

Movement of abdominal structures on magnetic resonance imaging during positioning changes related to lateral lumbar spine surgery: a morphometric study

Clinical article

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Object. The minimally invasive lateral interbody fusion of the lumbar spine through a retroperitoneal transpsoas approach has become increasingly used. Although preoperative imaging is performed supine, the procedure is performed with the patient in the lateral decubitus position. The authors measured the changes in location of the psoas muscle, aorta, inferior vena cava (IVC), iliac vessels, and kidneys with regard to the fixed lumbar spine when moving from a supine to a lateral decubitus position.

Methods. Unenhanced lumbar MRI scans were performed using a 3T magnet in 10 skeletally mature volunteers in the supine, left lateral decubitus (LLD), and right lateral decubitus (RLD) positions. Positional changes in the aorta, IVC, iliac vessels, and kidneys were then analyzed at all lumbar levels when moving from supine to RLD and supine to LLD. Values are presented as group means.

Results. When the position was changed from supine to RLD, both the aorta and the IVC moved up to 6 mm to the right, with increased movement caudally at L3–4. The aorta was displaced 2 mm anteriorly at L1–2, and the IVC moved 3 mm anteriorly at L1–2 and L2–3 and 1 mm posteriorly at L3–4. The left kidney moved 22 mm anteriorly and 15 mm caudally, while the right kidney moved 9 mm rostrally.

When the position was changed from supine to LLD, the aorta moved 1.5 mm to the left at all levels, with very minimal anterior/posterior displacement. The IVC moved up to 10 mm to the left and 12 mm anteriorly, with increased movement rostrally at L1–2. The left kidney moved 3 mm anteriorly and 1 mm rostrally, while the right kidney moved 20 mm anteriorly and 5 mm caudally.

The bifurcation of the aorta was an average of 18 mm above the L4–5 disc space, while the convergence of the iliac veins to form the IVC was at the level of the disc space. The iliopsoas did not move in any quantifiable direction when the position was changed from supine to lateral; its shape, however, may change to become more flat or rounded. When the position was changed from supine to RLD, the right iliac vein moved posteriorly an average of 1.5 mm behind the anterior vertebral body (VB) line (a horizontal line drawn on an axial image at the anterior VB), while the other vessels stayed predominantly anterior to the disc space. When the position was changed from supine to LLD, the right iliac vein moved to a position 1.4 mm anterior to the anterior VB line. There was negligible movement of the other vessels in this position.

Conclusions. The authors showed that the aorta, IVC, and kidneys moved a significant distance away from the surgical corridor with changes in position. At the L4–5 level, a left-sided approach may be riskier because the right common iliac vein trends posteriorly and into the surgical corridor, whereas in a right-sided approach it trends anteriorly.

(<http://thejns.org/doi/abs/10.3171/2012.3.SPINE1210>)

KEY WORDS • lateral interbody fusion • magnetic resonance imaging •
minimally invasive surgery • lateral approach • transpsoas • lumbar spine

MINIMALLY invasive LIF through a retroperitoneal transpsoas approach has become increasingly popular for the treatment of degenerative spinal disease, deformity, and trauma involving the thoracolumbar spine.^{12,14,20,21,25,28–30} It offers several potential advantages over traditional posterior approaches to interbody

fusion, including decreased muscle dissection, decreased postoperative muscle atrophy, and the ability to place a large interbody graft.¹¹ It allows access to the anterior spinal column without the risks associated with anterior lumbar interbody fusion, including manipulation of the great vessels, retrograde ejaculation, and abdominal adhesions as well as the cohort of possible complications that go along with it.^{7,27,32}

Anatomical studies of the thoracolumbar retroperitoneal region have demonstrated that peritoneal and retroperitoneal structures at risk during these procedures

Abbreviations used in this paper: DICOM = Digital Imaging and Communications in Medicine; IVC = inferior vena cava; LIF = lateral interbody fusion; LLD = left lateral decubitus; RLD = right lateral decubitus; VB = vertebral body.

include the aorta, IVC, common iliac vessels, kidneys, bowel, lumbar plexus, and to a much lesser extent, the spleen and liver.^{1,17,18} The recommended position is right lateral decubitus (RLD), or left side up. This theoretically decreases the risk of injury to the IVC and right common iliac vein, which lie along the right anterolateral border of the VB, while the aorta lies more directly anterior to the VB.^{10,16}

Surgical planning includes supine MRI; during minimally invasive LIF, however, the patient is in the lateral decubitus position. To our knowledge, the movement of the abdominal viscera when the position is shifted from supine to lateral decubitus is thus far unexamined and unreported. In the present study, we examine the direction and magnitude of movement of the aorta, IVC, common iliac vessels, psoas muscle, and kidneys when the position is shifted from the supine to the left and right lateral decubitus positions and the implications of this movement on the approach, preoperative planning, side preference, and complication avoidance.

Methods

This is an institutional review board–approved study involving a series of 10 healthy, skeletally mature adult volunteers who underwent lumbosacral MRI scans without gadolinium in the supine, left lateral decubitus (LLD), and RLD positions. To be included in the study, volunteers had to be between 18 and 65 years old and willing to undergo supine and lateral MRI. Volunteers were excluded if they were pregnant, had previous major abdominal or thoracic procedures, or had a contraindication for MRI.

All MRI studies were performed using a single 3T magnet (GE HDX platform, 8-channel torso array coil) with a single radiology technician performing each scan. An attempt was made to standardize the scans by asking each volunteer to inspire to their fullest ability and hold his or her breath during each sequence. As expected, however, variability did exist between the volunteers and their capacity for inspiration.

Images were analyzed using computer software imaging (OsiriX DICOM viewer); T2-weighted images were examined for the current study because these allowed for easy visuospatial recognition of abdominal structures. Two independent reviewers analyzed the images, and the senior author (J.S.U.) adjudicated any interrater discrepancies. The abdominal structures examined were the aorta, IVC, iliac vessels, kidneys, and psoas muscle. Analysis of multiple planes was required due to the complexity of movements. Axial images were used for all measurements except the cranial-caudal movements of the kidneys, which also required coronal images.

Similar measurements were made for both the aorta and IVC. The L1–2, L2–3, and L3–4 disc spaces were identified on axial T2-weighted slices. Then, using the dynamic angle function of the imaging software, perpendicular lines were drawn through the midspinous process/VB and the anterior VB. To cover all directions of movement, the distance from the left border of both the aorta and IVC to the vertical midline was measured, and the distance from the posterior border of the aorta and IVC

to the anterior VB line was measured. This was repeated at all 3 disc spaces in all positions for all 10 volunteers. If the borders of the aorta or IVC crossed their reference lines, a negative number was recorded (Fig. 1).

To identify vessel movement at the L4–5 disc space, a horizontal line was drawn at the anterior border of the axial image, and the distance that the iliac arteries/veins were displaced posterior to this line was measured in the lateral decubitus position relative to supine.

The average anterior-posterior and lateral movements of the aorta and IVC when the position was changed from the supine to the LLD or RLD were calculated for L1–2, L2–3, and L3–4.

Anterior-posterior and cranial-caudal movement was assessed for the kidneys as well. Axial views were examined to assess anterior-posterior displacement. A horizontal line was drawn through the posterior aspect of the disc space at the L-2 superior endplate. We measured the distance from this posterior VB line to the posterior border of the kidney (a negative number was assigned if the kidney border was posterior to the horizontal line, and a positive number was assigned if the kidney border was anterior to the horizontal line). This was assessed for all 10 volunteers in all 3 positions, and the amount and direction of movement was then calculated as the volunteers moved from supine to LLD and RLD positions.

Coronal views were examined to assess cranial and caudal kidney displacement. A horizontal line was drawn across the superior endplate of L-4. For each kidney, we measured the distance from the horizontal line to the inferior pole of the kidney (a negative number was assigned if the kidney border was caudal to the line and a positive number if it was rostral to the line). The amount and direction of movement was calculated as the patient moved from supine to LLD and RLD positions (Fig. 2).

The average movement of the aorta, IVC, kidneys, and iliac vessels from the supine to the left or right decubitus position was analyzed by disc space level using the paired t-test and the nonparametric paired Wilcoxon signed-rank test (for normally distributed variables) where appropriate. A p value < 0.05 was considered statistically significant.

Results

One hundred twenty intervertebral segments from 10 participants were analyzed for aorta, IVC, and iliac vessel measurements. The L1–2, L2–3, L3–4, and L4–5 disc spaces in supine, LLD, and RLD positions were included. The average age of the volunteers was 37 years (range 27–52 years). One volunteer showed early signs of degenerative scoliosis, with a coronal lumbosacral Cobb angle of 11°.

The compiled results of aorta and IVC movement at L1–4 can be found in Figs. 3 and 4, respectively, as well as in Table 1.

The L1–2 Level

When the volunteers' position shifted from supine to RLD, the aorta moved an average of 2.5 mm to the right and 2 mm anteriorly ($p < 0.02$). The IVC moved 5 mm

Positional changes in the lateral approach

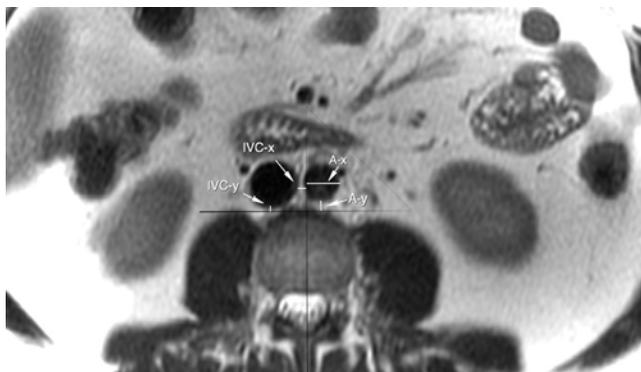


Fig. 1. Aorta/IVC measurement method. Axial T2-weighted MR image obtained in the supine position at the level of the L1–2 disc space demonstrating the method of measurement of both the aorta and the IVC in the medial-lateral and anterior-posterior planes. Distance in the medial-lateral plane was measured from the midspinous process–VB line for the IVC (IVC-x) and aorta (A-x). Distance in the anterior-posterior plane was measured from the anterior VB line for the IVC (IVC-y) and aorta (A-y). These measurements were compared with those obtained at the same disc space level in the LLD and RLD positions.

($p = 0.019$) to the right and 2.8 mm anteriorly. When the position shifted from supine to LLD, the aorta moved 1.5 mm ($p = 0.022$) to the left and 0.5 mm anteriorly, while the IVC moved 10.5 mm to the left ($p < 0.001$) and 12.4 mm anteriorly ($p = 0.001$).

The L2–3 Level

When the volunteers' position shifted from supine to RLD, the aorta moved 5.4 mm ($p = 0.001$) to the right and 0.7 mm anteriorly, while the IVC moved 5.4 mm ($p = 0.007$) to the right and 3.1 mm anteriorly. When the position shifted from supine to LLD, the aorta moved 1.6 mm to the left and 0.1 mm anteriorly, while the IVC moved 4.3 mm to the left ($p = 0.006$) and 4.7 mm anteriorly ($p < 0.005$).

The L3–4 Level

When the volunteers' position shifted from supine to RLD, the aorta moved 5.6 mm ($p < 0.001$) to the right and 0.1 mm anteriorly, while the IVC moved 5.5 mm ($p < 0.001$) to the right and 1.1 mm posteriorly. When the position shifted from supine to LLD, the aorta moved 1.4 mm to the left and 0.04 mm posteriorly, while the IVC moved 1.7 mm to the left and 1.1 mm anteriorly ($p < 0.04$ for both).

The L4–5 Level

The aorta bifurcation into the right and left common iliac arteries occurred anterior to the L-4 VB, at 17.3 mm, 18.4 mm, and 17.5 mm above the disc space in the supine, RLD, and LLD positions, respectively. The common iliac veins converged to form the IVC within 2 mm in the rostral or caudal direction from the L4–5 disc space (Fig. 5; Table 2).

In the RLD position, the right common iliac vein moves posteriorly and was an average of 1.5 mm posterior to the anterior VB line, while the other vessels stayed



Fig. 2. Kidney measurement method. Coronal T2-weighted image obtained in the LLD position demonstrating the method of measuring cranial and caudal kidney movement. A horizontal line was drawn across the superior endplate of L-4, and the distance from each inferior kidney pole was recorded in the supine, LLD, and RLD positions.

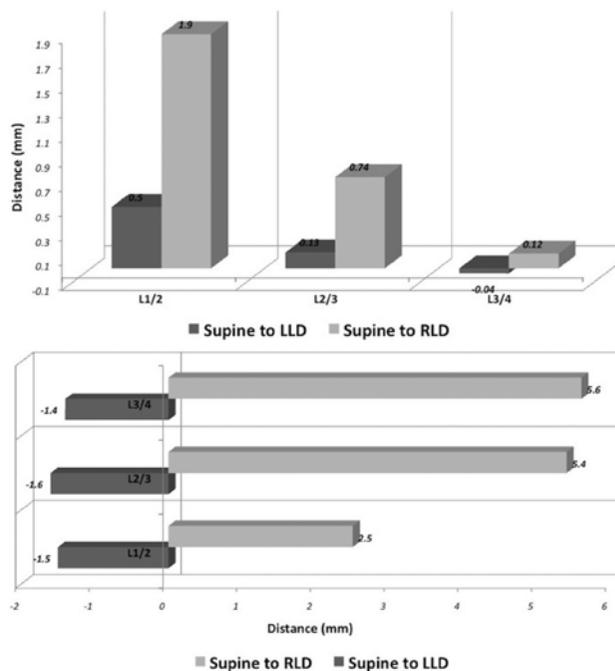


Fig. 3. Aorta movement. Graphs depicting aorta movement when position is changed from supine to LLD and supine to RLD in the anterior-posterior (upper) and medial-lateral (lower) directions at L1–2, L2–3, and L3–4. **Upper:** Anterior movement of the aorta is depicted with a positive value while posterior movement is depicted with a negative value. At L1–2 in the RLD position, the aorta moves 1.9 mm anteriorly ($p = 0.015$). All other movements in this plane are less than 1 mm and not statistically significant. **Lower:** Aorta movement to the right is depicted with a positive value, while movement to the left is depicted with a negative value. When the position is changed from supine to RLD, the aorta moves to the right 2.5 mm at L1–2 ($p = 0.01$), 5.4 mm at L2–3 ($p = 0.001$), and 5.6 mm at L3–4 ($p < 0.001$). When the position is changed from supine to LLD, the aorta moves less than 2 mm to the left. Data are given as mean values for 10 volunteers.

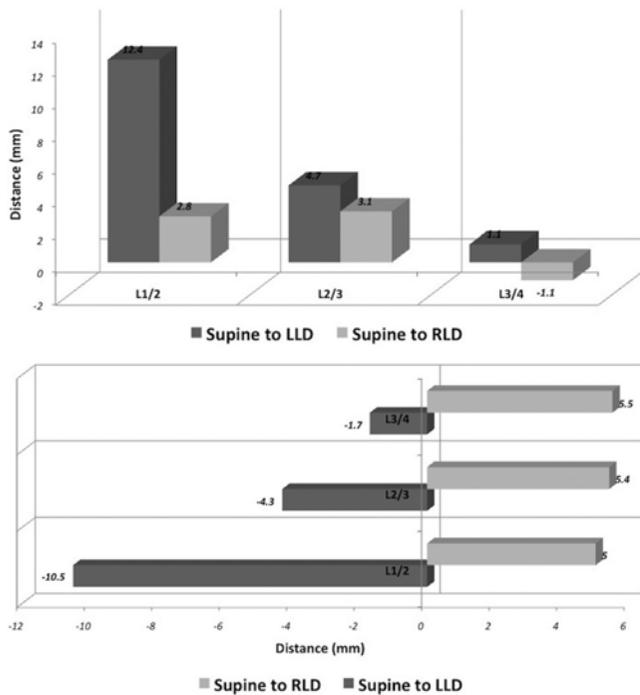


Fig. 4. Inferior vena cava movement. Graphs depicting IVC movement when the position is changed from supine to LLD and from supine to RLD in the anterior-posterior (upper) and medial-lateral (lower) directions at L1–2, L2–3, and L3–4. **Upper:** Anterior movement of the IVC is depicted with a positive value while posterior movement is depicted with a negative value. When the position is changed from supine to LLD, the IVC moves anteriorly 12.4 mm at L1–2 ($p = 0.001$), 4.7 mm at L2–3 ($p = 0.005$), and 1.1 mm at L3–4 ($p = 0.037$). The IVC movements when the position was changed from supine to RLD were not statistically significant, but it is interesting to note the posterior movement of 1.1 mm at L3–4. **Lower:** The IVC movement to the right is depicted with a positive value, while movement to the left is depicted with a negative value. All values are statistically significant.

predominantly anterior to the disc space. In the LLD position, the right common iliac vein was an average of 1.4 mm anterior to the anterior VB line; there was negligible movement of the other vessels (Fig. 6; Table 2).

The Iliopsoas Muscle

There was no discernible trend in movement on lateral positioning for the iliopsoas muscle; however, the muscle does undergo morphological changes and becomes more flat or rounded with movement. Our observations are similar to those described by Hu et al.,¹⁰ who demonstrated that the iliopsoas muscle appears to increase in size and lie more ventrally as it courses from L-1 to L-5.

The Kidneys

When the volunteers’ position shifted from supine to LLD, the left kidney moved an average of 2.9 mm anteriorly and 0.9 mm in the cranial direction (a difference that did not reach statistical significance), while the right kidney moved 20 mm ($p = 0.001$) anteriorly and 4.8 mm in the caudal direction. When the volunteers’ position shifted from supine to RLD, the left kidney moved an average

TABLE 1: Summary of aorta, IVC, and kidney movement when placed from supine to LLD and RLD positions*

Structure & Level	Supine to LLD	p Value	Supine to RLD	p Value
aorta				
L1–2	0.5 mm anterior 1.5 mm left	0.441 0.022	2 mm anterior 2.5 mm right	0.015 0.01
L2–3	0.1 mm anterior 1.6 mm left	0.75 0.416	0.7 mm anterior 5.4 mm right	0.063 0.001
L3–4	0.04 mm posterior 1.4 mm left	0.935 0.081	0.1 mm anterior 5.6 mm right	0.834 <0.001
IVC				
L1–2	12.4 mm anterior 10.5 mm left	0.001 <0.001	2.8 mm anterior 5 mm right	0.085 0.019
L2–3	4.7 mm anterior 4.3 mm left	0.005 0.006	3.1 mm anterior 5.4 mm right	0.35 0.007
L3–4	1.1 mm anterior 1.7 mm	0.037 0.011	1.1 mm posterior 5.5 mm right	0.106 <0.001
kidneys				
left	2.9 mm anterior 0.9 mm cranial	0.431 0.829	22 mm anterior 15 mm caudal	<0.001 0.001
right	20 mm anterior 4.8 mm caudal	0.001 0.064	0.3 mm anterior 9 mm cranial	0.864 0.152

* Boldface p values are statistically significant.

of 22 mm anteriorly ($p < 0.001$) and 15 mm caudally ($p < 0.001$), while the right kidney moved 0.3 mm anteriorly and almost 9 mm cranially (Fig. 7; Table 1).

Discussion

Retroperitoneal transposas minimally invasive LIF of the thoracolumbar spine allows for anterior access to

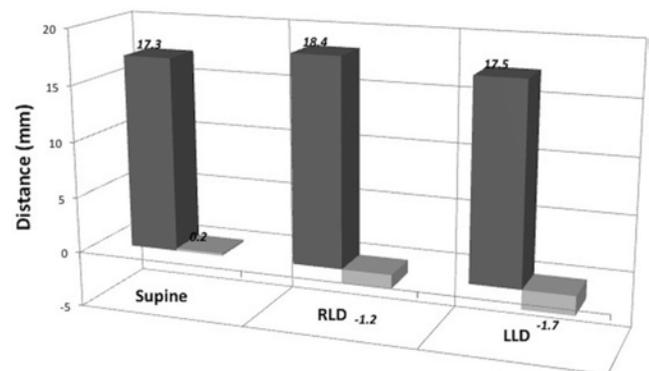


Fig. 5. Aorta bifurcation and IVC convergence. Graph depicting distance from the L4–5 disc space of the bifurcation of the aorta into the right and left common iliac arteries and the convergence of the right and left common iliac veins into the IVC. These are shown in the supine, RLD, and LLD positions. (A positive value indicates cranial direction, while a negative value indicates caudal direction.) In all positions the aorta bifurcation was on average 18 mm cranial to the L4–5 disc space, while the common iliac veins converged to form the IVC at the level of the disc space.

Positional changes in the lateral approach

TABLE 2: Summary of aorta bifurcation and IVC convergence data and right common iliac vein location relative to anterior VB line at L4–5

Structure	LLD	RLD
aorta bifurcation	18 mm cranial to L4–5 disc space	18 mm cranial to L4–5 disc space
IVC convergence	2 mm caudal to L4–5 disc space	1.1 mm caudal to L4–5 disc space
right common iliac vein	1.4 mm anterior to anterior VB line at L4–5	1.5 mm posterior to anterior VB line at L4–5

the disc space without significant dissection and mobilization of the great vessels.^{1,7,10,13,16–18,27,28,32} Although reported to be safe and reproducible, this approach is not without potential complications,^{2,4,6,9,15,19,23,24,26} and a thorough understanding of the regional anatomy is essential to safely perform this procedure.^{5,8,10,28} Also critical in complication avoidance is correct patient positioning, adequate fluoroscopic imaging, and nerve monitoring.³¹ The most common complications are related to lumbar plexus injury and the most potentially devastating complications are vascular and visceral injuries.

Uribe et al.²⁸ described the safe working zones in the lateral approach to the lumbar spine using cadaveric dissection with the specimens in the lateral position, similar to intraoperative positioning. In a recent study of the neurovascular anatomy encountered during the lateral transpsoas approach to the lumbar spine, supine MRI scans were evaluated to assess safe operative zones, with the L4–5 level having the most potential for complications.¹³ The authors should be commended on the study design and very thorough description of neurovascular structures at risk at each level with a left- or right-sided approach. However, as they point out in their discussion, “The exact effect of this positioning on anatomic structures in comparison to the lateral decubitus position used for LTIF [lateral transpsoas interbody fusion] is uncertain.”¹³

In this morphometric study, we attempted to determine motion of the kidneys, aorta, IVC, iliac vessels, and iliopsoas muscle with patient placement in the lateral decubitus position, as is done in thoracolumbar minimally invasive LIF. Careful attention to positioning has been thought to provide protection against vascular or kidney injury, but no study has attempted to quantify this risk.

Based on industry recommendations, the default position of the retroperitoneal transpsoas minimally invasive LIF approach to the lumbar spine is RLD, or left side up. The rationale behind this is unclear, though different opinions exist. Some believe it to be preferable for right-handed surgeons, while others believe it is used to avoid liver injury, although the procedure is done in the retroperitoneal space. Another opinion is that it may be easier to manipulate arterial rather than venous structures during dissection as the former may be less prone to injury. No empirical evidence exists as yet to support the use of a right- or left-sided approach during minimally invasive LIF. Understanding the movement of commonly injured abdominal structures when a patient is placed in the lat-

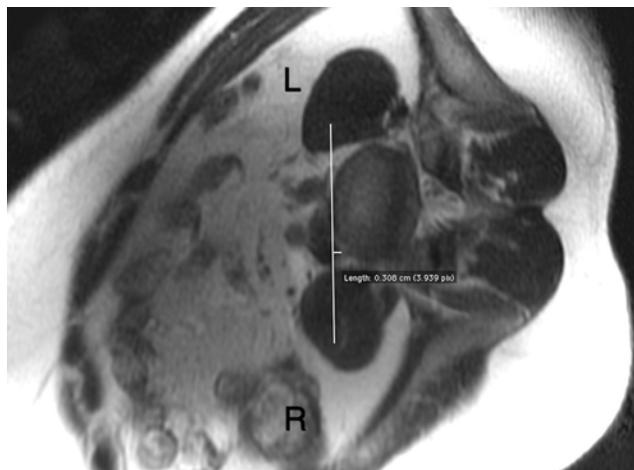


Fig. 6. Right common iliac vein measurement method. Axial T2-weighted image obtained in the RLD position at the L4–5 disc space depicting the right common iliac vein 3 mm posterior to the anterior border of the disc space.

eral position may assist in defining the optimal operative technique.

Although the bowel, liver, spleen, and neural elements in the abdomen are theoretically at risk for injury

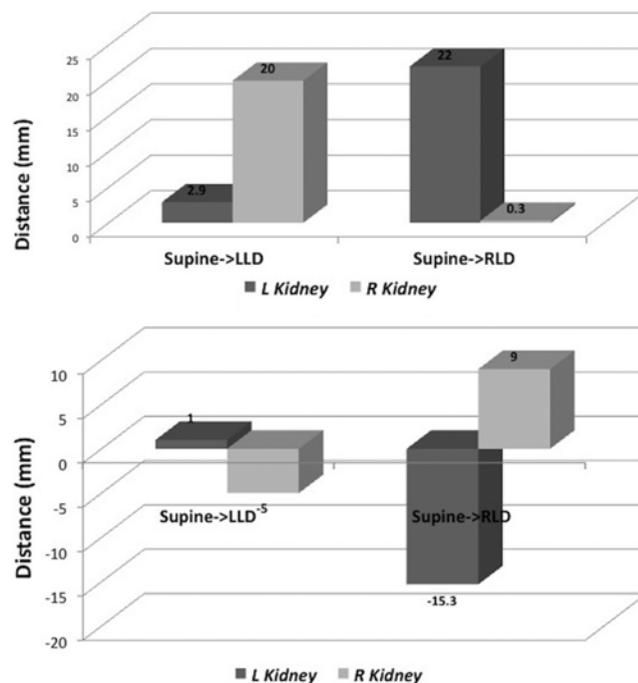


Fig. 7. Kidney movement. Graphs depicting left and right kidney movement when changing from the supine to the LLD position and from the supine to the RLD position in the anterior-posterior (upper) and cranial-caudal (lower) directions. **Upper:** Anterior kidney movement is depicted with a positive value, while posterior movement is depicted with a negative value. The kidney on the side of the approach moves anteriorly 20 mm and 22 mm ($p = 0.001$). **Lower:** Cranial kidney movement is depicted with a positive value, while posterior movement is depicted with a negative value. Of note, the left kidney moves caudally 15 mm when the position is changed from supine to RLD ($p = 0.001$).

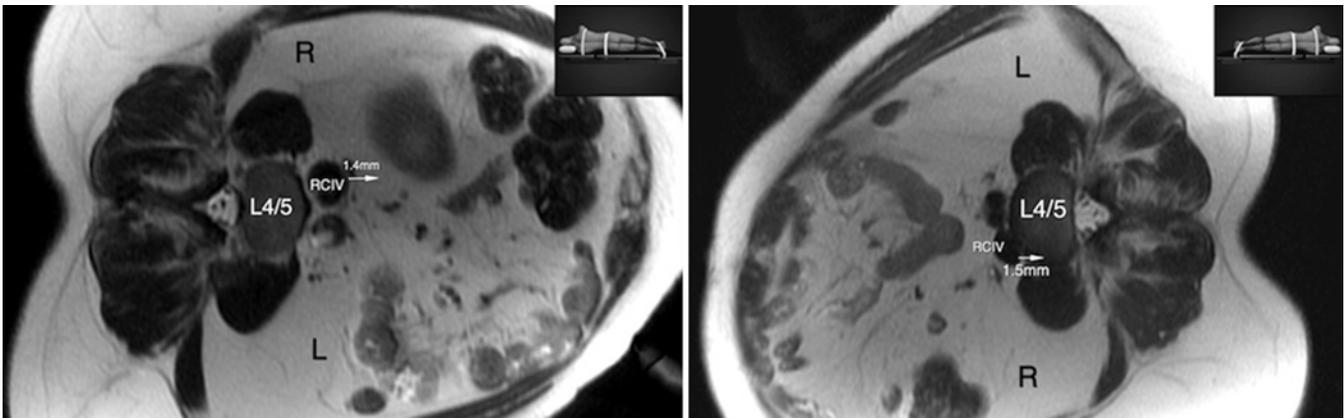


Fig. 8. Axial T2-weighted MR images obtained at the L4–5 disc space in the LLD (**left**) and RLD (**right**) positions (**insets** demonstrate patient positioning). Note the right common iliac vein (RCIV) anterior movement in a right-sided approach and posterior movement in a left-sided approach.

in the retroperitoneal transpsoas approach, we were unable to reliably quantify and reproduce the movements of these structures because of imaging limitations. Thus, our focus remained on the aorta, IVC, kidneys, iliopsoas, and common iliac vessels. Using the spine as a fixed structure, we were able to measure movement of the aorta and IVC in 2 planes at the L1–2, L2–3, and L3–4 levels. The L4–5 level was difficult to assess because the aorta splits on average 1.8 mm above the disc space into the left and right common iliac arteries, and the IVC exists as the left and right common iliac veins at the disc space. We did, however, discover that in the RLD position, the right common iliac vein moves posteriorly into the surgical corridor an average of 1.5 mm, while in the LLD position, it moves anteriorly 1.4 mm, inhabiting the space anterior to the surgical corridor. The other iliac vessels generally remain anterior to the L4–5 disc space in the lateral position. This supports performing minimally invasive LIF at the L4–5 level with a right-sided approach (Fig. 8).

Movement at L5–S1 was excluded from this study as it is generally inaccessible via the lateral approach due to constraints by the iliac crest and complexity of the lumbosacral plexus. Of note, the psoas muscle did not move in the anterior/posterior or rostral/caudal direction, though it did change shape with lateral positioning. Measurements of kidney movement could also be recorded in 2 dimensions using the spine as a fixed reference. However, movement of the diaphragm during the respiratory cycle may have altered the position of the kidney and skewed measurements between patients, likely most significantly during cranial/caudal measurements.

Supine to LLD Position (right-sided approach)

At all levels studied, the aorta moved less than 2 mm to the left and less than 0.5 mm anteriorly, which is not statistically significant (Fig. 9; Table 1). This is also unlikely to produce any clinical significance as it is moving away from the surgical field. At L1–2, we discovered that the IVC moved 12 mm anteriorly and 10 mm to the left, which is statistically significant ($p = 0.001$). At L2–3 the IVC moved 5 mm anteriorly and 4 mm to the left ($p < 0.006$), and at L3–4 the IVC movement was less than 2

mm ($p < 0.05$). Interestingly, the right kidney moved 20 mm ($p = 0.001$) anteriorly and 5 mm caudally. We can thus conclude that when a right-sided approach is used, aorta movement has very little impact on the surgical corridor, and both the kidney and the IVC were found to move anteriorly and away from the surgical field, more significantly at the more cranial levels.

Supine to RLD Position (left-sided approach)

The aorta moved to a statistically significant extent to the right 2.5 mm, 5.4 mm, and 5.6 mm at L1–2, L2–3, and L3–4, respectively ($p < 0.01$), and 2 mm anteriorly at L1–2 ($p = 0.015$) (Fig. 10; Table 1). This generally places it at less risk since it slides along the anterior border of the anterior longitudinal ligament and away from surgical instruments in a left-sided approach (given that there is no anterior migration of instruments). The IVC shifted at least 5 mm to the right at all levels ($p < 0.02$), approximately 3 mm anteriorly at L1–2 and L2–3, and 1.1 mm posteriorly at L3–4 ($p = 0.11$). In combination with the left kidney moving more than 2 cm ($p < 0.001$) anteriorly, a left-sided approach would seem safe from injury to these structures, putting the aorta at decreased risk at the caudal levels and the vena cava at decreased risk at the more cranial levels.

Although there appears to be no clear conclusion based on these data whether a right- or left-sided approach would be preferable in every case, a few key points may be made. At L1–2 and L2–3, it seems that all relevant structures move anteriorly and are therefore not at risk for violation during the surgical approach. However, at L3–4 the IVC moves slightly posteriorly along the lateral VB with a left-sided approach, thus indicating that a right-sided approach may be less risky at this level. Another important piece of information we discovered is that a left-sided approach at L4–5 may increase the risk of injury to the right common iliac vein, while in an approach from the right the vein moves anteriorly. This may also lead the surgeon to choose a right-sided approach at L4–5. The kidneys on the side of the approach move more than 2 cm anteriorly when the patient is placed in the lateral position and thus should provide no restriction

Positional changes in the lateral approach

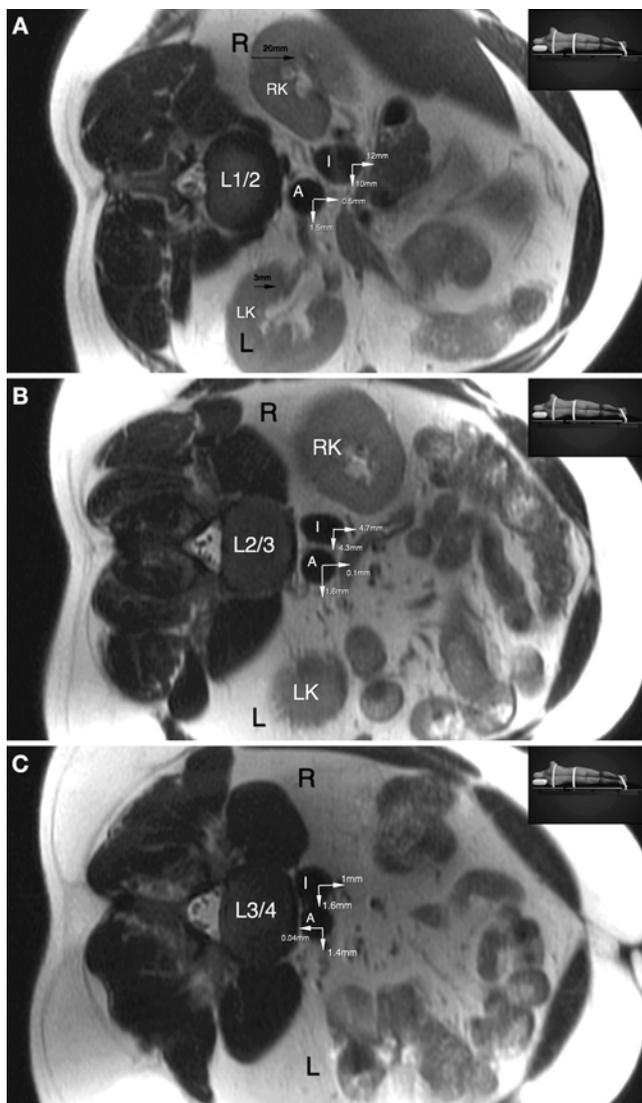


FIG. 9. Axial T2-weighted MR images obtained in the LLD position at L1–2 (A), L2–3 (B), and L3–4 (C). The arrows demonstrate the direction of movement of the aorta (A), IVC (I), and the right and left kidneys (RK and LK). The insets show the patient positioning. Note that all structures moved anteriorly at all levels, except for the aorta at L3–4, where it moved slightly posteriorly (0.04 mm).

on laterality. Each patient should be taken as an individual, however, and this should be a multifactorial decision involving iliac crest height, location of the vessels and organs, and coronal deformity if it exists.

Because this is a pilot study, we believe our sample size of 10 volunteers is adequate for measurement estimations. Though likely to improve measurement accuracy and reproducibility, CT scanning was not an option given the introduction of contrast material and increased radiation to the volunteers. Although the DICOM viewer used is accurate up to a hundredth of a millimeter, imaging biases such as partial volume effects and magnetic inhomogeneities did exist.²² While several millimeters of movement may seem insignificant, in the clinical context a 2-mm shift of critical anatomical structures can poten-

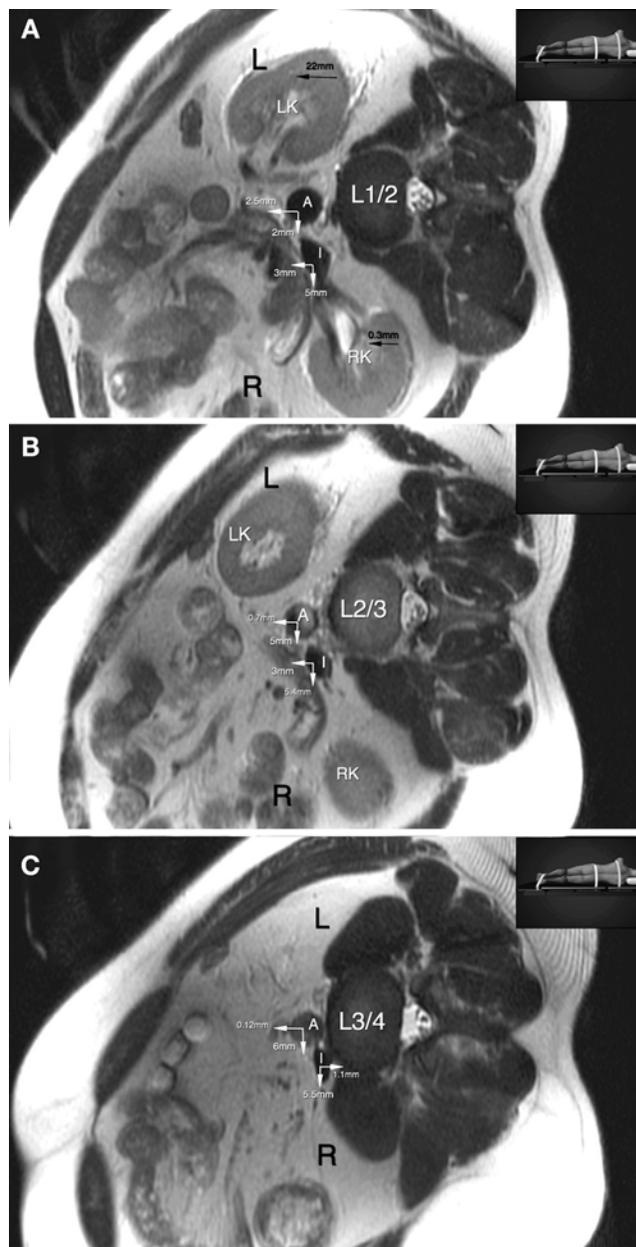


FIG. 10. Axial T2-weighted MR images obtained in the RLD position at L1–2 (A), L2–3 (B), and L3–4 (C). The arrows demonstrate the direction of movement of the aorta, IVC, and the right and left kidneys. The insets show the patient positioning. Note that all structures moved anteriorly at all levels except for the IVC at L3–4, where it moved slightly posteriorly (1.1 mm).

tially turn an uncomplicated approach into a catastrophic complication. Although not the true surgical position, the volunteers were strapped to the MRI table parallel to the suite floor, and then verified with laser beams to standardize the process. We attempted to minimize measurement errors by using 2 analysts. Interrater agreement was excellent with an intraclass correlation coefficient (ICC) greater than 0.996 for the supine, right decubitus, and left decubitus positions (ICC = 0.997, 0.998, and 0.999, respectively). An interesting aspect that warrants further

study is how body habitus may affect abdominal visceral movement. Lastly, imaging technology limits our ability to reliably reconstruct and assess movement of the lumbar plexus; however, MR neurography may solve this problem in the future.³

Conclusions

Movement of abdominal structures with lateral positioning has been hypothesized but never empirically analyzed until now. We show through a morphometric analysis that at L1–2 and L2–3, the aorta and IVC move away from the surgical corridor when the patient is placed in the lateral position, allowing for surgeon preference at these levels. At L3–4 this trend changes with slight posterior movement of the aorta in the LLD position and the IVC in the RLD position. Because the IVC tends to move more than the aorta, we believe a right-sided approach may be safer at this level. A right-sided approach may be favorable as well at L4–5 due to anterior movement of the right common iliac vein, versus posterior movement in a left-sided approach. The kidney on the side of the approach moves more than 2 cm anteriorly and caudally, so it should not be affected by laterality. These are trends in movement, but each operation should be evaluated on a case-by-case basis.

Disclosure

This work was not supported by any external sources of funding. None of the authors have any commercial interest in any of the devices mentioned in the article. Dr. Uribe is a paid consultant for and receives research grants from NuVasive, LLC.

Author contributions to the study and manuscript preparation include the following. Conception and design: Deukmedjian, Uribe. Acquisition of data: Martinez, Uribe. Analysis and interpretation of data: Deukmedjian, Le, Dakwar. Drafting the article: Deukmedjian, Uribe. 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: Deukmedjian. Statistical analysis: Deukmedjian. Administrative/technical/material support: Uribe. Study supervision: Uribe.

Acknowledgments

The authors would like to thank Mark Greenberg, M.D., for his invaluable assistance with photograph editing; Katherine Downes, M.P.H., of the Tampa General Hospital Office of Clinical Research for her assistance with biostatistical analysis; Deborah Scott of the University of South Florida Neurological Surgery Research Department for assisting with the institutional review board application; and Chris Fitzpatrick of Tower Diagnostics for organizing and performing the MRI scans.

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Manuscript submitted January 4, 2012.

Accepted March 1, 2012.

Please include this information when citing this paper: published online March 30, 2012; DOI: 10.3171/2012.3.SPINE1210.

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