **A,** Dextroscoliosis with right (counterclockwise) rotation of the vertebra resulted in a relative anterior position of the right nerve root and posterior position of the left vessel and nerve root. **B,** Levoscoliosis with left rotation of the vertebra (clockwise) rotation resulted in a relative anterior position of the left nerve root and a relative posterior position of the right vessel and nerve root (arrows pointing at the concave side of the deformity).

L1–L2 in 6 patients, and at L3–L4 in 3 patients. The average lumbar Cobb angle was 23° and the apical Cobb angle measured 18°.

With scoliosis, the nerve root at the apex of the convexity was situated relatively anterior to its position at the concavity. The maximal right nerve root overlap reached 22.8% in the dextroscoliotic spines, compared with only 9.7% for the left nerve root. Similarly, with levoscoliotic spines, the maximal nerve root overlap reached 21.4% on the left side compared with only 14.3% for the right side ($P < 0.05$) (Figure 4).

Furthermore, the vessels on the concave side of the curvature were positioned relatively posterior to their position in the normally aligned spines. The right vessels' overlap over the vertebral body reached 43.9% in the levoscoliotic spines, compared with 12.2% in the normal group. The left vessels' overlap in the dextroscoliotic spines reached 19.8%, compared with 1.2% in the normal group ($P < 0.05$) (Figure 4).

As a result of the greater degree of overlap between the neurovascular structures and the vertebral body found in the scoliosis subgroup, the surgical safe zone decreased to 40% in the levoscoliotic spines and 61% in the dextroscoliotic spines, compared with 70% in the nonscoliotic group (Figure 5). The altered location of the neurovascular structures was mostly dependent on the degree of rotatory deformity, measuring 12° in the levoscoliotic and 11° in the dextroscoliotic spines. Focal coronal deformity or lateral listhesis did not seem to affect the position of these structures.

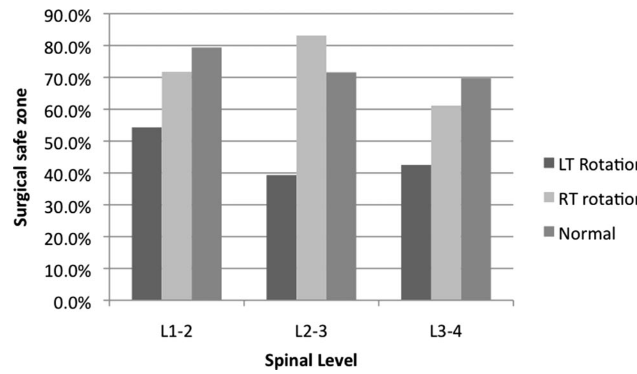

Figure 5. Comparison of the degree of safe zone between the scoliosis and the normal groups.

Discussion

The minimally invasive technique for performing lumbar interbody fusion through the lateral approach was first described by McAfee *et al.*[7] They used laparoscopic, rather than mini-open, instruments to perform the procedure. Newer techniques that use specially designed expanding retractors were introduced in recent years.[8,11] These techniques have several advantages over the laparoscopic technique. They do not require the use of an operative camera or the equipment needed to inflate the retroperitoneal cavity with gas.[6] Their biggest advantage over the laparoscopic technique is the ability to insert relatively large cages that rest on the apophyseal ring of the vertebral body and thereby enable the surgeon to achieve better restoration of the disc height. This has allowed significant deformity correction by minimally invasive techniques.

A significant disadvantage of the mini-open lateral techniques is the lack of direct visualization of the operative field during the initial exposure of the surgical corridor. This creates several technical challenges. Damage to the lumbar plexus is possible during penetration of the psoas muscle and positioning of the expandable retractors. To compensate for the lack of direct visualization of the operated field, the surgeon must rely on careful intraoperative fluoroscopic imaging and intraoperative neuromonitoring to avoid injury to the adjacent nerve roots.[8]

Injury to the retroperitoneal vessels is a potentially catastrophic complication with all anterior approaches. With the lateral approach techniques, laceration of the vessels on the contralateral side of the approach can occur when the anulus is being released in order to prepare the intervertebral space to accommodate a large cage. Unintentional breach of the anulus is also possible during the discectomy and the endplate preparation.

Previous studies have described the anatomy of the retroperitoneal area with respect to lateral surgical approaches to the spine.[12–16] However, none were designed to address the specific challenges of the technique. Gu *et al*[14] used cadaveric specimens to determine the location of the lumbar nerve root and the sympathetic trunk with reference to the superior border of the transverse process. They determined that the safe zone for making the discectomy should be located between the nerve roots and the sympathetic trunk that runs along the anterior third of the vertebral bodies underneath the psoas muscle. The genitofemoral nerve, arising from the L2 and L3 nerve roots, was responsible for narrowing this safe zone at the L2–L3 level. Similar observation was made by Moro *et al.*[16] They concluded that above the L4–L5 level, the surgical safe zone narrows only at the L2–L3 level by the genitofemoral nerve. As both of these studies were designed in reference to the laparoscopic surgical technique, neither of them used easily identifiable radiographic reference points for their measurements. Additionally, these studies collected their data from a relatively small sample group, and no reference was made as to different deformities of the spine.

Imaging studies were previously used for morphometric analysis of the vertebral column and the adjacent vascular structures in patients with adolescent idiopathic scoliosis for determining the safe zones for insertion of anterior vertebral body screws. Both computed tomography and MRI studies proved to be reliable tools to measure the relationships between the positions of the aorta and the spine for different types of thoracic curvatures.[17–21]

Our results indicate that when considering the nerve root and the retroperitoneal vessels, there is an abrupt change in the safe zone at the L4–L5 level. This finding is caused both by the relatively more anterior location of the nerve root and the more posterior position of the retroperitoneal vessels at the L4–L5 level compared with the other lumbar levels (excluding L5–S1 that is not accessible by the lateral approach). By using a relative ratio between the different structures and the vertebral body, rather than the absolute distance, clinically applicable values that can be used intraoperatively are established.

We did not find any significant alterations in the relative position of the neurovascular structures in the spondylolisthesis group (group 2). This is likely the result of the low listhesis grade in most of our sample group. However, lumbar scoliosis does cause both the position of nerve roots and the retroperitoneal vessels to shift relative to the vertebral body. Degenerative scoliosis can result from nonsymmetrical narrowing of the discs spaces, lateral listhesis, or rotation of the vertebrae.[22,23] Our finding indicates that the relative posterior position of the nerve root at the concavity of the deformity reduces the risk of nerve root injury when the approach is done from this side. However, at the concavity the risk of injury to the retroperitoneal blood vessels is greater especially if the surgeon unintentionally drifts anteriorly. Since the surgical safe zone is the narrowest in the levoscoliotic spines, these must be approached with greater scrutiny than other types of spinal conditions (Figure 5). Under these circumstances, if the surgeon opts to approach the disc from the convexity it is necessary to use a relative anterior entry point to the disc. However, at these locations the vessels on the contralateral side are at greater risk during anular release.

There are several disadvantages in using imaging analysis instead of cadaveric specimens for this study. The measurement accuracy using an imaging technique is inferior to direct measurements from a cadaver and is more prone to interobserver variability.[24] Moreover, not all of the images were exactly parallel to the direction of the vertebra. We addressed these problems by using 2 independent observers, a musculoskeletal radiologist and a spine surgeon to perform the measurements. Any image that had more than 10° of obliquity in reference to the lower endplate was excluded from the study. The biggest problem using the MRI modality was our inability to reliably locate the genitofemoral nerve and the sympathetic trunk to analyze their relative location in respect to the vertebral body. Although we are not aware of any clinically relevant injury to the sympathetic trunk during the lateral approached procedures, genitofemoral nerve paresthesias are a complication of this procedure.[6,7]

Conclusion

The lateral interbody fusion techniques are dependent on high quality fluoroscopic imaging. As the disc space is exposed, the exiting nerve root that lies within the psoas muscle must be avoided. On the contralateral side of the disc space, the retroperitoneal vessels may be at risk during release of the anulus and insertion of the interbody cage. This risk is significantly increased at the L4–L5 level where the more anterior position of the nerve root forces the discectomy window more anteriorly, which in turn increases risk of injury to the contralateral vessels. These risks are further increased with rotatory deformity of the spine. Meticulous care and consideration of these anatomic characteristics are required for safe application of this minimally invasive technique.

Key Points

- The MIS lateral approach techniques are dependent on high quality fluoroscopic imaging.
- Risk of injury to the exiting nerve root or the retroperitoneal vessels is significantly increased at the L4–L5 level.
- These risks are further increased with rotatory deformity of the spine.

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