

Assessment of Ureters at Dangerous Locations in Lateral Lumbar Interbody Fusion

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Abstract:

Introduction: This study aimed to investigate the ureteral running position from the viewpoint of the spine, and to identify the spinal level and left-right difference in the ureter at a dangerous location of ureteral injury during surgery.

Methods: This retrospective study included 100 consecutive patients (39 males and 61 females; average age, 70.4 years). Preoperative contrast-enhanced computerized tomography (CT) scans obtained in the supine position for patients who underwent lateral lumbar interbody fusion (LLIF) were analyzed. The ureter location was divided into four regions on the axial CT images based on the lumbar disk levels as follows: A (ventral-medial), B (ventral-lateral), C (dorsal-medial), and D (dorsal-lateral). The C region surrounded by the vertebral body and the psoas muscle was assumed to have the highest probability of ureteral injury. We examined the characteristics of the ureteral position at each disc level.

Results: In the upper lumbar spine, the ureter was outside the lateral dorsoventral axis from the contact point of the psoas muscle, while in the lower lumbar spine, it was inside the axis. The ureters located in the C region increased significantly in the lower lumbar disk levels (L1-L2 and L2-L3: 0%; L3-L4: 5.5%; L4-L5: 14.8%; L5-S: 31.5%). Comparing the left and right sides, especially at L4-L5, the ureter in the C region was observed in 21% of all ureters on the left side and in 9% on the right side. With respect to gender differences, the ureters present in the C region were significantly more common in women at lumbar disk levels L3-L4, L4-L5, and L5-S.

Conclusions: The ureters in the C region were common on the left side and at lower lumbar disk levels. To avoid ureteral injury, it is necessary to confirm the location of the ureter by using preoperative images and performing LLIF carefully.

Keywords:

ureter, lateral lumbar interbody fusion, lower lumbar disk levels

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Introduction

Lateral lumbar interbody fusion (LLIF) is a minimally invasive surgical technique used in managing lumbar spondylolisthesis and adult spinal deformity¹⁻⁴⁾. LLIF is performed retroperitoneally while in the lateral decubitus position^{5,6)}. In XLIF (Extreme lateral interbody fusion), we split the psoas muscle to reach the disk space, while oblique lateral interbody fusion (OLIF) involves access to the disk space via a corridor between the peritoneum and the psoas muscle. LLIF has various advantages, such as direct visualization of the disk space, greater indirect spinal cord decompression,

and restoration of disk height⁷⁾. However, there are reports of retroperitoneal organ damage, including nerve roots, blood vessels, intestinal tract, and ureters in LLIF surgery⁸⁾.

Ureteral injury was reported at a frequency of approximately 0.1%-0.3%⁸⁾. This rate of ureteral injury is not high; however, it is a serious type of injury⁹⁻¹¹⁾. Kubota et al. reported ureteral injury identified because of abdominal pain beginning on day two postsurgery, and permanent stent placement was required⁹⁾. Despite ureteral injury can cause serious complications for patients, limited research has been conducted on the anatomical risk of ureteral injury; moreover, little is known on the ureteral anatomical position. The

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ureter runs close to the iliopsoas muscle; however, the running position is different on the spinal level and the left-right sides. Understanding the relationship between the ureter, the vertebral body, and the psoas muscle can help spine surgeons to reduce the risk of ureteral injury.

Of the various anatomical ureteral positions, that between the vertebral body and the iliopsoas muscle is difficult to determine during surgical procedures in the retroperitoneal space (Fig. 1). There is a risk of ureteral injury in such cases if the ureter is not sufficiently separated from the psoas muscle. This study aimed to investigate the anatomical position of the ureter from the viewpoint of the spine, and to identify the spinal level and left-right difference in the ureter at a critical location of ureteral injury.

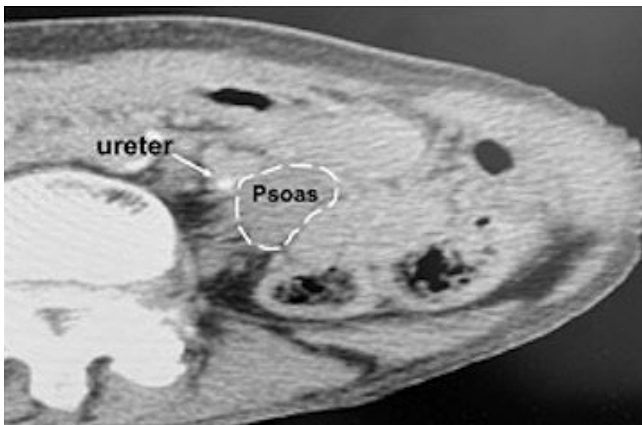


Figure 1. The ureter between the vertebral body and iliopsoas muscle.

Materials and Methods

With the approval of our Ethics Committee, we reviewed data of patients who underwent LLIF in our hospital from April 2016 to August 2018. The exclusion criteria were patients with renal dysfunction or allergies to the contrast used for computed tomography (CT). A total of 100 consecutive patients (male/female: 39/61, average age = 70.4 ± 8.4 years old) who were planned to undergo LLIF were retrospectively analyzed. The primary diseases were degenerative spondylolisthesis, degenerative scoliosis, and others in 47, 34, and 19 cases, respectively.

Classification of ureteral location

A 64-line multi-slice CT (Light Speed VCT; GE Healthcare Bio-Sciences, Piscataway, NJ, USA) was used, and the ureteral location at each disk level (L1-L2, L2-L3, L3-L4, L4-L5 and L5-S) was evaluated using contrast-enhanced CT. The ureter was evaluated in the excretory phase (4-5 minutes after contrast administration). We used either iohexol or iopamidol as intravenous contrast material, depending on body weight (600 mg L/kg). The acquisition parameters were as follows: tube voltage, 120 kV; tube current, 120-700 mA; SD, 14.58; and helical pitch, 1.375 mm. We also evaluated blood vessels (aorta, inferior vena cava, and gonadal arterioles). Vascular evaluations were performed in the arterial and venous phases. The ureteral positions were divided into the following four regions in the axial CT images: A, dorsal-medial side; B, dorsal-lateral side; C, ventral-medial

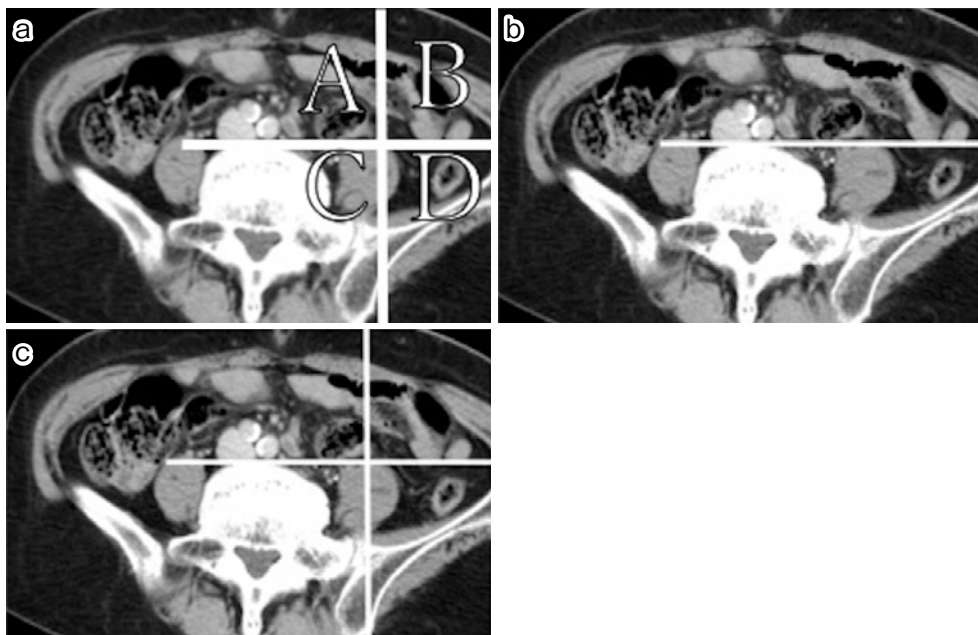


Figure 2. Classification of ureteral running location.

a A tangent line drawn from the ventral side of the lumbar disk to the psoas muscle.

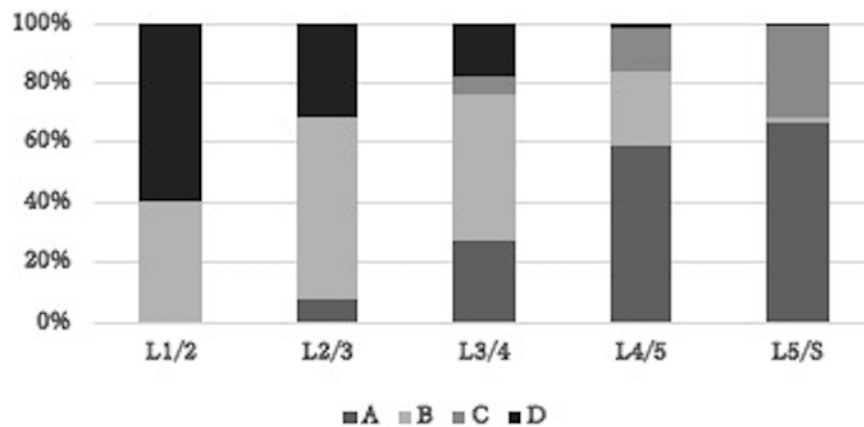
b Line drawn parallel to the dorsoventral axis from the contact point of the psoas muscle.

c Divided the region where the ureter run into four regions: A: dorsal medial side, B: dorsal lateral side, C: ventral medial side, D: ventral lateral side.

Table 1. Number of Ureters in Each Intervertebral Level.

	L1/2	L2/3	L3/4	L4/5	L5/S
A	0	14 (7.6)	52 (26.1)	113 (57.7)	122 (66.3)
B	19 (40.4)	111 (60.3)	100 (50.3)	51 (26.0)	3 (1.6)
C	0	0	11 (5.5)	29 (14.8)	58 (31.5)
D	28 (59.6)	59 (32.1)	36 (18.1)	3 (1.5)	1 (0.5)

Each table box shows a patient number (%).

**Figure 3.** Proportion of ureters in each intervertebral position.

side; and D, ventral-lateral side (Fig. 2a). To divide into four regions, a tangent line was drawn from the ventral side of the lumbar disk to the psoas muscle (Fig. 2b). Another line was drawn parallel to the dorsoventral axis from the point of contact with the psoas muscle (Fig. 2c). The ureter in the C region is surrounded by the vertebral body and the psoas muscle. It is perceived as being in the most dangerous anatomical position for a ureteral injury.

Statistical analysis

Each variable was reported as the mean \pm standard deviation. Fisher's exact test was used to analyze data to determine significant differences. All statistical analyses were performed using the Easy R (EZR) software (Saitama Medical Center, Jichi Medical University)¹². A P-value $<$ 0.05 was considered statistically significant.

Results

The spinal parameters of the subjects were as follows: lumbar lordosis = $24.0^\circ \pm 10.1^\circ$; pelvic incidence = $48.0^\circ \pm 10.0^\circ$; pelvic tilt = $30.1^\circ \pm 30.9^\circ$; and sacral slope = $24.0^\circ \pm 9.9^\circ$. In the actual surgery, there were no cases of ureteral injury secondary to intraoperative complications at our hospital.

Difference in lumbar disk level

At the upper lumbar disk levels (L1-L2, L2-L3), most of the ureters were located outside the lateral dorsoventral axis from the contact point of the psoas muscle (B and D regions). At L1-L2, all (100%) the ureters were in the B and

D regions. L2-L3 contained 92% of the ureters. There were 19 (40%) and 111 (60%) ureters in the B region at L1-L2 and L2-L3, respectively. Similarly, there were 28 (60%) and 59 (32%) ureters at the D region at L1-L2 and L2-L3, respectively. On the other hand, the ureters were located inside the axis (A and C regions) at the lower lumbar disk levels (L3-L4, L4-L5, L5-S). In particular in the lower lumbar areas, the greater proportion of ureters located in the C region were surrounded by the vertebral body and psoas muscle: L3-L4: 11 (6%); L4-L5: 29 (15%); and L5-S: 57 (32%) (Table 1, Fig. 3).

Left-right difference

Regarding left-right difference, the ureters in the A region were significantly more frequent on the right side compared to the left side at L4-L5 and L5-S ($P <$ 0.01). However, the ureter in the C region on the left side was significantly two times more abundant than that on the right side. (Fig. 4). Especially at L4-L5, the ureter in the C region was observed in 21% of the cases on the left side and in 9% on the right side ($P = 0.046$) (Table 2).

Gender difference

Regarding gender differences, the ureters present in the C region were significantly more common in women at the lumbar disk levels L3-L4, L4-L5, and L5-S (Table 3).

Spinal parameters and intervertebral levels

We examined the relationship between the ureteral regions and spinal parameters. Overall, the C region showed significantly larger PT and PI and smaller SS than the other re-

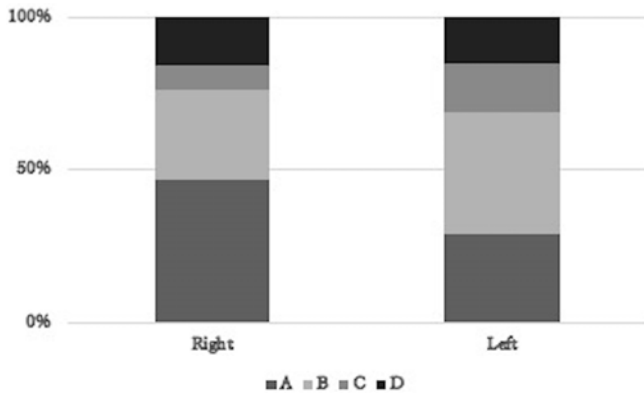


Figure 4. Proportion of ureters on the left and right side in all intervertebral levels.

Table 2. Proportion of Ureters on the Left and Right Side in Each Intervertebral Level.

	Left	Right	P-value
L1-L2			
A	0	0	n.s
B	15 (46.9)	4 (26.7)	n.s
C	0	0	n.s
D	17 (53.1)	11 (73.3)	n.s
L2-L3			
A	3 (3.1)	11 (12.8)	n.s
B	66 (67.3)	45 (52.3)	n.s
C	0	0	n.s
D	29 (29.6)	30 (34.9)	n.s
L3-L4			
A	21 (21.2)	31 (31.0)	n.s
B	57 (57.6)	43 (43.0)	<0.05
C	7 (7.1)	4 (4.0)	n.s
D	14 (14.1)	22 (22.0)	n.s
L4-L5			
A	45 (46.4)	68 (68.7)	<0.01
B	29 (29.9)	22 (22.2)	n.s
C	20 (20.6)	9 (9.1)	0.05
D	3 (3.1)	0	n.s
L5/S			
A	49 (53.3)	73 (79.3)	<0.01
B	2 (2.2)	1 (1.1)	n.s
C	40 (43.5)	18 (19.6)	<0.01
D	1 (1.1)	0	n.s

Each table box shows a patient number (%).

gions (Table 4). We also analyzed the relationship between the spinal parameters and the intervertebral levels. The ureter in the C region had a larger PT at L4-L5 and L5-S (Table 5).

Discussion

In the current study, the position of the ureter was significantly different depending on the lumbar disk level and laterality. In the upper lumbar spine, the ureter was outside the

Table 3. Relationship Between the Number of Ureters in the C Region and Gender Difference at Each Intervertebral Level.

	Men	Women	P-value
L3-L4	1 (1.2)	10 (8.3)	0.04
L4-L5	4 (5.1)	25 (21.2)	<0.01
L5-LS	15 (20.0)	58 (53.2)	<0.01

Each table box shows a patient number (%).

lateral dorsoventral axis from the contact point of the psoas muscle (B and D regions), while in the lower lumbar spine it was inside the axis (A and C regions) (Fig. 2c). Of the ureters located inside the psoas major muscle, some were found between the vertebral body and the psoas muscle, especially at the L4-L5 level. Regarding laterality, the proportion of ureters in the dangerous C region on the left was 21%. Concerning gender, ureters in the C region were more frequent in women in all intervertebral disks. When performing XLIF on L4-L5 from the left side in women, the position of the ureter has to be carefully evaluated before surgery. Also, the retroperitoneal space must be gently exposed, especially between the psoas muscle and the vertebral body.

The retroperitoneum is divided by fascial planes into precisely three compartments as follows: the anterior and posterior pararenal spaces and the perirenal space. The posterior pararenal space is confined by the anterior renal fascia (Gerota fascia) and posterior renal fascia (Zuckerkindl fascia). The kidneys and proximal ureters lie in the posterior pararenal space¹³. In adults, the ureter is 25-30-cm long with a diameter of 1.5-6 mm. In the retroperitoneum, the ureter is located just lateral to the tips of the transverse processes of the lumbar vertebrae. At the beginning of the pelvic inlet, it crosses the common iliac vessels. Finally, the ureter runs caudally to the bladder¹⁵. From a lateral perspective, the ureter crosses the posterior third of the upper lumbar vertebrae, approaches the middle third at L3, and reaches the anterior third at L4-L5 before descending into the pelvis¹⁶. In summary, the ureter from the kidney is initially located on the outside and gradually moves inward into the bladder. In this study, the ureter was present outside the lateral dorsoventral axis from the contact point of the psoas muscle in the upper lumbar spine (L1-L2 and L2-L3), and the proportion inside the dorsoventral axis increased with the lower lumbar spine (L3-L4 and L4-L5).

Ureteral injury was reported with a frequency of approximately 0.3%⁸. Abe et al. reported one ureteral injury in 155 patients who underwent OLIF at 11 institutions¹⁷. In the experiences of surgeons who actually injured the ureter, the ureteral injury was often unnoticed during the operation. In many cases, the damage was revealed by the appearance of symptoms after surgery. Since the ureter is attached to the retroperitoneum, it may be visually confirmed if it is delaminated; however, the damaged ureter may be in a position

Table 4. Relationship Between the Zone of the Ureter and the Spinal Parameters.

Factor	A	B	C	D	P-value
n	301	284	98	127	
Age	70.4±8.6	70.9±8.2	71.1±8.4	68.7±8.6	0.08
Cobb angle	8.2±13.4	7.1±13.0	10.8±14.3	7.3±14.3	0.12
LL	31.7±37.6	29.7±22.0	29.0±42.6	29.7±15.2	0.82
PI	47.5±10.0	47.1±9.6	51.4±9.6	49.3±10.6	<0.01
PT	23.6±10.0	22.6±9.8	29.2±10.6	23.2±9.1	<0.01
SS	23.7±9.9	24.5±9.6	21.9±10.1	26.0±9.6	0.01

mean±SD, LL: Lumber Lordosis, PI: Pelvic Incidence, PT: Pelvic Tilt, SS: Sacral Slope

Table 5. Relationship Between the Zone of the Ureter and Lumbar Parameters in Each Intervertebral Level.

L3-L4	Left			Right		
	C	Others	P-value	C	Others	P-value
n	7	93		4	96	
Age	73.3±5.5	70.2±8.6	0.35	73.5±6.5	70.3±8.5	0.46
Cobb angle	6.4±8.4	8.3±14.0	0.73	12.8±9.5	8.0±13.8	0.50
LL	21.3±22.2	27.9±15.5	0.29	15.2±27.2	28.0±15.4	0.12
PI	50.0±6.5	47.9±10.2	0.59	51.8±5.5	47.9±10.1	0.45
PT	31.6±10.2	23.4±10.0	0.04	32.5±13.7	23.6±9.9	0.09
SS	18.4±7.1	24.4±10.1	0.13	19.3±9.7	24.1±10.0	0.34
L4-L5						
n	20	80		9	91	
Age	69.9±10.6	70.5±7.9	0.75	74.2±4.8	70.0±8.6	0.16
Cobb angle	13.2±18.3	7.0±12.1	0.07	12.3±10.5	7.8±14.0	0.34
LL	22.5±19.5	28.7±14.9	0.13	16.4±15.4	28.6±15.7	0.03
PI	50.5±9.0	47.4±10.2	0.23	51.0±6.3	47.7±10.3	0.36
PT	29.0±10.6	22.8±9.7	0.02	33.2±8.2	23.0±9.9	<0.01
SS	20.9±10.8	24.7±9.7	0.14	17.8±7.2	24.5±10.0	0.05
L5/S						
n	40	60		18	82	
Age	70.6±8.6	70.3±8.4	0.87	70.4±8.2	70.4±8.5	0.98
Cobb angle	9.8±13.5	7.1±13.8	0.33	10.7±16.3	7.7±13.1	0.40
LL	27.8±17.5	27.2±15.1	0.84	21.7±17.5	28.7±15.5	0.09
PI	52.4±10.8	45.2±8.5	<0.01	50.8±11.3	47.5±9.7	0.21
PT	26.9±10.9	22.1±9.3	0.02	30.7±10.9	22.6±9.5	<0.01
SS	25.1±10.5	23.2±9.6	0.34	19.6±9.8	24.9±9.8	0.04

mean±SD, LL: Lumber Lordosis, PI: Pelvic Incidence, PT: Pelvic Tilt, SS: Sacral Slope

that is difficult to visually confirm. In particular, a ureter found between the psoas major muscle and the vertebral body (C region) is the most obscure in the surgical field compared to those found in other regions. It is actually difficult to confirm the position of ureter. As such, we considered that there was a high risk of ureteral injury in the C region. The ureter often moves ventrally along with the renal fascia by firmly delaminating the front of the psoas major muscle in the posterior pararenal spaces. However, it should be noted that ureters may attach to the ventral edge of the psoas major muscle because of the delaminating method or fascia adhesion. Taking this into account, the ureter in the C region is considered to have a high potential risk of injury.

LLIF is often performed from the left side, and also frequently at L4-5. In this study, the C region was significantly

present in the lower lumbar spine L4-L5. Additionally, the laterality was significantly left-sided (L4-L5 left: 21%). Anatomically, the right kidney lies lower than the left, pushed down by the liver. The upper pole of the left kidney lies at the level of the 12th thoracic vertebra and that of the right kidney lies at the level of the 1st lumbar vertebra¹⁸⁾. The apex of the sigmoid colon is located anterior to the abdominal segment of the left ureter as compared with the right ureter¹⁹⁾. These anatomical left-right differences might be associated with the anatomical relationship between the vertebral body and the ureter. The current study included few cases with severe spinal deformity (SVA >9.5 cm and/or Cobb angle >30°), and future studies should investigate whether spinal deformity could be a significant factor affecting the relationship between the vertebral body and the ureter. It is not

clear at which intervertebral level ureteral injury is more frequent. Kubota et al. and Sun et al. reported cases with ureteral injuries on the left side of L4-L5, while Anand et al. reported ureteral injury on the left side of L2-L3^{9,10,20}. Preoperative examinations have not been performed in these reported cases, and it is unclear in which areas the ureter was actually present. Ureteral injuries were reported by the Japanese Research Society for anterior and lateral approach spinal surgery in 2019. There are also some reports of ureteral damage at L4-L5, and the actual position of the ureter in those cases was between the psoas major muscle and the vertebral body. Thus, the ureter in the C region at L4-L5 might be at a higher risk of injury; however, because of the limited number of cases of ureteral injury, further research is needed to identify the actual risk of ureteral injury in LLIF.

In addition, most reports of ureteral injury occurred in women^{9,10,17,20}. In our study, most of the ureters present in the C region were found in women. In terms of anatomical differences in the ureter between men and women, the mean intravesical length of the pelvic ureter is shorter in women (14.81 mm) than in men (18.69 mm)²¹. In addition, the female pelvic organs include the uterus. It is not clear why ureters were more common in the C region in women, but such anatomical differences in the ureters and uterus have influenced this result, and further research is warranted in the future. Another finding was that the ureter in the C region had a larger PT at L4-L5 and L5-S. Presumably, the retroperitoneal organs, including the ureter, may shift dorsally in the lower lumbar levels in cases with a larger pelvic tilt.

Preoperative CT is crucial for accurately identifying the ureter. When XLIF is performed in the C region, there may be a high risk of ureteral injury because the ureter is in an obscure position due to the psoas major muscle. In OLIF, identifying the area where the ureter is located is essential so that ureteral damage in the C region is reduced. However, since the C region is close to the surgical field, careful surgical exposure is also necessary. Thus, contrast-enhanced CT is a useful assessment that provides preoperative anatomic features of the ureter and blood vessels. However, the radiation exposure during this procedure is problematic. We are currently investigating whether MRI can accurately determine the relationship between the ureter and the vertebral body and whether it is feasible to perform contrast-enhanced CT only in cases in which identification of the ureter is difficult on MRI. Nevertheless, examining the ureter before surgery and planning for a safe surgery in any cases involving lateral-access surgery is essential. There are some limitations to this study. First, the CT imaging position was supine in this study. The actual surgical position is usually the lateral decubitus position, so it is thought that the retroperitoneal organs move from the supine position to the lateral decubitus position²². The second limitation was that this study was retrospective in nature. In addition, this study included a small number of cases, few cases with severe deformities, and it focused on grade 1 degenerative spondy-

lolisthesis. Therefore, large-scale research that included cases with spinal deformities is required in the future.

In conclusion, we examined the relationship between LLIF corridor and the ureteral running location using preoperative contrast-enhanced CT. On the left side of L3-L4 and L4-L5, which are the most frequently LLIF-operated vertebrae, approximately 14% of the ureters were located in the C region between the psoas major muscle and the vertebral body, and were at risk of potential ureteral injuries. Therefore, we should pay attention to the ureter in the preoperative image, and the dangerous ureter between the vertebral body and the psoas major muscle requires more caution during surgical operation.

Conflicts of Interest: Tokumi Kanemura is a consultant for Medtronic and NUVASIVE.

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Ethical Approval: The study was approved by the Institutional Review Board of Konan Kosei Hospital.

Approval code:30-048(0332)

Informed Consent: Informed consent was obtained from all participants in this study.

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