Neurospine 2024;21(3):820-832.
https://doi.org/10.14245/ns.2448536.268

Neurospine
pISSN 2586-6583 eISSN 2586-6591

Original Article

Incidence and Risk Factors for Lumbar Sympathetic Chain Injury After Oblique Lumbar Interbody Fusion

Corresponding Author
Vit Kotheeranurak
https://orcid.org/0000-0002-9593-429X

Department of Orthopaedics, Faculty of Medicine, Chulalongkorn University, and King Chulalongkorn Memorial Hospital, 1873 Rama IV Road, Pathumwan, Bangkok 10330, Thailand
Email: vitinspine@gmail.com

Received: May 28, 2024
Revised: July 21, 2024
Accepted: July 27, 2024

Weerasak Singhatanadgige[1,2], Thanadol Tangdamrongtham[1], Worawat Limthongkul[1,2], Wicharn Yingsakmongkol[1,2], Stephen J. Kerr[3], Teerachat Tanasansomboon[2], Vit Kotheeranurak[1,2]

[1]Department of Orthopedics, Faculty of Medicine, Chulalongkorn University and King Chulalongkorn Memorial Hospital, Bangkok, Thailand
[2]Center of Excellence in Biomechanics and Innovative Spine Surgery, Chulalongkorn University, Bangkok, Thailand
[3]Research Affairs, Faculty of Medicine, Chulalongkorn University, Bangkok, Thailand

Objective: Oblique lumbar interbody fusion (OLIF), performed using a retroperitoneal approach, can lead to complications related to the approach, such as lumbar sympathetic chain injury (LSCI). Although LSCI is a common complication of OLIF, its reported incidence varies across studies due to an absence of specific diagnostic criteria. Moreover, research on the risk factors of postoperative sympathetic chain injuries after OLIF remains limited. Therefore, this study aimed to describe the incidence, and identify independent risk factors for LSCI, in patients with degenerative lumbar spinal diseases who underwent OLIF.

Methods: Between October 2020 and August 2023, a retrospective review was conducted at our institute on 200 patients who underwent OLIF at 1 to 4 consecutive spinal levels (L1–5) for degenerative spinal diseases including spinal stenosis, spondylolisthesis, degenerative scoliosis. We excluded those with infections, trauma, tumors, and lower extremity edema/warmth due to other causes. The patients were categorized into 2 groups: those with and without LSCI symptoms. Demographic data, operative data, and pre- and postoperative parameters were evaluated for their association with LSCI using a univariate logistic regression model. Variables with a p-value < 0.1 in the univariate analysis were included in a multivariate model to identify the independent risk factors.

Results: Thirty-five of 200 patients (17.5%) developed LSCI symptoms after OLIF. Multivariate logistic regression analysis indicated that prolonged retraction time, particularly exceeding 31.5 miniutes, remained an independent risk factor (adjusted odds ratio, 12.59; $p < 0.001$).

Conclusion: This study demonstrated that prolonged retraction time was an independent risk factor for LSCI following OLIF, particularly when it exceeded 31.5 minutes. Protecting the lumbar sympathetic chain during surgery and minimizing retraction time are crucial to avoiding LSCI following OLIF.

Keywords: Lumbar, Fusion, Sympathetic, Injury, Risk factor, Incidence

INTRODUCTION

Prepsoas or oblique lumbar interbody fusion (OLIF) was first introduced by Silvestre et el.[1] in 2012 and is gaining popularity among spine surgeons for treating various spinal diseases.[2] This technique is performed retroperitoneally, using a surgical corridor between the major vessels and psoas muscle, to achieve indirect decompression of the spinal canal and neural foramina, providing spinal fusion, restoring lumbar lordosis (LL), and correcting spinal deformity.[3-5] Most previous studies demon-

strated excellent clinical and radiographic results after OLIF.[6-8] OLIF offers several advantages over other lumbar interbody fusion techniques. As a minimally invasive, muscle-sparing procedure, it avoids damage to posterior spinal structures seen in conventional posterior lumbar interbody fusion, resulting in less blood loss, shorter operative time and a faster recovery peroid.[9,10] Compared to anterior lumbar interbody fusion, OLIF results in fewer vascular and hypogastric plexus injuries. It is more suitable for upper lumbar segments, and compared to transpsoas or extreme lateral lumbar interbody fusion, OLIF has a lower incidence of lumbar plexus injury and does not require intraoperative neuromonitoring.[11] However, the complications following OLIF are common. These include cage subsidence, psoas weakness, groin/anterior thigh pain or numbness, vascular injury, and sympathetic chain injury.[12-14]

Lumbar sympathetic chain injury (LSCI) is a common complications following OLIF, but its incidence may be underestimated because it is often overlooked in routine examinations.[10] In previous studies the incidence of LSCI following OLIF varies from 0% to 29.6% with different diagnostic methods.[15-17] Mehren et al.[15] conducted a retrospective analysis of 812 patients who underwent OLIF and found no cases of LSCI based on patient-reported symptoms and palpation. To improve the diagnostic accuracy of LSCI, Hrabalek et al.[18] proposed the use of thermography. Using this technique, Pan et al.[16] retrospectively studied 54 patients who underwent OLIF and found that 16 patients (29.6%) had LSCI. All patients with LSCI reported experiencing moderate to severe discomfort in the early postoperative peroid. The lumbar sympathetic chain (LSC) runs along the anterolateral aspect of the lumbar vertebral body located in the surgical corridor of the OLIF procedure.[19,20] The left LSC is always noticeable in the surgical field and in some cases may obscure access to the intervertebral disc space,[21] possibly causing iatrogenic injury to the LSC during the procedure.[22] The manifestations of LSCI include increased skin temperature, anhidrosis, swelling, skin discoloration, dysesthesia, and neuralgia of the affected limb.[23,24] Although this complication may be temporary in some patients, it decreases patient satisfaction and reduces quality of life in the postoperative peroid.[16,25] Studying factors associated with LSCI is crucial to understanding the etiology, and identifying those which are potentially modifiable. A single retrospective study of 210 patients who underwent OLIF at the L4–5 level identified dextroscoliosis and tear-drop psoas as independent risk factors for postoperative sympathetic chain dysfunction (PSCD). The authors also noted a positive correlation between surgical duration and PSCD, attributing it to prolonged nerve stretching, although the exact retraction time was not recorded.[26]

There is growing concern that the incidence of LSCI following OLIF may be underdetected, potentially due to inadequate monitoring or diagnostic limitations. Additionally, retraction time during surgery might influence the risk of LSCI, yet its role has not been thoroughly investigated. Therefore, this study aimed to determine the incidence of LSCI, and identify potential risk factors for this condition in patients with degenerative lumbar spinal diseases who underwent OLIF. We hypothesized that the overall incidence of LSCI following OLIF is underdetected and that longer retraction time plays a significant role in the LSCI development.

MATERIALS AND METHODS

1. Study Design

This retrospective review was conducted at our institute between October 2020 and August 2023. This study was approved by the Institutional Review Board of the Faculty of Medicine at Chulalongkorn University (COA No. 0157/2024). A waiver of informed consent was granted because of the retrospective nature of the study.

We conducted a chart review and included patients who underwent OLIF at 1 to 4 consecutive spinal levels (L1–5) for degenerative lumbar spinal diseases, including degenerative disc disease, disc herniation, spinal stenosis, spondylolisthesis, degenerative scoliosis, adjacent segment disease, and symptomatic pseudarthrosis. We excluded patients with a condition that might impede accurate assessment of LSCI with a thermometer including infections, trauma, tumors, peripheral edema or warmth of lower extremities for conditions such as deep vein thrombosis, cellulitis, renal disease, liver disease, or congestive heart failure. We also excluded patients with <3 months follow-up as symptom resolution could not be ascertained.

2. Diagnostic Criteria of LSCI

Although the diagnostic criteria for LSCI remain uncertain, Pan et al.[16] proposed basing a diagnosis on at least one positive clinical finding of LSC dysfunction. We believe that to minimize false positives, at least 2 criteria should be met. Therefore, in our study, LSCI was diagnosed when a minimum of 2 of the following criteria were met: (1) skin temperature difference of ≥ 0.5°C between lower limbs tested using digital infrared thermometer, (2) decreased sweating in the starch-iodine (Minor's) test,[27] (3) limb swelling and skin discoloration on inspection

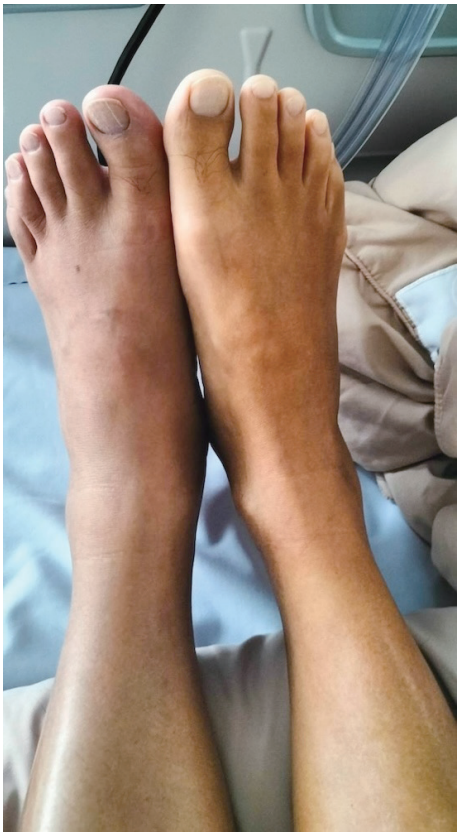

Fig. 1. Visual examination of swelling and discoloration in the left lower extremity resulting from lumbar sympathetic chain injury on the affected side.

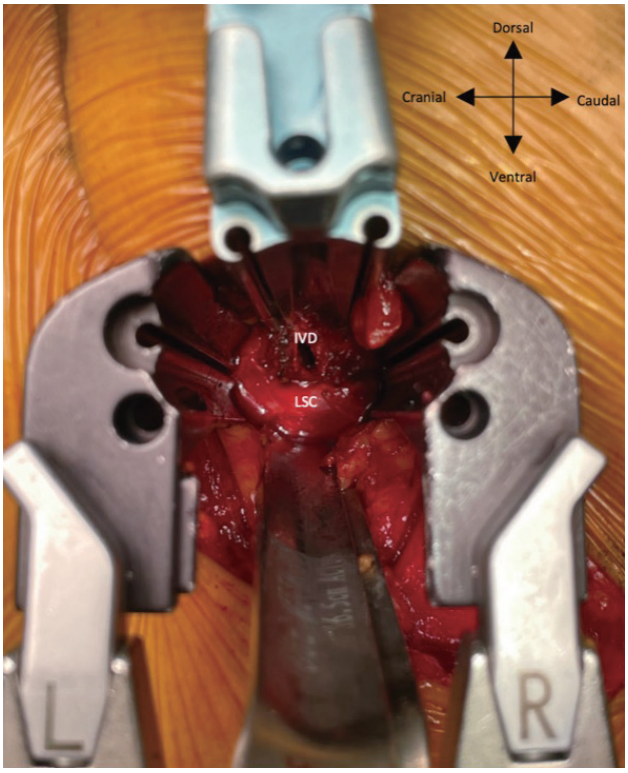

Fig. 2. Intraoperative image during the OLIF L4–5 procedure showing that the LSC was in the pathway of intervertebral disc access and required anterior retraction during discectomy, endplate preparation, and cage insertion. LSC, lumbar sympathetic chain; IVD, intervertebral disc.

(Fig. 1). Mean skin temperature was based on 3 consecutive measurements using a digital infrared thermometer (Model: TIE-240, HoMedics, Township, MI, USA). All patients were in a supine position with their lower limbs fully extended. The measurements were taken by the same doctor at the anterior aspect of midcalves from a distance of 2 fingerbreadths (3–4 cm). The accuracy of the device was ±4°C at room temperature of 24°C–26°C. The status of LSCI was diagnosed within 24 hours postoperatively using the same criteria in all patients.

3. Surgical Technique

All patients underwent the procedure under general anesthesia. They were placed in the right lateral decubitus position and secured with tape. Using a left-sided approach, an oblique skin incision was made, followed by blunt dissection of the abdominal muscles. The intervertebral disc was accessed through a retroperitoneal approach, with the left psoas muscle retracted dorsally and vascular structures retracted ventrally to widen the surgical corridor, followed by application of a tubular retractor system (OLIF25 retractor system, Medtronic, Memphis, TN, USA). To prevent accidental injury to the LSC, we consistently searched for it during the surgical approach, especially at the L4–5 level. Blunt dissection was used to identify the intervertebral disc, and coagulation was used sparingly to avoid harming the sympathetic fibers or ganglion. If the LSC was in the surgical pathway, it was carefully undermined and mobilized to the side with less tension, typically anterior (Fig. 2). Following confirmation of the disc level and application of the tubular retractor system, annulotomy was performed, followed by removal of the disc material and cartilaginous endplate using a disc shaver and pituitary rongeur. A Polyetheretherketone cage (CLYDESDALE spinal system, Medtronic) filled with 2–3 mL of demineralized bone matrix (Grafton, Medtronic) or recombinant human bone morphogenetic protein-2; rhBMP-2 (Infuse, Medtronic) was then inserted into the disc space after determining the appropriate size with the cage trial. Anterolateral or posterior pedicle screw instrumentation was applied at the discretion of the surgeon. Finally, the abdominal muscles and skin were closed layer-by-layer.

https://doi.org/10.14245/ns.2448536.268

4. Postoperative Period

The patients with LSCI who experienced discomfort were treated supportively. After discharge from the hospital, the patients were scheduled for follow-up appointments at 2 weeks, 6 weeks, 3 months, 6 months, and 1 year, and annually thereafter. Patients with LSCI were assessed for symptoms and underwent measurement of skin temperature differences between both lower extremities at each follow-up time point. The resolution of the complication was defined as the disappearance of symptoms and a return of skin temperature in the affected limb to normal, with no more than a 0.5°C difference compared to the opposite side.

5. Outcome Measurements

All data were retrospectively collected from paper-based or electronic medical records. The patients were categorized into 2 groups: those with and without LSCI. Patient demographic data, including age, sex, body mass index, smoking status, comorbidities, bone mineral density, previous spinal fusion surgery, previous retroperitoneal surgery, presence of spondylolisthesis, degree of slippage in spondylolisthesis, operative level, number of operative segments, and presence of scoliosis (both levo- and dextroscoliosis), were collected. Scoliosis was defined as a lateral curvature of the spine of > 10°. Some of the operative and all radiographic data were collected from patients who underwent single-level surgery (n = 120). All radiographic parameters were evaluated using digital radiographic images reviewed on PACS (picture archiving and communications system). The radiographic caliper provided a resolution of 0.1 mm. Each parameter underwent dual measurement by 2 independent spine surgeons, and the mean value for each parameter was determined. Operative data, including operative time, retraction time, estimated blood loss, instrumentation type, and navigation system type, were analyzed. The retraction time was recorded since the tubular retractors were initially expanded until they were removed. The preoperative radiographic parameters measured on the lateral lumbar spine radiograph in the standing position included anterior disc height (ADH), posterior disc height (PDH), LL, pelvic incidence minus LL mismatch (PI–LL mismatch), and segmental lordosis (SL). SL was defined as the Cobb angle between the superior and inferior endplates of the upper and lower vertebral bodies, respectively. We also reviewed the preoperative radiographic parameters of T1- and T2-weighted magnetic resonance images in the supine position, which consisted of anterior elevation of the left psoas muscle; the distance between anterior boarder of the disc to the anterior border of the left psoas muscle; lateral elevation of the left psoas muscle; the distance between lateral boarder of the disc to the lateral border of the left psoas muscle; cross-sectional area of left psoas muscle; surgical corridor width; the distance from the lateral border of the abdominal aorta to the anteromedial border of the left psoas muscle (AA-PM); distance between the medial border of the left LSC and the lateral border of abdominal aorta (LSC-AA); distance between the lateral border of the left LSC and the anteromedial border of the left psoas muscle (LSC-PM); presence of the left LSC at the disc level; and the diameter of the left LSC (Fig. 3). Postoperative standing radiographs at 2-week follow-up were also compared with the preoperative parameters. The cage position was calculated as the proportion of the distance from the posterior border of the superior endplate of the lower vertebral body to the center of the interbody cage and the length of the superior endplate of the lower vertebral body (Fig. 4).[28]

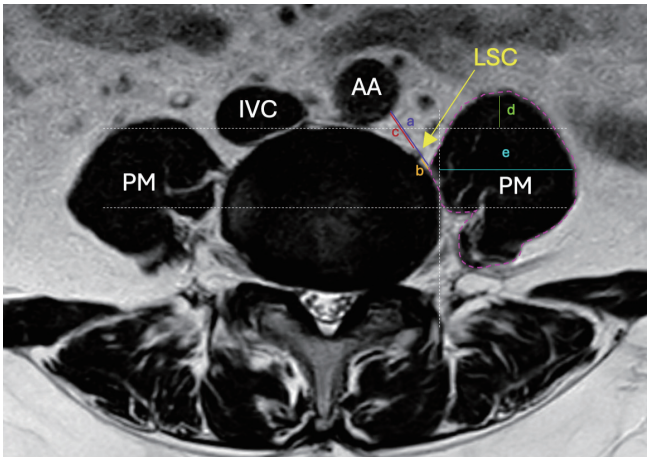

Fig. 3. T2-weighted image at the L4–5 disc level in axial view. (a) The distance from the lateral border of the abdominal aorta to the anteromedial border of the left psoas muscle (AA-PM), the surgical corridor. (b) The distance from the lateral border of the left LSC to the anteromedial border of the left psoas muscle (LSC-PM). (c) The distance from the medial border of the left LSC to the lateral border of the abdominal aorta (LSC-AA). (d) The distance from the anterior border of the vertebral body to the anterior border of the left psoas muscle. (e) The distance from the lateral border of the vertebral body to the lateral border of the left psoas muscle. Yellow arrow showing the left LSC. Pink dashed line showing the cross-sectional area of the left psoas muscle. PM, psoas major muscle; IVC, inferior vena cava; AA, abdominal aorta; LSC, lumbar sympathetic chain.

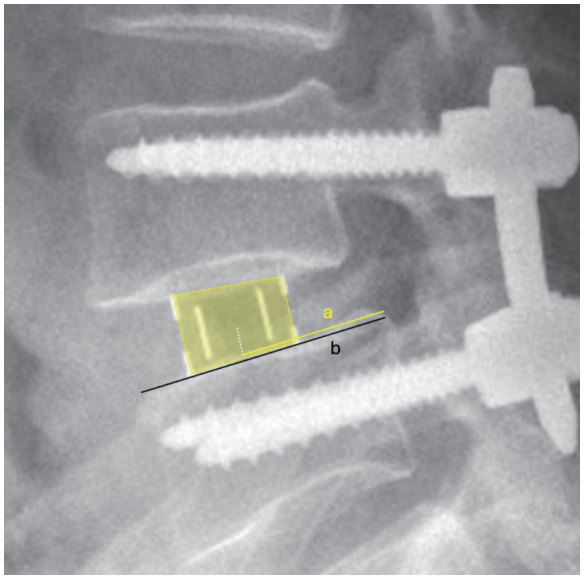

Fig. 4. Measurement of the cage position in the lateral x-ray image. The cage position is determined by the formula a/b × 100 (%). (a) The distance from the posterior border of the superior endplate of the lower vertebral body to the center of the interbody cage. (b) The length of the superior endplate of lower vertebral body.

6. Statistical Analyses

Analyses were conducted using Stata 18 (StataCorp, College Station, TX, USA). Initially, a comparative analysis was performed to identify any differences in demographic, disease-related and operative characteristics between patients with and without LSCI including all patients regardless of the number of operative segments. Pre- and postoperative parameters were assessed in patients who had OLIF at a single level, by study group. In these analyses, categorical variables were compared across study groups using chi-square test or Fisher exact test. Continuously distributed variables were compared using a t-test or Mann-Whitney U-test for normally or nonnormally distributed variables respectively.

Univariable logistic regression was used to assess the magnitude of association between patient characteristics and radiological parameters and the outcome of LSCI for patients who had single-level surgery. Variables with p-values <0.1 were adjusted for as potential confounders in a multivariable model which was used to calculate adjusted odds ratios (adjORs) and 95% confidence intervals (CIs). Receiver operating characteristic (ROC) curve analysis was used to determine the value of retraction time that maximized the sum of sensitivity and specificity (Youden index). Backward selection was used to arrive at the final multivariate model by successively dropping the parameter with the least significant p-value until we arrived at the most parsimonious model that minimized the Aikake information criterion. The goodness of fit of this final model was tested using the Hosmer–Lemeshow goodness-of-fit statistic, and model discrimination was assessed using the area under the ROC curve (AUC). Statistical significance was defined as $p<0.05$.

RESULTS

Of the 200 patients included in our study, 35 (17.5%) developed LSCI after OLIF. No patients with LSCI reported neuralgia; some were asymptomatic, while the majority had only discomfort. All patients with LSCI recovered within 6 months postoperatively, with the mean ± standard deviation duration of LSCI being 3.2 ± 1.8 months, ranging from 2 weeks to 6 months. We compared the demographic data of the patients in both groups and found no significant differences in any of the variables ($p>0.05$) (Table 1).

According to the operative parameters, operative times were comparable between the 2 groups (162.28 ± 33.15 minutes vs. 147.79 ± 33.93 minutes, $p=0.10$). However, the retraction time was significantly longer in patients in the LSCI group (41 [35–45] minutes vs. 27 [21–35] minutes, $p<0.001$). In the ROC curve analysis, retraction time >31.5 minutes maximized the performance characteristics with a sensitivity of 0.78, specificity of 0.70, and an area under the curve of 0.74 (95% CI, 0.63–0.85) (Fig. 5). There was no significant difference between the 2 groups in terms of estimated blood loss (100 [50–200] mL vs. 100 [50–100] mL, $p=0.38$) and type of instrumentation consisting of a posterior pedicle screw-rod (94.3% [33 of 35] vs. 97.6% [161 of 165]) and an anterolateral pedicle screw-rod/plate (5.7% [2 of 35] vs. 2.4% [4 of 165], $p=0.283$). However, the type of navigation system used during surgery differed significantly between the 2 groups. The application rate of computed tomography (CT)-based navigation systems was higher (94.3% [33 of 35] vs. 72.1% [119 of 165]), whereas that of fluoroscopic guidance was lower (5.7% [2 of 35] vs. 27.9% [46 of 165], $p=0.01$) in patients with LSCI (Table 2).

During preoperative magnetic resonance imaging (MRI), the left psoas muscle morphology demonstrated that anterior elevation (1.43 ± 4.42 mm vs. -0.07 ± 6.80 mm, $p=0.37$), lateral elevation (30.55 ± 5.53 mm vs. 30.51 ± 7.23 mm, $p=0.98$) and cross-sectional area (986.04 ± 387.64 mm^3 vs. 1,023.65 ± 355.99 mm^3, $p=0.68$) of the left psoas muscle were comparable between the 2 groups. There was no statistically significant difference between the surgical corridor widths of the 2 groups (16.40 ± 8.47 mm

 https://doi.org/10.14245/ns.2448536.268

Table 1. Demographic characteristics of patients who underwent oblique lumbar interbody fusion

Variable	Total (n = 200)	LSCI (+) (n = 35)	LSCI (-) (n = 165)	p-value
Sex				
Male	48 (24.0)	9 (25.7)	39 (23.6)	0.79
Female	152 (76.0)	26 (74.3)	126 (76.4)	
Age (yr)	67.44 ± 9.18	66.26 ± 9.91	67.68 ± 9.02	0.40
BMI (kg/m^2)	25.80 ± 4.53	25.57 ± 4.50	25.85 ± 4.55	0.74
Smoking	23 (11.5)	3 (8.6)	20 (12.1)	0.77
Underlying disease	165 (82.5)	29 (82.9)	136 (82.4)	0.95
Hypertension	128 (64.0)	22 (62.9)	106 (64.2)	0.88
Diabetes mellitus	49 (24.5)	5 (14.3)	44 (26.7)	0.12
Dyslipidemia	76 (38.0)	9 (25.7)	67 (40.6)	0.10
Chronic kidney disease	8 (4.0)	1 (2.9)	7 (4.2)	1.00
Stroke/cerebrovascular disease	10 (5.0)	1 (2.9)	9 (5.5)	1.00
Heart disease	12 (6.0)	2 (5.7)	10 (6.1)	1.00
Cancer	10 (5.0)	2 (5.7)	8 (4.8)	0.69
Bone mineral density (T score)	-1.39 ± 1.29	-1.22 ± 1.30	-1.44 ± 1.29	0.38
> -1	73 (36.5)	11 (31.5)	63 (38.2)	0.34
-1 to -2.5	102 (51.0)	20 (57.1)	81 (49.1)	
< -2.5	25 (12.5)	4 (11.4)	21 (12.7)	
Previous spinal fusion	15 (7.5)	3 (8.6)	12 (7.3)	0.73
Previous retroperitoneal surgery	5 (2.5)	0 (0.0)	5 (3.0)	0.59
Diagnosis				
Spondylolisthesis	102 (51.0)	17 (48.6)	85 (51.5)	0.38
Degenerative scoliosis	43 (21.5)	9 (25.7)	34 (20.6)	
Spinal stenosis	34 (17.0)	4 (11.4)	30 (18.2)	
ASD	8 (4.0)	1 (2.9)	7 (4.2)	
HNP/DDD	9 (4.5)	3 (8.6)	6 (3.6)	
Pseudarthrosis	4 (2.0)	1 (2.9)	3 (1.8)	
Level				
1	120 (60.0)	18 (51.4)	102 (61.8)	0.58
2	45 (22.5)	9 (25.7)	36 (21.8)	
3	24 (12.0)	6 (17.1)	18 (10.9)	
4	11 (5.5)	2 (5.7)	9 (5.5)	
Multilevel surgery	80 (40.0)	17 (48.6)	63 (38.2)	0.25
Segment L4–5	107 (53.5)	18 (51.4)	89 (53.9)	0.79
Spondylolisthesis	102 (51.0)	17 (48.6)	85 (51.5)	0.75
Spondylolisthesis grading (n = 102)				
Nonspondylolisthesis	98 (49.0)	18 (51.4)	80 (48.5)	0.26
Grade I	90 (45.0)	13 (37.1)	77 (46.7)	
Grade II	12 (6.0)	4 (11.4)	8 (4.8)	
Scoliosis	50 (25.0)	11 (31.4)	39 (23.6)	0.33
Type of scoliosis				
Nonscoliosis	150 (75.0)	24 (68.6)	126 (76.4)	0.39
Levo-scoliosis	26 (13.0)	7 (20.0)	19 (11.5)	
Dextroscoliosis	24 (12.0)	4 (11.4)	20 (12.1)	

Values are presented as number (%) or mean ± standard deviation.
LSCI, lumbar sympathetic chain injury; BMI, body mass index; ASD, adjacent segment disease; HNP, herniated nucleus pulposus; DDD, degenerative disc disease.

vs. 15.11 ± 7.60 mm, p = 0.52). The left LSC was identified on MRI in 62% of the patients (75 of 120), and the incidence of its presence was significantly higher in patients with LSCI (83.3% [15 of 18] vs. 58.8% [60 of 102], p = 0.04). No significant difference was shown in the left LSC diameter (2.74 ± 1.05 mm vs. 2.95 ± 1.26 mm, p = 0.54), LSC-AA (8.73 ± 7.30 mm vs. 10.47 ± 7.03, p = 0.40), and LSC-PM (4.69 ± 4.06 mm vs. 3.90 ± 3.51, p = 0.45). The preoperative lateral lumbar radiograph demonstrated significantly lower ADH in patients with LSCI (5.70 ± 3.19 mm vs. 8.01 ± 3.28 mm, p = 0.01); however, no significant differences in PDH (4.40 ± 2.12 mm vs. 5.43 ± 2.31 mm, p = 0.078), PI–LL mismatch (9.28° ± 12.05° vs. 10.27° ± 14.61°, p = 0.79), LL (45.78° ± 9.74° vs. 45.43° ± 16.48°, p = 0.93), and SL (12.89° ± 5.20° vs. 13.68° ± 7.96°, p = 0.69) were observed between the groups. The postoperative parameters on the lateral lumbar radiograph showed no significant difference in any variables including ADH (11.57 ± 3.22 mm vs. 12.64 ± 2.64 mm, p = 0.13), PDH (7.87 ± 2.24 mm vs. 8.59 ± 1.84 mm, p = 0.143), PI–LL mismatch (7.39° ± 10.15° vs. 8.38° ± 12.69°, p = 0.75), LL (47.67° ± 9.94° vs. 47.32° ± 14.05°, p = 0.92), SL (17.11° ± 4.99° vs. 15.77° ± 7.18°, p = 0.45), and the cage position (56.26% ± 7.64% vs. 53.71% ± 8.48%, p = 0.24) (Table 3).

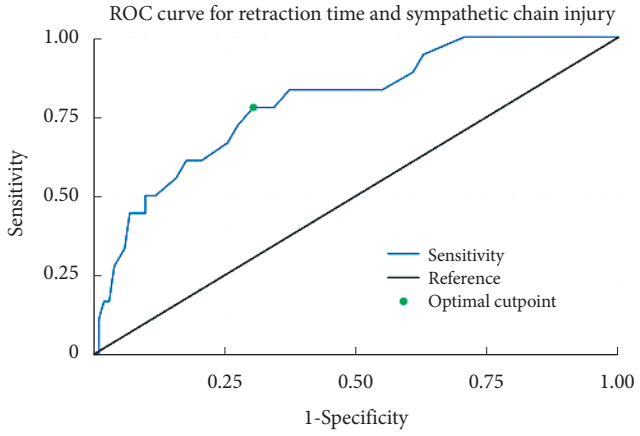

Fig. 5. Receiver operating characteristic (ROC) curve analysis indicated that retraction times exceeding 31.5 minutes achieved a sensitivity of 0.78 and a specificity of 0.70, with the area under the ROC curve measuring 0.74 (95% confidence interval [CI], 0.63–0.85).

A positive correlation was found between the occurrence of LSCI and some variables in the univariable analysis, including the utilization of CT-based navigation during the surgery (unadjusted odds ratio [OR], 6.38; p = 0.01), presence of the left LSC on preoperative MRI (OR, 3.79; p = 0.04), and differences in pre- and postoperative ADH and SL (OR, 1.22; p = 0.06 and OR, 1.11; p = 0.07, respectively). Lower preoperative ADH and PDH were also positively correlated with LSCI in the univariate analysis (OR, 0.8; p = 0.08 and OR, 0.82; p = 0.08, respectively) (Table 4). In the final multivariate model, the only independent risk factor for LSCI was prolonged retraction time exceeding 31.5 minutes following OLIF (adjOR, 12.59; 95% CI, 2.59–53.72; p < 0.001). Nevertheless, the adjORs and 95% CI for CT vs. fluoroscopic navigation (adjOR, 9.22; 95% CI, 0.92–92.56) and the presence of left LSC on MRI (adjOR, 4.37; 95% CI, 0.88–21.63) were consistent with a clinically important elevated risk of LSCI (Table 5). The AUC of this final model was 0.88 (95% CI, 0.80–0.95) demonstrating the model could accurately discriminate

Table 2. Operative parameters of patients who underwent oblique lumbar interbody fusion

Variable	Total (n = 200)	LSCI (+) (n = 35)	LSCI (-) (n = 165)	p-value
Operative time (min) (n = 120)	149.97 ± 34.07	162.28 ± 33.15	147.79 ± 33.93	0.10
Retraction time (min) (n = 120)	28 (22–37)	41 (35–45)	27 (21–35)	< 0.001*
≤ 31.5	75 (62.5)	4 (22.2)	71 (69.6)	
> 31.5	45 (37.5)	14 (77.8)	31 (30.4)	
Blood loss (mL) (n = 120)	100 (50–150)	100 (50–200)	100 (50–100)	0.38
Type of instrumentation				
Posterior pedicle screw-rod	194 (97.0)	33 (94.3)	161 (97.6)	0.28
Anterolateral pedicle screw-rod/plate	6 (3.0)	2 (5.7)	4 (2.4)	
Navigation system				
CT-based	152 (76.0)	33 (94.3)	119 (72.1)	0.01*
Fluoroscopic	48 (24.0)	2 (5.7)	46 (27.9)	

Values are presented as mean ± standard deviation, median (interquartile range), or number (%).
LSCI, lumbar sympathetic chain injury; CT, computed tomography.
*p < 0.05, statistically significant differences.

https://doi.org/10.14245/ns.2448536.268

Table 3. Pre- and postoperative radiographic parameters of patients who underwent oblique lumbar interbody fusion at a single level

Variable	Total (n = 120)	LSCI (+) (n = 18)	LSCI (-) (n = 102)	p-value
Psoas AE (mm) (n = 120)	0.15 ± 6.50	1.43 ± 4.42	-0.07 ± 6.80	0.37
Psoas LE (mm) (n = 120)	30.51 ± 6.98	30.55 ± 5.53	30.51 ± 7.23	0.98
Psoas CSA (mm^2) (n = 120)	1,018.01 ± 359.45	986.04 ± 387.64	1,023.65 ± 355.99	0.68
Surgical corridor (AA-PM) (mm) (n = 120)	15.31 ± 7.71	16.40 ± 8.47	15.11 ± 7.60	0.52
Presence of left LSC on MRI (n = 120)				
No	45 (37.5)	3 (16.7)	42 (41.2)	0.04*
Yes	75 (62.5)	15 (83.3)	60 (58.8)	
LSC diameter (mm) (n = 75)	2.91 ± 1.21	2.74 ± 1.05	2.95 ± 1.26	0.54
LSC-AA (mm) (n = 75)	10.12 ± 7.07	8.73 ± 7.30	10.47 ± 7.03	0.40
LSC-PM (mm) (n = 75)	4.05 ± 3.61	4.69 ± 4.06	3.90 ± 3.51	0.45
Preoperative x-ray parameters				
ADH (mm) (n = 120)	7.66 ± 3.36	5.70 ± 3.19	8.01 ± 3.28	0.01*
PDH (mm) (n = 120)	5.28 ± 2.30	4.40 ± 2.12	5.43 ± 2.31	0.08
PI–LL (°) (n = 120)	10.12 ± 14.22	9.28 ± 12.05	10.27 ± 14.61	0.79
LL (°) (n = 120)	45.48 ± 15.63	45.78 ± 9.74	45.43 ± 16.48	0.93
SL (°) (n = 120)	13.56 ± 7.60	12.89 ± 5.20	13.68 ± 7.96	0.69
Postoperative x-ray parameters				
ADH (d) (n = 120)	12.48 ± 2.74	11.57 ± 3.22	12.64 ± 2.64	0.13
PDH (°) (n = 120)	8.48 ± 1.91	7.87 ± 2.24	8.59 ± 1.84	0.14
PI–LL (°) (n = 120)	8.23 ± 12.31	7.39 ± 10.15	8.38 ± 12.69	0.75
LL (°) (n = 120)	47.38 ± 13.48	47.67 ± 9.94	47.32 ± 14.05	0.92
SL (°) (n = 120)	15.98 ± 6.89	17.11 ± 4.99	15.77 ± 7.18	0.45
Cage position (%) (n = 120)	54.09 ± 8.38	56.26 ± 7.64	53.71 ± 8.48	0.24

Values are presented as mean ± standard deviation or number (%).
LSCI, lumbar sympathetic chain injury; AE, anterior elevation; LE, lateral elevation; CSA, cross-sectional area; AA, abdominal aorta; PM, psoas muscle; LSC, lumbar sympathetic chain; MRI, magnetic resonance imaging; ADH, anterior disc height; PDH, posterior disc height; PI, pelvic incidence; LL, lumbar lordosis; SL, segmental lordosis.
*$p < 0.05$, statistically significant differences.

between participants with and without LSCI in our study, with an accuracy of 80%, and there was no evidence of poor fit (Hosmer and Lemeshow chi-square p = 0.66).

DISCUSSION

In this retrospective study, we demonstrated the incidence of LSCI in 17.5% (n = 35) of 200 patients with degenerative spinal diseases who underwent OLIF. Multivariable binary logistic regression demonstrated that prolonged retraction exceeding 31.5 minutes during the surgery, had a strong positive association with the incidence of LSCI. In univariable analysis, the utilization of CT-based navigation during the operation presence of left LSC on preoperative MRI, and differences in pre- and postoperative ADH and SL also showed a positive association with development of LSCI. Moreover, lower preoperative ADH and PDH were also associated with a higher risk of LSCI in the univariable analysis.

OLIF utilizes the surgical window between the left psoas muscle and aorta or left common iliac artery to approach the intervertebral disc and achieve the goal of spinal fusion.[15] The left LSC travels along the anterolateral border of the lumbar vertebra within the surgical corridor, and is therefore at risk of injury during this surgery.[18] The clinical presentations of LSCI include increased body temperature, decreased sweating, swelling, and discoloration of the lower limb in the operated side.[24] However, some patients do not recognize the clinical symptoms of sympathetic dysfunction despite damage to the LSC during surgery.[29]

Table 4. Univariable analysis of risk factors for lumbar sympathetic chain injury after oblique lumbar interbody fusion at a single level

Variable	OR†	95% CI	p-value
Demographic data			
Sex, male:female	1.12	0.48–2.59	0.79
Age (yr)	0.98	0.95–1.02	0.40
BMI (kg/m^2)	0.99	0.91–1.07	0.74
Smoking	0.68	0.19–2.43	0.55
Underlying disease	1.03	0.39–2.71	0.95
Hypertension	0.94	0.44–2.01	0.88
Diabetes mellitus	0.46	0.17–1.26	0.13
Dyslipidemia	1.12	0.48–2.59	0.79
Bone mineral density (T score)			
Normal & T score > -1	1.00	Reference	
-1 to -2.5	0.93	0.39–2.21	0.87
< -2.5	0.63	0.17–2.27	0.48
Previous spinal fusion	1.20	0.32–4.48	0.79
Previous retroperitoneal surgery	-	-	NA
Diagnosis			0.72
Spondylolisthesis	1.00	Reference	
Degenerative scoliosis	1.32	0.54–3.26	
Spinal stenosis	0.67	0.21–2.14	
ASD	0.71	0.08–6.19	
HNP/DDD	2.50	0.56–10.99	
Pseudarthrosis	1.67	0.16–17.00	
Multilevel surgery	1.53	0.73–3.18	0.26
Segment L4–5	0.90	0.44–1.88	0.79
Spondylolisthesis	0.89	0.43–1.84	0.75
Spondylolisthesis grading			
Nonspondylolisthesis	1.00	Reference	
Grade I	0.75	0.34–1.64	0.47
Grade II	2.22	0.60–8.19	0.23
Scoliosis	1.48	0.67–3.29	0.34
Nonscoliosis	1.00	Reference	
Levo-scoliosis	1.93	0.73–5.10	0.18
Dextroscoliosis	1.05	0.33–3.35	0.93
Operative parameters			
Operative time (min)	1.01	1.00–1.03	0.10
Retraction time (min)	1.18	1.09–1.27	< 0.001*
≤ 31.5	1.00	Reference	
> 31.5	8.02	2.44–26.31	
Blood loss (mL)	1.00	1.00–1.02	0.27
Type of instrumentation			
Posterior pedicle screw-rod	1.00	Reference	
Anterolateral pedicle screw-rod/plate	2.44	0.43–13.87	0.32
Navigation system			0.01*
CT-based	6.38	1.47–27.67	
Fluoroscopic	1.00	Reference	
Radiographic parameters			
Psoas AE	1.04	0.96–1.13	0.37
Psoas LE	1.00	0.93–1.08	0.98
Psoas CSA	1.00	1.00–1.00	0.68
Surgical corridor (AA-PM)	1.02	0.96–1.09	0.51
Presence of left LSC on MRI			0.04*
No	1.00	Reference	
Yes	3.79	1.03–13.91	
LSC diameter	0.85	0.52–1.41	0.54
LSC-AA	0.96	0.89–1.05	0.39
LSC-PM	1.06	0.91–1.23	0.45
Preoperative x-ray parameters			
ADH	0.80	0.67–0.95	0.01*
PDH	0.82	0.66–1.02	0.08*
PI–LL	1.00	0.96–1.03	0.78
LL	1.00	0.97–1.03	0.93
SL	0.99	0.92–1.05	0.68
Postoperative x-ray parameters			
Difference of ADH	1.22	0.99–1.51	0.06*
Difference of PDH	1.09	0.84–1.41	0.52
Difference of PI–LL	1.00	0.93–1.07	1.00
Difference of LL	1.00	0.93–1.07	1.00
Difference of SL	1.11	0.99–1.25	0.07*
Cage position	1.04	0.98–1.10	0.24

OR, odds ratio; CI, confidence interval; BMI, body mass index; ASD, adjacent segment disease; HNP, herniated nucleus pulposus; DDD, degenerative disc disease; CT, computed tomography; AE, anterior elevation; LE, lateral elevation; CSA, cross-sectional area; AA, abdominal aorta; PM, psoas muscle; LSC, lumbar sympathetic chain; MRI, magnetic resonance imaging; ADH, anterior disc height; PDH, posterior disc height; PI, pelvic incidence; LL, lumbar lordosis; SL, segmental lordosis; N/A, data not applicable.
*p < 0.1, statistical significance in univariable analysis. †Unadjusted odds ratio estimated by logistic regression model.

https://doi.org/10.14245/ns.2448536.268

Table 5. Multivariable analysis of risk factors for lumbar sympathetic chain injury after oblique lumbar interbody fusion

Variable	AdjOR†	95% CI	p-value
Retraction time (min)			0.001*
≤31.5	1.00	Reference	
>31.5	12.59	2.95–53.72	
Navigation system			0.06
CT-based	9.22	0.92–92.56	
Fluoroscopic	1.00	Reference	
Presence of left LSC on MRI			0.07
No	1.00	Reference	
Yes	4.37	0.88–21.63	
Preoperative x-ray parameters			
ADH	0.85	0.63–1.15	0.29
PDH	0.74	0.51–1.08	0.12
Postoperative x-ray parameters			
Difference of ADH	0.95	0.68–1.32	0.60
Difference of SL	1.04	0.89–1.22	0.06

AdjOR, adjusted odds ratio; CI, confidence interval; CT, computed tomography; LSC, lumbar sympathetic chain; MRI, magnetic resonance imaging; ADH, anterior disc height; PDH, posterior disc height; SL, segmental lordosis.
*$p < 0.05$, statistical significance in multivariable analysis. †Adjusted odds ratio estimated by logistic regression model.

The severity of symptoms and the duration of recovery may depend on the type and location of the injury to the LSC. None of our patients reported neuralgia; most experienced only mild discomfort. We believe the LSCI observed in our study was likely due to traction or compression injury rather than resection or coagulation, due to the careful protection of the LSC during the operation. Although there may have been an injury to the LSC intraoperatively, it is likely to involve the branches, as the ganglion is generally clearly visible. Consequently, our patients' symptoms were mild, with a shorter recovery time compared to previous studies.[16,26] A recent systematic review and meta-analysis reported the incidence of LSCI in a series of 20 prepsoas studies was 5.4% (11 of 412 patients). The authors hypothesized that the incidence of LSCI following OLIF in previous studies may have been underreported due to the lack of specific diagnostic methods and routine postoperative neurological examinations.[10] Hrabalek et al.[18] showed that thermography effectively diagnoses LSCI after anterior and lateral lumbar interbody fusion, enhancing diagnostic accuracy. Silvestre et al.[1] reported that 1.7% patients (3 out of 179) who underwent OLIF exhibited symptoms indicative of LSCI, with no reference made to diagnostic tests for this complication. Kim et al.[17] also reported that 13.8% (4 of 29) patients experienced sympathetic chain injury following OLIF L4–5, diagnosed by physical examination and temperature assessment with a digital infrared thermometer. Pan et al.[16] conducted a retrospective study involving 54 patients who underwent OLIF and diagnosed LSCI in 29.6% (16 patients) using a digital thermometer. Among these patients, 87.5% (14 of 16 patients) reported moderate discomfort, while 12.5% (2 of 16 patients) reported severe discomport, with symptoms typically persisting for 1.5 to 12 months. Our study demonstrated that the incidence of LSCI after OLIF was 17.5% (35 of 200 patients), consistent with the range reported in previous studies. However, it seems that LSCI might be underestimated in specific studies, potentially because of asymptomatic patients, lack of diagnostic tools for detection, and underrecognition by physicians.[15,30,31] To mitigate underdiagnosis, we utilized a combination of physical examination and digital infrared thermometer as diagnostic methods to obtain the accurate incidence of LSCI.

During the surgical approach in OLIF, the left LSC can be inadvertently injured by resection, electrocoagulation, compression, or traction. Some authors failed to address the importance of preserving the LSC during surgical procedures,[17,22,30] whereas others recommended anterior retraction of the LSC if necessary.[1,4,15] In our cases where the LSC obstructed the working channel, we aimed to protect the LSC by gently retracting it aside before proceeding with the work on the intervertebral disc. Unfortunately, this surgical technique inadvertently exposes LSC to compression and traction injuries. Some studies indicated that both the duration and extent of nerve manipulation were crucial factors influencing the incidence and severity of nerve injury as well as the recovery period.[32,33] Itthipanichpong et al.,[34] who studied 43 cadavers, found that an estimate of an ability to mobilize the left LSC during OLIF at L2–3, L3–4, and L4–5 was approximately 3 mm.

Based on retraction time, Uribe et al.[35] conducted a retrospective study involving 323 patients who underwent L4–5 extreme lateral interbody fusion, revealing that 4.5% (13 patients) developed postoperative symptomatic neurapraxia of the lumbar plexus nerve, which showed significant positive association with prolonged retraction time. Recently, Zhao et al.[26] also found a direct correlation between extended surgical time and the incidence of LSCI in patients undergoing L4–5 OLIF in univariate analysis; however, precise retraction time was not documented. Similarly, our study revealed that prolonged retraction time plays a significant role in the incidence of LSCI, and is particularly problematic when duration exceeds 31.5 minutes. Unfortu-

nately, we did not record the magnitude of the nerve manipulation during surgery. Therefore, our recommendation is to reduce both the duration and extent of LSC retraction during OLIF procedures during discectomy, endplate preparation, and cage insertion to minimize compression and/or traction injuries, thereby potentially reducing the occurrence of LSCI.

We also found that the likelihood of LSCI was significantly higher in patients operated under CT-based navigation than in those operated under fluoroscopic guidance in the univariate analysis. A possible reason for this could be the increased time spent in navigation during the surgical workflow, resulting in a longer retractor time. This is the most likely explanation that the significant association with this parameter was no longer observed in our multivariable model. According to a radiographic study, the location and running course of LSC can be accessed in the preoperative MRI.[36] According to Mahatthanatrakul et al.,[37] the left LSC was identifiable in 90.9% (131 of 144) of patients with lumbar spinal diseases, with a higher likelihood of being unidentifiable in patients with scoliosis. Although our study showed that the presence of LSC on preoperative MRI of the intervertebral disc level was not a potential risk factor for LSCI, univariable analysis demonstrated a positive relationship between these 2 factors. We believe that if the LSC can be identified on the MRI, it indicates that part of the LSC was large and situated in the surgical pathway, making it more susceptible to injury. Traction or compression of these parts results in the obvious symptoms of LSCI. Conversely, the absence of LSC on MRI could indicate part of the interganglion branches. In cases of injury to these branches, only minor symptoms may be present, which can evade detection through physical examination and diagnostic methods. The preoperative ADH and PDH showed an inverse association with the incidence of LSCI in our univariable analysis, which was not consistent with the results of the multivariable model. A decrease in the intervertebral disc height is a result of degenerative processes, often accompanied by osteophyte formation. These osteophytes may lead to displacement of the LSC and reduced intraoperative mobilization ability, potentially contributing to a greater likelihood of LSCI in more degenerated spines.[38] In addition, the difference between pre- and postoperation ADH and SL exhibited a positive association with the incidence of LSCI in univariable analysis, potentially attributed to the elongation of the spinal column from the spinal cage. However, this significance was not observed in the adjusted analysis.

Our study has several limitations. First, it is a retrospective review with inherent selection biases and the possibility of hidden confounding factors. All radiographic and some operative parameters, including retraction time, were analyzed only in patients who underwent single-level surgery due to numerous confounding factors and potential measurement errors. Second, this study was conducted at a single institute where surgeons tend to have similar surgical techniques, and the results may not be generalizable to other settings. Third, the diagnostic criteria for LSCI are not standardized, and further studies are needed to establish reliable criteria. Lastly, intraoperative injury to the LSC, a critical factor influencing LSCI, was not documented in the database. Nevertheless, we consistently protected the LSC during the surgical procedure by retracting it aside. Despite these limitations, this study was based comprehensive diagnostic criteria and a large sample size, and offers valuable insights into the incidence of and risk factors for LSCI following OLIF. Prospective multicentre studies conducted with diverse patient populations would provide additional information to contribute to the evidence base.

CONCLUSION

In this retrospective study, we noted that LSCI occurred in 17.5% (35 out of 200) patients who underwent OLIF. Furthermore, prolonged retraction time emerged as an independent risk factor for LSCI, particularly when it exceeded 31.5 minutes. Although meticulous disc preparation and cage insertion in the proper position are necessary in OLIF to achieve spinal fusion, protecting the LSC during surgery and reducing retraction time should be prioritized to prevent LSCI.

NOTES

Conflict of Interest: The authors have nothing to disclose.

Funding/Support: This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contribution: Conceptualization: WS; Formal analysis: SJK, TT; Investigation: TT; Methodology: WL, WY; Project administration: WS, VK; Writing – original draft: TT; Writing – review & editing: VK.

ORCID

Weerasak Singhatanadgige: 0000-0001-7166-1381
Thanadol Tangdamrongtham: 0000-0002-4215-8880
Worawat Limthongkul: 0000-0002-0116-8791
Wicharn Yingsakmongkol: 0000-0002-8784-7604

https://doi.org/10.14245/ns.2448536.268

Stephen J. Kerr: 0000-0002-1919-4525
Teerachat Tanasansomboon: 0000-0002-2448-2118
Vit Kotheeranurak: 0000-0002-9593-429X

REFERENCES

1. Silvestre C, Mac-Thiong JM, Hilmi R, et al. Complications and morbidities of mini-open anterior retroperitoneal lumbar interbody fusion: oblique lumbar interbody fusion in 179 patients. Asian Spine J 2012;6:89-97.
2. Park HY, Ha KY, Kim YH, et al. Minimally invasive lateral lumbar interbody fusion for adult spinal deformity: clinical and radiological efficacy with minimum two years follow-up. Spine (Phila Pa 1976) 2018;43:E813-21.
3. Mobbs RJ, Phan K, Malham G, et al. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. J Spine Surg 2015;1:2-18.
4. Fujibayashi S, Hynes RA, Otsuki B, et al. Effect of indirect neural decompression through oblique lateral interbody fusion for degenerative lumbar disease. Spine (Phila Pa 1976) 2015;40:E175-82.
5. Molinares DM, Davis TT, Fung DA. Retroperitoneal oblique corridor to the L2-S1 intervertebral discs: an MRI study. J Neurosurg Spine 2016;24:248-55.
6. Li HM, Zhang RJ, Shen CL. Radiographic and clinical outcomes of oblique lateral interbody fusion versus minimally invasive transforaminal lumbar interbody fusion for degenerative lumbar disease. World Neurosurg 2019;122:e627-38.
7. Zhao L, Xie T, Wang X, et al. Comparing the medium-term outcomes of lumbar interbody fusion via transforaminal and oblique approach in treating lumbar degenerative disc diseases. Spine J 2022;22:993-1001.
8. Shimizu T, Fujibayashi S, Otsuki B, et al. Indirect decompression via oblique lateral interbody fusion for severe degenerative lumbar spinal stenosis: a comparative study with direct decompression transforaminal/posterior lumbar interbody fusion. Spine J 2021;21:963-71.
9. Joseph JR, Smith BW, La Marca F, et al. Comparison of complication rates of minimally invasive transforaminal lumbar interbody fusion and lateral lumbar interbody fusion: a systematic review of the literature. Neurosurg Focus 2015;39:E4.
10. Walker CT, Farber SH, Cole TS, et al. Complications for minimally invasive lateral interbody arthrodesis: a systematic review and meta-analysis comparing prepsoas and transpsoas approaches. J Neurosurg Spine 2019;30:446-60.
11. Xu DS, Walker CT, Godzik J, et al. Minimally invasive anterior, lateral, and oblique lumbar interbody fusion: a literature review. Ann Transl Med 2018;6:104.
12. Kotheeranurak V, Jitpakdee K, Lin GX, et al. Subsidence of interbody cage following oblique lateral interbody fusion: an analysis and potential risk factors. Global Spine J 2023;13:1981-91.
13. Quillo-Olvera J, Lin GX, Jo HJ, et al. Complications on minimally invasive oblique lumbar interbody fusion at L2-L5 levels: a review of the literature and surgical strategies. Ann Transl Med 2018;6:101.
14. Abe K, Orita S, Mannoji C, et al. Perioperative complications in 155 patients who underwent oblique lateral interbody fusion surgery: perspectives and indications from a retrospective, multicenter survey. Spine (Phila Pa 1976) 2017;42:55-62.
15. Mehren C, Mayer HM, Zandanell C, et al. The oblique anterolateral approach to the lumbar spine provides access to the lumbar spine with few early complications. Clin Orthop Relat Res 2016;474:2020-7.
16. Pan Q, Yu H, He X, et al. Lumbar sympathetic trunk injury: an underestimated complication of oblique lateral interbody fusion. Orthop Surg 2023;15:1053-9.
17. Kim JS, Choi W, Sung J. 314 Minimally invasive oblique lateral interbody fusion for L4-5: clinical outcomes and perioperative complications. Neurosurgery 2016;63:190-1.
18. Hrabalek L, Sternbersky J, Adamus M. Risk of sympathectomy after anterior and lateral lumbar interbody fusion procedures. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub 2015;159:318-26.
19. Rutter G, Phan K, Smith A, et al. Morphometric anatomy of the lumbar sympathetic trunk with respect to the anterolateral approach to lumbar interbody fusion: a cadaver study. J Spine Surg 2017;3:419-25.
20. Rocco AG, Palombi D, Raeke D. Anatomy of the lumbar sympathetic chain. Reg Anesth 1995;20:13-9.
21. Gragnaniello C, Seex KA. Anterior to psoas fusion of the lumbar spine. Neurosurg Focus 2013;35(2 Suppl):Video 13.
22. Li JX, Phan K, Mobbs R. Oblique lumbar interbody fusion: technical aspects, operative outcomes, and complications. World Neurosurg 2017;98:113-23.
23. Buche M, Randour P, Mayne A, et al. Neuralgia following lumbar sympathectomy. Ann Vasc Surg 1988;2:279-81.
24. Schulte TL, Mester B, Oberdiek D, et al. Approach-related lesions of the sympathetic chain in anterior correction and instrumentation of idiopathic scoliosis. Eur Spine J 2010;19:

1558-68.
25. Kasliwal MK, Deutsch H. Anhidrosis after anterior retroperitoneal approach for L4-L5 artificial disc replacement. J Clin Neurosci 2011;18:990-1.
26. Zhao L, Hou W, Shi H, et al. Risk factors for postoperative sympathetic chain dysfunction following oblique lateral lumbar interbody fusion: a multivariate analysis. Eur Spine J 2023;32:2319-25.
27. Hornberger J, Grimes K, Naumann M, et al. Recognition, diagnosis, and treatment of primary focal hyperhidrosis. J Am Acad Dermatol 2004;51:274-86.
28. Gong K, Lin Y, Wang Z, et al. Restoration and maintenance of segment lordosis in oblique lumbar interbody fusion. BMC Musculoskelet Disord 2022;23:914.
29. Gragnaniello C, Seex K. Anterior to psoas (ATP) fusion of the lumbar spine: evolution of a technique facilitated by changes in equipment. J Spine Surg 2016;2:256-65.
30. Woods KR, Billys JB, Hynes RA. Technical description of oblique lateral interbody fusion at L1-L5 (OLIF25) and at L5-S1 (OLIF51) and evaluation of complication and fusion rates. Spine J 2017;17:545-53.
31. Fujibayashi S, Kawakami N, Asazuma T, et al. Complications associated with lateral interbody fusion: nationwide survey of 2998 cases during the first 2 years of its use in Japan. Spine (Phila Pa 1976) 2017;42:1478-84.
32. Dezawa A, Unno K, Yamane T, et al. Changes in the microhemodynamics of nerve root retraction in patients with lumbar spinal canal stenosis. Spine (Phila Pa 1976) 2002;27:2844-9.
33. Pedowitz RA, Garfin SR, Massie JB, et al. Effects of magnitude and duration of compression on spinal nerve root conduction. Spine (Phila Pa 1976) 1992;17:194-9.
34. Itthipanichpong T, Tanasansomboon T, Jaruthien N, et al. Lumbar sympathetic chain tract and mobility of oblique lumbar interbody fusion approach: a cadaveric study. World Neurosurg 2023;175:e775-9.
35. Uribe JS, Isaacs RE, Youssef JA, et al. Can triggered electromyography monitoring throughout retraction predict postoperative symptomatic neuropraxia after XLIF? Results from a prospective multicenter trial. Eur Spine J 2015;24 Suppl 3:378-85.
36. Feigl GC, Kastner M, Ulz H, et al. The lumbar sympathetic trunk: its visibility and distance to two anatomical landmarks. Surg Radiol Anat 2013;35:99-106.
37. Mahatthanatrakul A, Itthipanichpong T, Ratanakornphan C, et al. Relation of lumbar sympathetic chain to the open corridor of retroperitoneal oblique approach to lumbar spine: an MRI study. Eur Spine J 2019;28:829-34.
38. Feigl GC, Kastner M, Ulz H, et al. Topography of the lumbar sympathetic trunk in normal lumbar spines and spines with spondylophytes. Br J Anaesth 2011;106:260-5.

 https://doi.org/10.14245/ns.2448536.268