Integrated anatomy of the neuromuscular, visceral, vascular, and urinary tissues determined by MRI for a surgical approach to lateral lumbar interbody fusion in the presence or absence of spinal deformity

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Abstract:

Introduction: To comprehensively investigate the anatomy of the neuromuscular, visceral, vascular, and urinary tissues and their general influence on lateral lumbar interbody fusion (LLIF) surgery in the presence or absence of spinal deformity.

Methods: We retrospectively reviewed 100 consecutive surgery cases for lumbar degenerative disease of patients aged on average 70.5 years and of which 67 were women. A sagittal vertical axis deviation of more than 50 mm was defined as adult spinal deformity (ASD: 50 patients). The degenerative disease of the other patients was defined as lumbar spinal stenosis (LSS: 50 patients). We analyzed the relative anatomical position of the psoas major muscle, lumbar plexus, femoral nerves, inferior vena cava, abdominal aorta and its bifurcation, ureter, testicular or ovarian artery, kidney and transverse abdominal muscle in patients with ASD or with LSS, using preoperative magnetic resonance imaging (MRI).

Results: For patients with ASD, the L4-5 intervertebral disk was closer to the lumbar nerve plexus than it was in those with LSS ($p < 0.0001$), and a rising psoas sign at the L4-5 disk was significantly more frequent in patients with ASD than in those with LSS ($p < 0.05$). The aortic bifurcation frequently appeared at the level of L4-5 in patients with either degenerative disease, so the common iliac artery may pass near the disk. The inferior vena cava passed closer to the center of the L4-5 disk in patients with ASD than it did in those with LSS ($p < 0.05$). The transverse abdominal muscle at L2-3, L3-4, and L4-5 was closer to and less than 3 mm from the kidneys in many more patients with ASD than was the case for patients with LSS ($p = 0.3$, $p < 0.05$, $p = 0.29$, respectively).

Conclusions: We recommend careful preoperative MRI to determine the location of organs to help to avoid intraoperative complications during LLIF surgery, especially for patients with ASD.

Keywords:

lateral lumbar interbody fusion, abdominal anatomy, adult spinal deformity, complication, MRI

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Introduction

Lateral lumbar interbody fusion (LLIF) surgery is increasingly used as an alternative to traditional approaches because it is a less invasive surgical technique, characterized by smaller skin incisions, a smaller amount of bleeding, and direct and wide visualization. The lateral retroperitoneal and transpsoas approaches to the intervertebral disk are safe and facilitate quicker access to the target region than traditional anterior transperitoneal or extraperitoneal approaches, thereby avoiding lumbar nerve plexus damage and paravertebral muscular and ligamentous disruption by using a dilator integrated with neuroelectromyographic monitoring[1-3]. Use of a large lordosis cage allows the attainment of a solid and stable intervertebral disk space, providing strong anterior support for interbody distraction and disk height restoration, and achievement of favorable sagittal and coronal physiological curvature after appropriate interbody cage placement in LLIF[4]. In addition, the current procedure results in correction of spondylolisthesis and rotatory deformity, and

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indirect nerve decompression by ligamentotaxis force, especially for the anterior longitudinal ligament[5]. Benefits of LLIF include decreased postoperative pain, shorter hospital stay, and faster return to ordinary daily living. However, several complications peculiar to LLIF have been reported; these complications include damage to blood and lymphatic vessels, nerves, ureters, and viscera, sometimes causing sexual dysfunction, experienced after an anterior approach[1,6-8]. To reduce complications correlated with an extreme lateral approach, careful preoperative anatomical investigation is essential.

During LLIF surgery, the retroperitoneal space is transversed and the psoas major muscle bluntly separated, retracting the muscles and lumbar nerve plexus. The location of the psoas major muscle and the course of the lumbar nerve plexus or nerve roots, bowel, ureters, and vessels are different in each patient, and at each intervertebral disk level. In addition, the relative anatomical locations of these structures are changed in the case of spinal deformity. However, to our knowledge, the relevant anatomy to elucidate the differences resulting from intervertebral disk level and the presence of spinal deformity has not been studied in detail. The purpose of current study was to investigate the anatomy of neuromuscular, visceral, vascular, and ureteral tissues with respect to the LLIF surgical procedure and to clarify anatomical variance in cases of spinal deformity.

Materials and Methods

We retrospectively reviewed 100 consecutive surgical cases of lumbar degenerative disease treated at our university hospital from July 2014 to September 2015. We included a cohort of 67 female and 33 male patients with a mean age of 70.5 (range 53 to 85) years in this study. A sagittal vertical axis (SVA) of less than 50 mm, lumbar lordosis of more than 30°, and a Cobb angle of less than 10° were defined as lumbar spinal stenosis (LSS)[9]. In this study, a SVA of more than 50 mm was defined as adult spinal deformity (ASD)[10]. Surgery for LSS was performed on 50 patients, whereas the other 50 patients underwent surgery for ASD. The grouping was determined independently by two physicians. Patients with previous back surgery, lumbar disk herniation, vertebral fracture, isthmic spondylolisthesis, tumor, or inflammatory diseases were excluded.

Magnetic resonance imaging (MRI) was obtained via a 3 T system (GE Medical Systems, Milwaukee, WI, USA). Preoperative axial T1- and T2-weighted continuous images adjusted to each intervertebral disk space were obtained at 3.5 mm slice intervals. We analyzed the location of the psoas major muscle, lumbar nerve plexus, femoral nerve, and inferior vena cava at the level of the L2-3, L3-4, and L4-5 disks according to Kepler's method[11]. In addition, we analyzed the relative locations of the abdominal aorta and its bifurcation, testicular or ovarian arteries, kidneys, and transverse abdominal muscle. We determined the anterior-to-posterior diameter of the psoas major muscle, and the distance from the anterior edge of the psoas major, anterior aspect of the lumbar nerve plexus, anterior aspect of the femoral nerve, posterior edge of the inferior vena cava, ureter, and testicular or ovarian artery to the anterior edge of the disks, the distance from the abdominal aorta to the lateral aspect of the disks, the tendency of bifurcation of the aorta, and the distance from the posterior edge of the kidneys to the anterior edge of the transverse abdominal muscle.

Statistical analysis

Data were analyzed using a two-sided Student *t* test or Fisher exact test to determine significant differences. All statistical calculations were performed using Prism version 4.0 (Graph Pad Software, La Jolla, CA, USA). For all tests, $p < 0.05$ was considered statistically significant.

Results

Distribution of the psoas major muscle

There was no significant difference in the anterior-to-posterior diameter of the psoas major muscle between patients with ASD or with LSS. The anterior edge of the muscle was located significantly more forward of the anterior edge of the L3-4 and L4-5 disks in patients with ASD than it was in patients with LSS ($p < 0.05$; Fig. 1A). A rising psoas sign, which was defined as a more than 10 mm anterior position of the anterior edge of the psoas major from the anterior edge of the L4-5 disk, was significantly more frequent in patients with ASD than in those with LSS ($p < 0.05$; Fig. 1B).

Location of the lumbar nerve plexus and the femoral nerve

The distance from the anterior aspect of the lumbar nerve plexus to the anterior edge of the disk was significantly greater in patients with LSS than in those with ASD (L2-3: $p < 0.005$, L3-4: $p < 0.05$, L4-5: $p < 0.0001$; Fig. 2A). The distance from the anterior aspect of the femoral nerve to the anterior edge of the L3-4 disk and to the L4-5 disk was also significantly greater in patients with LSS than in those with ASD (L3-4: $p < 0.0005$, L4-5: $p < 0.0001$; Fig. 2B).

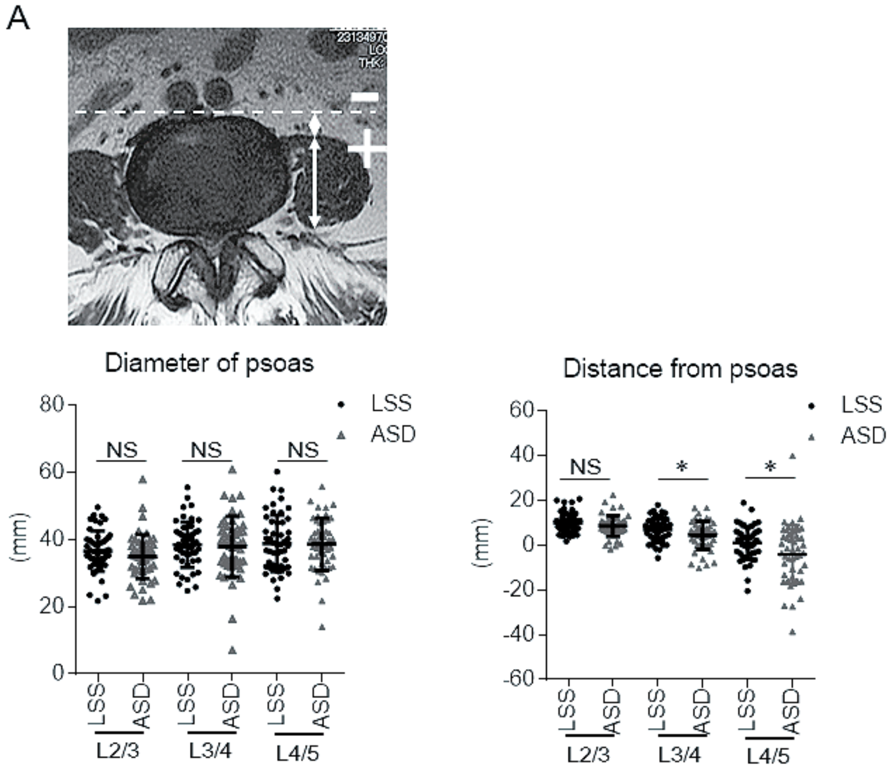
Location of the aorta

The distance from the abdominal aorta to the lateral aspect of the L4-5 disk was significantly greater in patients with ASD than in those with LSS ($p < 0.05$), whereas there was no significant difference in the distance for L2-3 or L3-4 (Fig. 3A). There was no occurrence of aortic bifurcation at L3-4, whereas the bifurcation appeared frequently at L4-5 in patients with either disorder (LSS 60%, ASD 60%).

Location of the inferior vena cava

The distance from the posterior edge of the inferior vena cava to the anterior edge of the L4-5 disk was significantly greater in patients with ASD than in those with LSS (Fig. 3 B). However, there were significantly more cases of ASD

A



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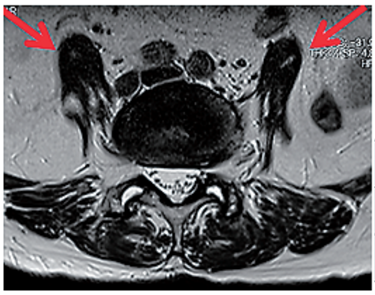

%	L2/3	L3/4	L4/5
LSS	0	0	4
ASD	0	6	26*

Figure 1.
A: The diameter and relative location of the psoas major muscle at the levels of the L2-3, L3-4, and L4-5 disks were analyzed according to Kepler's method using preoperative axial T1- and T2-weighted continuous magnetic resonance imaging. There was no significant difference in the anterior-to-posterior diameter of the psoas major muscle between patients with ASD or with LSS. The anterior edge of the psoas major was located significantly more forward of the anterior edge of the L3-4 and L4-5 disks in patients with ASD than in those with LSS.
B: A rising psoas sign, defined as where the anterior edge of the psoas major was more than 10 mm anterior of the anterior edge of the disk, was found significantly more frequently at L4-5 ($p<0.05$) in patients with ASD than in those with LSS.

than of LSS for which the distance was greater than 10 mm at L3-4 (LSS 10%, ASD 20%: $p < 0.05$) and at L4-5 (LSS 8%, ASD 30%: $p < 0.05$).

Location of the ureter and testicular or ovarian artery

The distance from the ureter to the anterior edge of the disk was not significantly different between patients with ASD or with LSS at the level of L2-3, L3-4, or L4-5 (Fig. 4). The distance from the testicular or ovarian artery to the anterior edge of the disk was not significantly different between patients with ASD or with LSS at either L3-4 or L4-5 (Fig. 4).

Location of the kidney

The distance from the posterior edge of the kidney to the anterior edge of the transverse abdominal muscle was not significantly different between patients with ASD or with LSS at the level of the L2-3, L3-4, or L4-5 disk (Fig. 5).

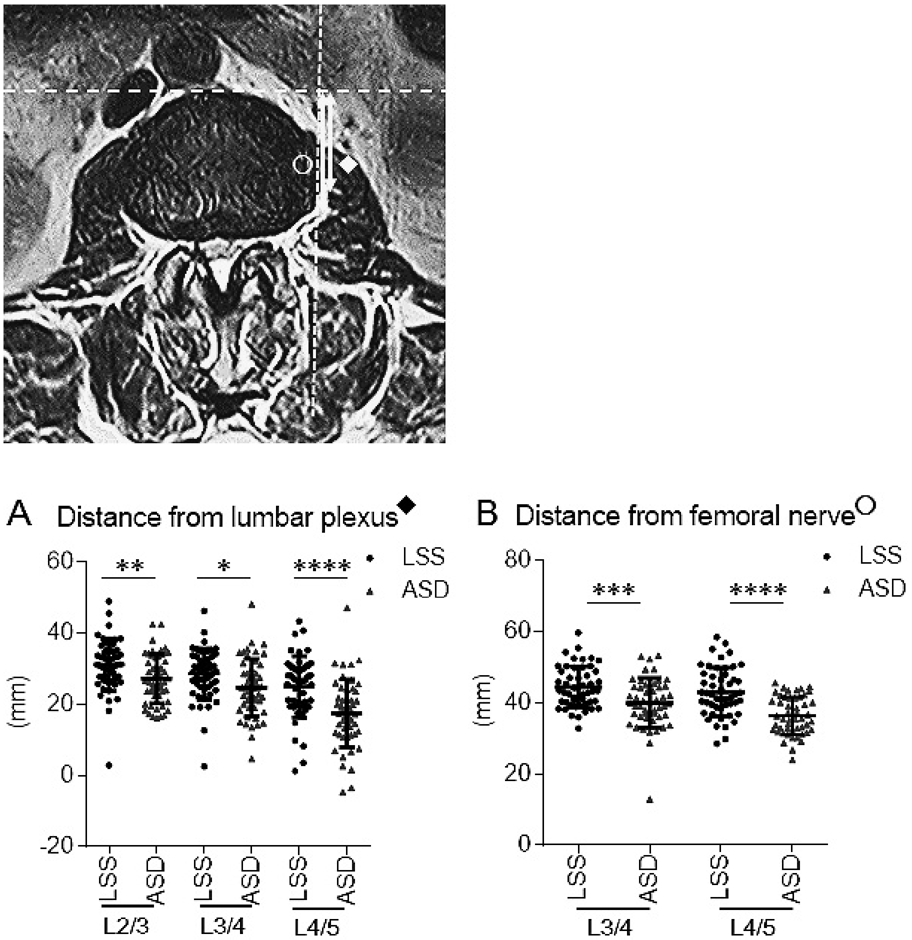

Figure 2. The locations of the lumbar nerve plexus and femoral nerve in patients with lumbar spinal stenosis (LSS) or with adult spinal deformity (ASD).

A: The distance from the anterior aspect of the nerve plexus (diamond) to the anterior edge of the disk was significantly greater at the levels of L2-3 ($p<0.005$), L3-4 ($p<0.05$), and L4-5 ($p<0.0001$) in patients with LSS than in those with ASD.

B: The distance from the anterior aspect of the femoral nerve (circle) to the anterior edge of the disk was significantly greater at L3-4 ($p<0.0005$) and L4-5 ($p<0.0001$) in patients with LSS than in those with ASD.

However, there were significantly more cases of ASD than of LSS for which the distance was greater than 3 mm at L2-3 (LSS 30%, ASD 50%: $p = 0.03$), at L3-4 (LSS 22%, ASD 32%: $p < 0.05$), and at L4-5 (LSS 12%, ASD 20%: $p = 0.03$).

Discussion

Reported complications for the LLIF procedure are reoperation at 1.8%, neural deficits at 7%, and total incidents at 6.7% in 600 patients[8)]. Another report presented a complication rate of 35.1% for LLIF surgery for 160 patients[12)]. Precise anatomical knowledge is essential to avoid intra- and postoperative complications.

Anatomical relationships between the lumbar nerve plexus and major blood vessels, lumbar psoas major muscle and abdominal large vessels, and lumbar psoas major muscle and lumbar nerve plexus as related to LLIF procedures have been investigated separately[11,13-15)]. Cadaveric study revealed that all parts of the lumbar nerve plexus are located from the dorsal quarter of the L4 vertebral body and dorsally at the level of L2-3 and above. The genitofemoral nerve descends obliquely forward through the psoas major muscle, emerging on the abdominal surface between the cranial third of the L3 vertebra and the caudal third of the L4 vertebra[14)]. The safety zone to avoid nerve injury was considered to be L4-5 and above. Another study examined the course of the lumbar nerve plexus using magnetic resonance neurography (MRN) in 35 patients. MRN imaging clearly showed the lumbar nerve plexus at the dorsal half of L4-5 on the left and right sides[16)].

However, a general and comprehensive anatomical investigation including muscles, blood vessels, nerve plexus, femoral nerve, and kidney together has not been reported. In addition, the relative anatomical locations of these structures may vary and be located unusually in the case of spinal de-

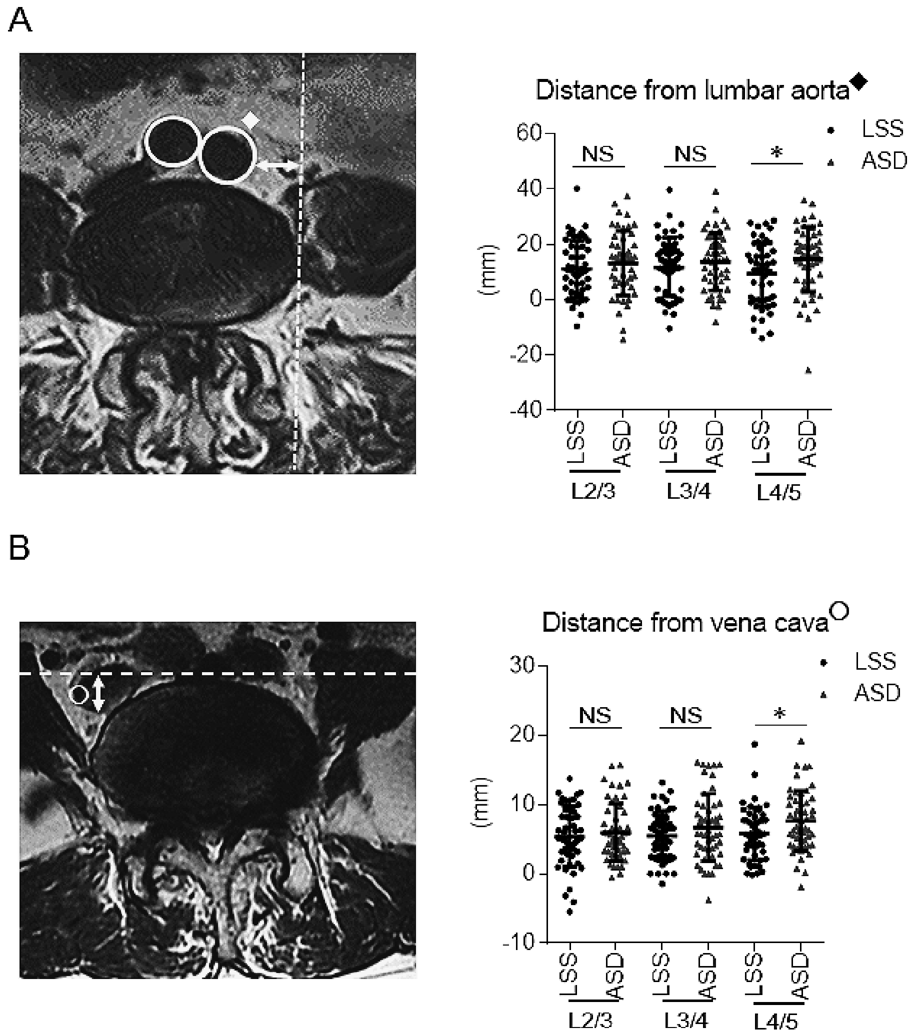

Figure 3. The relative locations of the lumbar aorta and vena cava in patients with lumbar spinal stenosis (LSS) or with adult spinal deformity (ASD).
A: The distance from the abdominal aorta (diamond) to the lateral aspect of the disk was significantly greater at the level of L4-5 ($p<0.05$) in patients with ASD than in those with LSS, whereas no significant difference was found for L2-3 or L3-4.
B: The distance from the posterior edge of the inferior vena cava (circle) to the anterior edge of the L4-5 disk was significantly greater in patients with ASD than in those with LSS ($p<0.05$).

formity. To our knowledge, the present study is the first to compare the relative location of tissues and organs in the presence or absence of spinal deformity.

Patients showing a rising psoas sign may be susceptible to nerve impairment, including that to the lumbar nerve plexus and femoral nerve, especially at the level of the L4-5 disk[17]. We found the anterior-to-posterior diameter of the psoas major muscle for the ASD and LSS groups was not significantly different, whereas the rising psoas sign was significantly more frequent in patients with ASD than in those with LSS at the level of the L4-5 disk. The distance from the anterior edge of the psoas major to the anterior edge of the disk, which is the working space in LLIF procedures, was significantly shorter in patients with ASD than in those with LSS. The distance from the anterior edge of the disk to the lumbar plexus at L2-3, L3-4, or L4-5 or the femoral nerve at L3-4 or L4-5 was significantly less in patients with ASD than in those with LSS. Therefore, patients with ASD may be more susceptible to nerve complications than those with LSS. It was difficult to specify the location of the genitofemoral nerve from preoperative imaging.

In the present study, we found no significant difference in the distance from the abdominal aorta to the lateral aspect of the disk, which is the working space in LLIF procedures, between patients with LSS and those with ASD at the level of L2-3 and L3-4, whereas it was significantly closer in those with LSS at the level of L4-5. There was no significant difference in the location of the bifurcation of the abdominal aorta between patients with either disorder. Intraoperative vascular injury to the iliac artery and postoperative thromboembolic events as complications of anterior lumbar interbody fusion (ALIF) have been reported[18,19]. There was a

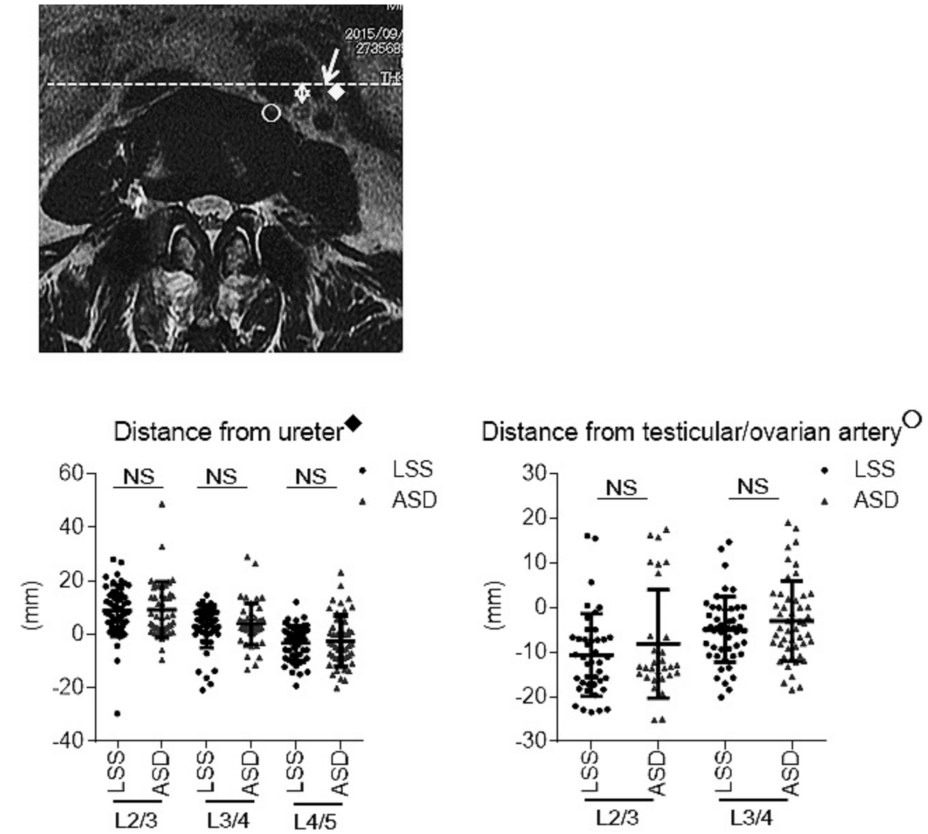

Figure 4. The relative locations of the ureter (diamond) and the testicular or ovarian artery (circle) in patients with lumbar spinal stenosis (LSS) or with adult spinal deformity (ASD).

A: The distance from the ureter to the anterior edge of the disk was not significantly different between patients with ASD or with LSS at the level of L2-3, L3-4, or L4-5.

B: The distance from the testicular or ovarian artery to the anterior edge of the disk was not significantly different between patients with ASD or with LSS at L3-4 or at L4-5.

tendency for major vascular injury during the anterior approach of 0% to 15.6%, most frequently at L4-5[20-23]. One case of LLIF-surgery-related perforation of the aorta required emergency laparotomy and vascular suture repair[24]. Many cases of anomalies of the aorta, including the location of the bifurcation, have been reported[24,25]. In the present study, the bifurcation appeared frequently at the level of the L4-5 disk in patients with either LSS or ASD, so the common iliac artery may run near the disk. Taken together, preoperative imaging is essential to identify the location and course of the aorta, the location of its bifurcation, and the location of the more caudally located common iliac artery, to avoid lethal intraoperative vascular injury.

More common than arterial injuries are venous injuries when mobilizing or retracting veins and exposing the lumbar spine anteriorly[26,27]. In addition, vascular variations in veins, including the iliolumbar vein, were found in more than 25% of patients undergoing anterior lumbar surgery[23]. Other venous anomalies, including a duplicated inferior vena cava in the retroperitoneum, have been reported and can result in both misdiagnosis and surgical complications[28]. An anatomical study of the LLIF approach using a cadaver revealed the distribution of the right common iliac vein at L4-5 and presence of aberrant veins traversing disk space and suggested vertically running vascular anastomoses[29]. Imaging analysis using 3D computed tomography (CT) identified the location of the major artery and vein at L3-4 and L4-5 and revealed location differences according to sex[30]. The present study showed that the distance from the posterior edge of the inferior vena cava to the anterior edge of the L4-5 disk was significantly greater in patients with ASD than in those with LSS. In patients with ASD, this distance at L3-4 and L4-5 was more often greater than 10 mm than it was in patients with LSS. The course of the inferior vena cava in patients with ASD was nearer the center of the disk at L3-4 and L4-5, thereby providing a narrower working space for LLIF, than it was in patients with LSS. Therefore, we strongly recommend preoperative imaging to avoid critical venous accidents in patients with ASD.

There are some reports of the presence of urinary tract anomalies in patients undergoing surgery[1,32]. When approaching to the pararenal space, there is a possibility of injuring the external membrane of the urinary tract. The present study demonstrated no significance difference in the course of the ureter for patients with ASD or with LSS.

Intraoperative colonic injury during percutaneous neph-

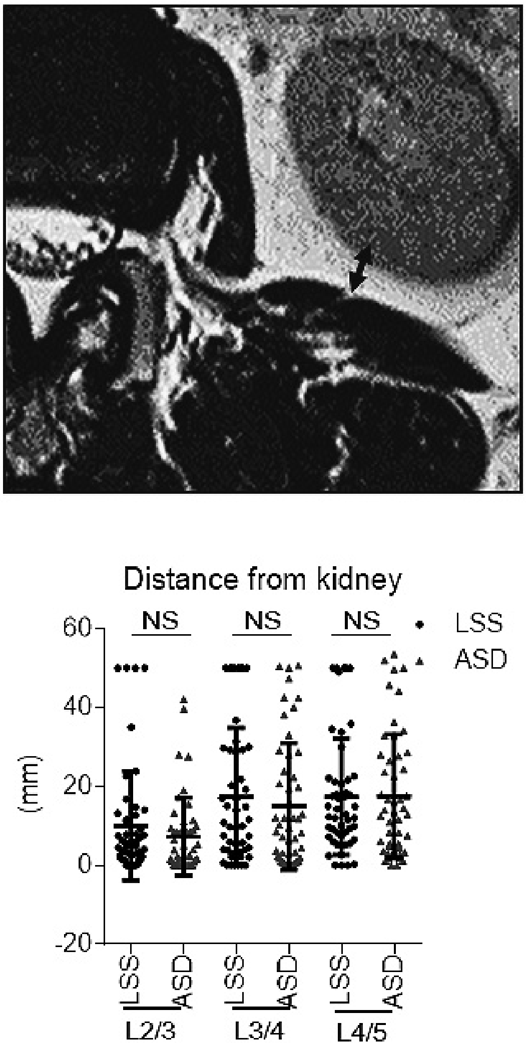

Figure 5. The relative location of the kidney in patients with lumbar spinal stenosis (LSS) or with adult spinal deformity (ASD).
The distance from the posterior edge of the kidney to the anterior edge of the transverse abdominal muscle at the level of the L2-3, L3-4, or L4-5 disk was not significantly different between patients with ASD or with LSS.

rolithotomy (PNL), a common procedure for patients with renal calculi, has been reported[33,34]. Among 804 patients who underwent PNL, 394 with abdominal CT images were retrospectively reviewed. The retrorenal colon positioning was such that the ascending or descending colon was located between the posterolateral border of the psoas major muscle and the kidney in 27 cases (6.9%), including 18 (4.6%) on the left side, 4 (1.0%) on the right side, and 5 (1.3%) on both sides. Colonic perforation injuries were seen in 2 cases (0.3%)[35]. The percutaneous procedures around the inferior pole of the kidney in PNL may result in retrorenal colon injury. A retrorenal colon accompanied by advanced scoliosis (a Cobb angle over 45°) was found in 25 of 100 patients. Only 7 cases (3.5%) were found in 200 control patients without scoliosis. Patients with advanced scoliosis demonstrate a significant increase in the frequency of renal colon[36]. In the present study, there were significantly more patients with ASD than with LSS in whom the distance from the posterior edge of kidney to the anterior edge of transverse abdominal muscle was greater than 3 mm. There were many more patients with ASD in whom the transverse abdominal muscle was nearer the kidney at the level of the L2-3, L3-4, and L4-5 disk than was the case for patients with LSS. Complications of bowel injury after LLIF surgery at L3-4 and L4-5 have been reported[1]. Older patients with a low BMI favorably show the existence of a retrorenal colon, possibly because of low adipose tissue content in the retroperitoneal space[13,15,16]. In these circumstances, it is more difficult for the bowel to move ventrally and easier to approach the anterior pararenal extraperitoneal space.

A previous study involving 10 healthy, skeletally mature, adult volunteers used MRI to examine the positional changes in the aorta, inferior vena cava, and kidneys at different lumbar levels when the participants moved from a supine to the right or left lateral decubitus position. The aorta, inferior vena cava, and kidneys moved significantly with the change in surgical approach from a supine to the lateral position. In addition, a right-sided approach may be favorable at the L4-5 disk level because of anterior movement of the right common iliac vein. Therefore, further investigation is required to detail the movement of tissues accurately and precisely when patients are moved from a supine to the actual surgical position[37].

Limitations of this study include the variation in the criteria applied to define ASD and LSS. ASD was defined only by the SVA, and it included various kinds of spinal deformities such as idiopathic scoliosis, degenerative scoliosis, and lumbar degenerative kyphosis. LSS was defined by SVA, lumbar lordosis, and Cobb angle. In addition, this study was based on MRI conducted with the patient in a supine position; however, patients undergoing LLIF are arranged in a lateral decubitus position. The current study included only a small sample and so it was not possible to compare our findings with consideration of the different sexes and ages of the patients.

LLIF is promising as a less invasive surgery, and it can attain a solid intervertebral disk space, strong anterior support, and physiological curvature. However, detailed and extensive preoperative anatomical knowledge is essential to avoid complications during LLIF surgery, especially for patients with ASD.

Conflicts of Interest: The authors declare that there are no conflicts of interest.

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