Minimally Invasive Oblique Lateral Interbody Fusion for L4-5: Surgical Outcomes and Perioperative Complications

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Research Article

Keywords: degenerative disorders, minimally invasive spinal, oblique lateral interbody fusion, complication

Posted Date: April 13th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1445188/v1

Abstract

Purpose:

Oblique lateral interbody fusion is increasingly being used by spine surgeons due to its many advantages. Although clinical analysis of oblique lateral interbody fusion has been assessed in many studies, surgical outcomes and perioperative complications of oblique lateral interbody fusion technique at L4-5 level have been rarely reported. The aim of this study is to investigate surgical outcomes and perioperative complications of oblique lateral interbody fusion for patients with degenerative disorders at L4-5, with it being the most common level of degenerative lumbar spine disease.

Methods:

Twenty-eight patients who underwent oblique lateral interbody fusion at L4-5 were enrolled. The numeric rating scale and Oswestry disability index score were used to assess clinical and functional outcomes. Radiological data included fusion rate, as well as measured changes in the disc and bilateral foramen height. Perioperative complications were also assessed.

Results:

The numeric rating scales for back and leg, and Oswestry disability index were significantly improved at postoperative 6-month, 1-year, and 2-year compared with preoperative condition ($p < 0.05$). The changes in the disc height, bilateral foramen height, and segmental lordotic angle between the preoperative and postoperative periods were significant ($p < 0.05$). Disc heights at postoperative 6 months, 1 year, and 2 years were 12.1, 12.0, and 11.7mm, respectively. The segmental lordotic angle at postoperative 6 months, 1 year, and 2 years were 14.9, 14.2, and 14.6 degrees, respectively. Fusion rates at postoperative 6-month, 1-year, and 2-year were 85.71%, 96.42%, and 100%, respectively. Complications occurred in 7 of 28 patients, there was no major complication (0%) occurred. Sympathetic chain symptoms were the most common approach-related complications.

Conclusion:

Oblique lateral interbody fusion could be considered as an acceptable surgical option for degenerative lumbar lesions, especially at L4-5 level.

Introduction

Along with aging of social population and changes in modern working and living styles, degenerative lumbar spine disease (DLSD) has become a common problem [1]. Over the past few years, surgeons in the field of spinal surgery have attempted to treat DLSD through various methods, including lumbar interbody fusion (LIF) which plays an important role in the management of DLSD [2]. Many previous studies have described both advantages and disadvantages of various LIF surgeries. However, there is no definitive evidence showing that one approach is superior to another in terms of clinical or radiological outcomes [3].

Both surgeons and patients attempt to innovate surgical techniques to achieve shorter operative time and faster recovery with reduced operative complications. Thus, minimally invasive LIF surgery has become the current trend due to this continuous increase in demand for clinical results [4].

LIF can be performed with five main approaches: posterior lumbar interbody fusion (PLIF) [5], transforaminal lumbar interbody fusion (TLIF) [6], anterior lumbar interbody fusion (ALIF) [7], lateral lumbar interbody fusion (LLIF), and oblique lateral interbody fusion (OLIF). Along with better understanding and refinement of minimally invasive spinal (MIS) surgery techniques, there has been a trending shift from traditional PLIF and TLIF to MIS-TLIF, as well as from traditional ALIF and LLIF to OLIF. OLIF is increasingly being used by spine surgeons due to its many advantages.

ALIF, PLIF, TLIF show high rates of success, however, intraoperative concerns and iatrogenic complications are also known [8–12]. The most common complication of LLIF is nerve injury: it has been reported that 30% of patients show paresthesia in the leg and 27% of patients show thigh pain after DLIF surgery [13]. To counter approach-related hurdles of ALIF, PLIF, TLIF and LLIF, OLIF has been proposed as a solution to access lumbar disc space by taking advantages of the surgical space between the aorta and psoas muscle [14,15]. The proto-type of OLIF was first described by Michael Mayer in 1997 [16]. Consequently, many authors have performed OLIF-related clinical analyses [9,14,17]. Although clinical analyses of OLIF have been assessed in many studies, surgical outcomes and perioperative complications of OLIF technique at L4-5 level have been rarely reported. Therefore, the objective of this study is to determine surgical outcomes and perioperative complications of OLIF in patients with degenerative disorders at L4-5, the most common level of DLSD.

Materials And Methods

Patient population

This is a retrospective study in a single center conducted between June 2016 and May 2019. The method used in this study is the same as that used in another study by the authors[18]. This study was approved by the Institutional Review Board (IRB) of our institution. Patients who were 18 years or older who suffered from low back pain and/or leg pain confirmed to be low-grade (Meyerding Grade I or II) isthmic spondylolisthesis or degenerative spondylosis (including degenerative spondylolisthesis, central stenosis with foraminal/extraforaminal stenosis, degenerative disc disease (DDD), and recurrent herniated nucleus pulposus (HNP)) at L4-5 level, with radiological examinations confirmation, with OLIF procedure at L4-5 alone, were included in this study. All patients had chronic and persistent radicular leg pain, progressive neurologic deficits, persistent and unremitting lower-back pain for more than 3 months, and loss of quality of life before surgery was performed. All patients having a minimum of 10 mm corridor of OLIF were enrolled in this study. Exclusion criteria were: 1) patients who were younger than 18 years of age, 2) with follow-up period less than 1 year, 3) with scoliosis (Cobb's angle > 15 degrees), 4) combined with

other level fusion surgery, 5) with acute spondylodiscitis, trauma, or spinal metastasis, and 6) with less than 10 mm corridor of OLIF.

Clinical data

Clinical data were collected from electrical chart record systems. Demographic data included age, gender, body mass index (BMI), bone mineral density (BMD), and primary diagnosis of L4-5 level, surgical protocol, and follow-up periods. Perioperative data included co-morbidities, hospital stay, anesthesia time, operation time, intraoperative blood loss, transfusion, complications, numeric rating scale (NRS, 0–10), Oswestry disability index (ODI, 0-100%) score, and satisfaction of patients. Clinical data were assessed before surgery and postoperatively at 6 months, 1 year, and 2 years.

Radiological data

Preoperative evaluation consisted of plain radiographs of the lumbar spine, whole spine, computed tomography (CT), and magnetic resonance imaging (MRI). All patients having a minimum of 10 mm corridor of OLIF were enrolled in this study. Radiological data after surgery were obtained from antero-posterior, lateral and dynamic standing X-ray images at 1 month, 3 months, 6 months, 1 year, and 2 years. Whole spine X-rays and CT were obtained at 6, 12, and 24 months after surgery. An independent observer other than the charging surgeon made radiographic evaluations. Disc height of L4-5 was measured at the midpoint of spinal column on a lateral standing plain radiograph (Fig. 1). The segmental lordotic angle was measured between the upper endplate of the cranial side of the vertebral body and the lower endplate of the caudal side of the vertebral body for L4-5 level (Fig. 2). The lumbar lordotic angle was measured between the upper endplate of the L1 vertebral body and the upper endplate of the S1 vertebral body (Fig. 2). Foramen height of L4-5 was measured between the lower pedicle arch of the cranial side of the vertebral body and the upper pedicle arch of the caudal side of the vertebral body (Fig. 3). Fusion was defined according to Modified Bridwell fusion criteria [19,20]. Any cage subsidence, cage dislodgment, and hardware failure were recorded. Those parameters were determined using a measuring program with a built-in picture archiving communication system (Maroview, Marotech, Seoul, Korea).

Surgical protocol

Patient was placed in a right-sided lateral decubitus position. Under fluoroscopic control, the anatomical surface of L4-5 intervertebral disc in its true lateral view was marked on the skin. Standard preoperative preparation of surgical field was done. Surgeon performed all procedures of OLIF in front of the patient. Skin incision (2.5-3 cm) was made in the L4-5 intervertebral disc level and parallel to external oblique muscle fibers (Fig. 4). External oblique, internal oblique, and transverse abdominal muscles were dissected along the direction of their fibers using a blunt muscle-splitting technique. Retroperitoneal space was accessed by blunt dissection along the retroperitoneal fat tissue. The peritoneal sac was mobilized anteriorly. The psoas muscle was dissected with index finger and retracted posteriorly. The L4-5 intervertebral disc space was exposed and tubular retractor system was docked (Fig. 5). Special attention was given to the genitofemoral nerve, the sympathetic chain, left common iliac artery, segmental arteries, and iliolumbar veins. Imaging guidance under the fluoroscopy was used to confirm

the correct level. After discectomy, vertebral endplates were prepared and subchondral bone was gently exposed. To achieve interbody fusion, a cage packed with allograft bone chips mixed with demineralized bone matrix (DBM) (GRAFTON Putty (Medtronic, Memphis, TN)) was inserted (Fig. 6) for all subjects in exception to two cases. In two cases of severe osteoporosis and rheumatoid arthritis, iliac bone graft was harvested for interbody fusion. After the anterolateral procedure, posterior lumbar stabilization was performed with percutaneous pedicle screw fixation for most cases. There was no neuromonitoring used in the OLIF surgery of all patients.

Statistical analysis

Statistical analysis was done by statisticians in our institute using Statistical Analysis System (SAS) Version 9.4 (SAS Institute, Cary, NC, USA). Different parameters measured between preoperative and postoperative data were assessed with Chi-square test for categorical variables. Data are presented as n (%) for categorical variables and mean ± standard deviation (SD) for continuous variables. Repeated measures Analysis of variance (RMANOVA) was used to compare continuous variables of patients between their preoperative and postoperative data. Generalized estimating equations (GEE) were used to compare categorical variables of patients between preoperative and postoperative data. A P value < 0.05 was considered statistically significant.

Results

Patient characteristics

A total of 28 patients were included in this study. The mean age of these patients was 63.8 ± 7.9 years (range, 49.0-78.0 years). The mean follow-up duration was 27.8 ± 9.4 months (range, 12.0-46.0 months). Demographic data of patients are summarized in Table 1.

Clinical outcomes

The mean hospital stay of all patients was 6.4 ± 3.2 days (range, 4.0-31.0 days). The mean operation time was 113.9 ± 83.1 minutes (range, 70.0-290.0 minutes) and the mean operation time of per level OLIF procedure was 42.9± 22.6 minutes (range, 30.0-70.0). Two patients were transfused intraoperatively. The mean blood transfusion volume was 33.6 ± 25.2 ml (range, 0-500.0 ml). Perioperative data of patients are summarized in Table 2. ODI significantly (P < 0.05) improved at postoperative 6 months, 1 year, and 2 years compared with the preoperative condition (Table 3). NRS for back and leg also significantly (P < 0.05) improved at postoperative 6 months, 1 year, and 2 years compared with the preoperative condition (Table 3). One patient who had been treated due to dermatomyositis underwent radiofrequency ablation for sacroiliac joint pain a year after the OLIF technique was performed.

The most common co-morbidity was associated to cardiovascular problems (11/28, 39.3%) such as hypertensive disorders and endocrinological diseases (10/28, 35.7%). There were 6 patients

with diabetes, 3 patients with rheumatoid arthritis, and 1 patient with dermatomyositis (Table 4). Complications occurred in 7 (25%) of 28 patients. Approach-related complications occurred in 6 (21.4%) of 28 patients. Sympathetic chain symptoms were the most common approach-related complications (4 patients). Approach non-related complications occurred in 1 (3.6%) of 28 patients (Table 5). All 7 patients were treated with conservative care, of which 6 gradually recovered within 3- to 6-months period. In the other one patient, symptoms persisted beyond 6 months. Fortunately, we don't have any fatal complications in this study enrolled.

Patient's satisfaction rate (PSR), return to daily activity, and surgical recommendation to others at every follow-up period were also evaluated. Results at final follow-up were summarized in Table 6.

Radiological outcome

Disc heights at postoperative 6 months, 1 year, and 2 years were 12.1, 12.0, and 11.7mm, respectively, which significantly ($P < 0.05$) increased compared with preoperative disc height. Bilateral foramen height also significantly ($P < 0.05$) increased at postoperative 6 months, 1 year, and 2 years (16.6, 16.1, and 15.4mm, respectively, in the left side, and 17.2, 16.3, and 15.7mm, respectively, in the right side). Segmental lordotic angle at postoperative 6 months, 1 year, and 2 years were 14.9, 14.2, and 14.6 degrees, respectively. There was a significant ($P < 0.05$) increase postoperatively compared with preoperative data. Lumbar lordotic angle at postoperative 6 months, 1 year, and 2 years were 41.5, 41.5, and 41.2 degrees, respectively. In general, there was significant ($P < 0.05$) increase postoperatively compared with preoperative data (Table 7).

Based on modified Bridwell fusion criteria, fusion rates of L4-5 level at postoperative 6 months, 1 year, and 2 years were 85.71%, 96.42%, and 100%, respectively (Table 8). A subsidence of L4-5 occurred in 6 (21.4%) patients at 1 year after surgery and in 7 (25.0%) patients at 2 years after surgery (Table 9). There was no revision surgery related to cage subsidence. Any symptomatic pseudo-arthrodesis has not been observed during the follow-up period.

Discussion

The incidence of degenerative lumbar disease is continuously increasing due to the ageing of the population. The most common levels of degenerative lesions in the lumbar spine are L4-5 and L5-S1 levels, which include: DDD, HNP, lumbar spinal stenosis, and unstable spinal disorders with chronic and sustained clinical symptoms [21]. Due to increasing demand for minimally invasive surgery, spine surgeons have a tendency of preferring MIS-TLIF [22–24], ALIF, LLIF, and OLIF. Although these have pros and cons in terms of surgical approaches and corridor, these techniques have given high fusion rate and satisfactory clinical results. ALIF and LLIF have strong advantages of restoration of sagittal and coronal alignment as well as high fusion rate. However, even though the incidence is low, ALIF has serious complications such as retrograde ejaculation and visceral or vascular injury [25–27]. According to the literature [28], LLIF has

frequent complications related to the approach such as lumbar plexopathy and others. Nevertheless, this approach may decrease vascular complications if compared to ALIF. In addition, it may not only yield a wide intervertebral endplate for spinal fusion but also result in excellent radiologic restoration of sagittal and coronal alignment. A previous cadaver study [29] reported that the incidence of LLIF approach-related lumbar plexus injury at L4-5 level is higher than that of other lumbar levels. To counter approach-related hurdles of ALIF and LLIF, OLIF has been proposed as a solution to access lumbar disc space through the corridor between the left common iliac artery and the anterior belly of the psoas muscle [14,15].

Many spine surgeons are adopting the OLIF technique due to its many potential advantages [14,30,31]. Moreover, recent study revealed that OLIF has a lower incidence of lumbar plexopathy when compared to direct lateral transpsoas interbody fusion [32]. Although the clinical analyses of OLIF have been investigated in many studies, surgical outcomes and perioperative complications of OLIF technique focused on L4-5 level have rarely been reported. In this study, we investigated surgical outcomes and perioperative complications of OLIF at L4-5 to determine whether OLIF is an acceptable procedure at L4-5 level or not.

Considering the origin of the technique, OLIF is a novel variation of the traditional lumbar interbody fusion technique developed from both ALIF and LLIF techniques. The main advantages of OLIF technique can be summarized as follows: (1) OLIF utilizes the potential space between the lateral border of the abdominal aorta and the anterior border of left psoas muscles. It is minimally invasive, resulting in less bleeding, shorter operative time, and faster postoperative mobilization [14]. (2) OLIF allows removal of a large amount of disc and a large volume of bone graft, thus achieving timely and solid fusion through indirect spinal canal decompression. It can effectively restore the disc space and intervertebral foramen height, allowing deformity correction with good results similar to ALIF or LLIF [30,33,34]. (3) OLIF uses a corridor that lies in the front of the psoas muscle, thereby enabling surgeons to avoid injury to that particular muscle as well as keeping away from the lumbar plexus. (4) Compared to direct lateral transpsoas interbody fusion, OLIF could be done in the patients with high ilium. Theoretically, this could avoid postoperative thigh weakness or lumbar plexopathy compared to the splitting maneuver of psoas muscle fibers in LLIF [32]. Moreover, intraoperative neurophysiological monitoring is not required [35], thus having a benefit in terms of cost-effectiveness. (5) The approach is not performed through the peritoneal cavity, therefore avoiding interference with abdominal organs. In addition, the incision in the abdominal wall is made along muscle fibers. This technique maintains the dominance of rectus abdominis, reduces nerve damage, improves postoperative wound healing, and prevents abdominal hernia [35].

Some previous studies [14,30,33,34,36,37] have reported that OLIF procedure is an acceptable technique in lumbar interbody fusion for degenerative lumbar spine disease. It has been reported to have good surgical results without major complications. Most degenerative lumbar lesions occur at the L4-5 level. Theoretically, OLIF technique may be able to avoid neurologic deficit associated with trans-psoas approach, which was also revealed by a previous study [32]. Our results demonstrated that: (1) clinical symptoms of all cases were improved significantly after surgery. ODI and NRS for back and leg

significantly ($P < 0.05$) improved at postoperative 6 months, 1 year, and 2 years compared with preoperative data. Patient satisfaction rate, return to daily activity, and surgical recommendation to others were also evaluated in all patients, showing good to excellent outcomes for all criteria. (2) All patients have had good surgical results without major complications (0%). Although a few patients complained of sympathetic syndrome and lumbar plexopathy, most symptoms were mild and transient. The majority of the symptoms improved within 6 months after surgery. There was no vascular or urinary injury in OLIF at L4-5 level. However, one case of ureter injury occurred in OLIF at L2-3 level [38], which was not enrolled in this study. The mean hospital stay after surgery was 6.4 days, longer than that expressed in other published data. Nonetheless, this criterion is not related to complications but rather with insurance and healthcare system regulations in authors' country. (3) Radiological data including disc height, segmental lordotic angle, and lumbar lordotic angle showed excellent results, thereby achieving good sagittal alignments. Foramen height was significantly increased postoperatively compared with preoperative data, thereby achieving good indirect decompression. Based on modified Bridwell fusion criteria, fusion rates of L4-5 level at postoperative 6 months, 1 year, 2 years were 85.71%, 96.42%, and 100%, respectively, similar to results of previous studies. The low fusion rate at 6 months and 1 year might be explained by the fact that the autograft from iliac bone was not used routinely because allograft with DBMs were used in all subjects in exception to two.

Lumbar plexus and psoas injury are unlikely in OLIF as dissection is performed anterior to the psoas muscle. However, potential risks associated with OLIF surgery include sympathetic dysfunction and vascular injury [31]. Thus, we should pay great attention to individual differences in OLIF regional anatomy, particularly in preoperative analysis. There was no vascular, urinary tract, or bowel injury in the patients enrolled in this study. Sympathetic chain symptoms were the most common approach-related complications (14.2%). During follow-up periods, four patients showed sympathetic chain symptoms (left leg swelling), three of which gradually recovered within 2 to 4 months. For the other remaining patient, mild symptoms persisted beyond 6 months. Lumbar plexopathy was observed in two patients. One patient suffered from left inguinal discomfort, this patient were treated with conservative care and gradually recovered 3 to 6 months after surgery. Another patient had mild paresthesia on inguinal area and subjective weakness, for only 6 months, only when he ran or climbed the stairs.

In cases of severe canal stenosis due to facet hypertrophy and lateral recess stenosis, it is not easy to achieve satisfactory decompression by OLIF alone. For such situations, patients underwent additional laminotomy or laminectomy at the same level (L4-5). In our series, 7 patients underwent additional decompressive laminotomy or laminectomy after OLIF at L4-5 level. Access corridor between the abdominal aorta and the left psoas muscles of less than 10 mm was a contraindication for OLIF procedure in our series.

In this study, the mean age of participant was 63.8 years. Most patients had medical co-morbidities (17/28, 60.7%). Nevertheless, their overall clinical outcome was satisfactory. There was no serious complication reported. Therefore, OLIF may be considered as an acceptable surgical option for degenerative lumbar lesions at L4-5 level.

Even though this study was the first investigation focusing on OLIF at L4-5 level, it had several limitations. First, it had a retrospective study design with a small samples size. A larger number of patients should be enrolled in future studies to confirm our findings. In addition, the duration of follow-up was relatively short. Further follow-up is needed to strengthen these observations. Lastly, a comparative study with other types of fusion surgery is needed. This is also the work we need to do in the future.

Conclusion

Due to increasing demand for minimally invasive surgery, OLIF procedure has been favored by many spine surgeons. Our clinical and radiologic results suggest that OLIF could be considered as a one of the acceptable surgical option for degenerative lumbar lesions, especially at L4-5 level.

Abbreviations

degenerative lumbar spine disease (DLSD)

bone mineral density (BMD)

Oswestry Disability Index (ODI)

lumbar interbody fusion (LIF)

oblique lateral interbody fusion (OLIF)

Declarations

Competing interests

The authors declare that they have no Conflicts of Interest.

Ethics approval and consent to participate

We got ethics approval from the Weihai Central Hospital ethics committee and were under Helsinki Declaration. Informed consent obtained from all patients had been written. This was a retrospective study, so the trial registration was not required.

Consent for publication

Not Applicable.

Availability of data and materials

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no Conflicts of Interest.

Funding

Not Applicable.

Authors' contributions

In our study, HBC and CZJ participated in the design of the study, YZP performed the statistical analysis and interpretation of data. ZCC drafted of the manuscript, JSK helped to draft the manuscript. All authors read and approved the final manuscript.

Acknowledgements

This does not apply.

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Tables

Table 1

Demographic data

Mean age: years (range)	63.8 ± 7.9 (49.0-78.0)
Gender: M/F	22/34
Mean BMI: cm/kg (range)	24.4 ± 3.5 (17.6-30.9)
Mean BMD: T-score (range)	-1.72 ± 1.74 (-4.6-2.1)
BMD ≤ -3.0 patients	12
Primary diagnosis of L4-5	
- DDD	4
- HNP (recurrent)	4
- Stenosis	24
- Spondylolisthesis	24
Mean follow-up periods: month (range)	27.8 ± 9.4 (12.0-46.0)
- 1 year: person	16
- 2 years: person	40

M: male; F: female; BMI: body mass index; BMD: bone mineral density; DDD: degenerative disc disease; HNP: herniated nucleus pulposus; OLIF: oblique lateral interbody fusion; TLIF: transforaminal lumbar interbody fusion.

Data are presented as n for categorical variables and mean ± standard deviation for continuous variables (range). Repeated measures analysis of variance was used to compare continuous variables of patients between preoperative and postoperative data. A P value < 0.05 was considered statistically significant.

Table 2

Perioperative data

Mean hospital stay: day (range)	6.4 ± 3.2 (4.0-31.0)
Mean anesthesia time: minute (range)	161.9 ± 84.1 (100.0-345.0)
Mean operation time: minute (range)	113.9 ± 83.1 (70.0-290.0)
Mean operation time of per level OLIF: minute (range)	42.9± 22.6 minutes (30.0-70.0).
Intraoperative blood loss: ml (range)	82.1 ± 24.8 (50.0-800.0)
Transfused patient: person	2
OLIF: oblique lateral interbody fusion.	
Data are presented as n for categorical variables and mean ± standard deviation for continuous variables (range).	

Table 3

Comparison of NRS and ODI score between preoperatively and postoperatively

Mean NRS for back: 0-10 (range)			
Pre-op	Post-op		*p* value
4.6 ± 2.3 (0-9)	6 months	2.3 ± 2.6 (0-6)	0.0029
	1 year	3.3 ± 1.9 (0-7)	0.0078
	2 years	2.4 ± 2.0 (0-7)	0.0107
Mean NRS for leg: 0-10 (range)			
Pre-op	Post-op		
6.1 ± 2.0 (2-10)	6 months	2.5 ± 1.7 (0-6)	< 0.0001
	1 year	2.1 ± 1.5 (0-6)	< 0.0001
	2 years	2.8 ± 2.0 (0-7)	0.0016
Mean ODI: 0-100% (range)			
Pre-op	Post-op		
48.1 ± 11.5 (34-67)	6 months	28.7 ± 17.1 (8-56)	< 0.0001
	1 year	26.1 ± 15.6 (12-56)	< 0.0001
	2 years	27.1 ± 14.0 (12-58)	0.0004
NRS: numeric rating scale; ODI: Oswestry disability index.			
Descriptive data are presented as mean ± standard deviation (range); Repeated measures analysis of variance was used to compare continuous variables of patients between preoperative and postoperative data; A P value < 0.05 was considered statistically significant.			

Table 4

Classification of co-morbidities

	Number of patients	Percentage
Cardiovascular	22	39.3%
Endocrinologic	20	35.7%
Pulmonary	8	14.3%
Gastrointestinal	2	3.6%
History of cancer	2	3.6%
Data are presented as n (%) for categorical variables.		

Table 5

Complications

Total	14 (25%)
Approach-related complication	
Sympathetic chain symptom	8 (14.2%)
Lumbar plexopathy (transient, less than 6 months)	2 (3.6%)
Lumbar plexopathy (> 6 months)	2 (3.6%)
Approach-nonrelated complication	
Iliac bone harvest pain	2 (3.6%)
Data are presented as n (%) for categorical variables	

Table 6

Satisfaction of patients

	Final follow-up
PSR: 0-100 (range)	76.7 ± 13.5 (40.0-100.0)
Return to daily activity: %	98.35
Surgical recommendation to others: %	89.67
PSR: patient's satisfaction rate. *Data are presented as % and mean ± standard deviation (range).*	

Table 7

Radiological factor

Disc height: mm (range)			
Pre-op	Post-op		*p* value
8.4 ± 3.6 (0-16.6)	Immediately	13.8 ± 2.1 (10.5-18.6)	< 0.0001
	6 months	12.1 ± 1.9 (9.0-16.4)	< 0.0001
	1 year	12.0 ± 2.0 (9.0-16.4)	< 0.0001
	2 years	11.7 ± 1.7 (9.0-14.2)	0.0019
Foremen height: mm (range)			
Pre-op	Post-op		*p* value
Lt	Lt		
14.9 ± 2.4 (9.1-19.8)	6 months	16.6 ± 1.9 (11.9-20.2)	< 0.0001
	1 year	16.1 ± 2.0 (11.5-19.2)	0.0033
	2 years	15.4 ± 1.7 (12.0-18.3)	0.0076
Rt	Rt		
14.4 ± 2.5 (9.5-18.6)	6months	17.2 ± 1.9 (14.2-21.9)	< 0.0001
	1 year	16.3 ± 2.1 (13.4-22.4)	< 0.0001
	2 years	15.7 ± 1.9 (13.2-19.0)	0.0070
Segmental lordotic angle: degree (range)			
Pre-op	Post-op		*p* value
13.4 ± 6.1 (0.1-25.1)	Immediately	15.9 ± 6.1 (3.3-28.2)	0.0032
	6 months	14.9 ± 7.2 (2.5-32.6)	0.0044
	1 year	14.2 ± 6.9 (2.5-32.6)	0.0066
	2 years	14.6 ± 8.5 (6.0-32)	0.0052
Lumbar lordotic angle: degree (range)			
Pre-op	Post-op		*p* value
39.2 ± 9.4 (20.8-56.5)	Immediately	41.1 ± 9.3 (24.3-64.8)	0.0042
	6 months	41.5 ± 9.5 (26.9-63.7)	0.0072
	1 year	41.5 ± 9.6 (26.9-59.7)	0.0054
	2 years	41.2 ± 8.9 (27.0-58.0)	0.0083
op: operation; Lt: left; Rt: right.			

Descriptive data are presented as mean ± standard deviation (range); Repeated measures analysis of variance was used to compare continuous variables of patients between preoperative and postoperative data; A P value < 0.05 was considered statistically significant..

Table 8

Fusion rate of L4-5 level

	6 months	1 year	2 years
Fusion rate %	85.71	96.42	100
Data are presented as %.			

Table 9

Cage subsidence

		1 year (21.4%)	2 years (25%)
Cage subsidence	2-5 mm: number (%)	10 (17.8%)	12 (21.4%)
	> 5mm: number (%)	2 (3.6%)	2 (3.6%)
Data are presented as n (%) for categorical variables			

Figures

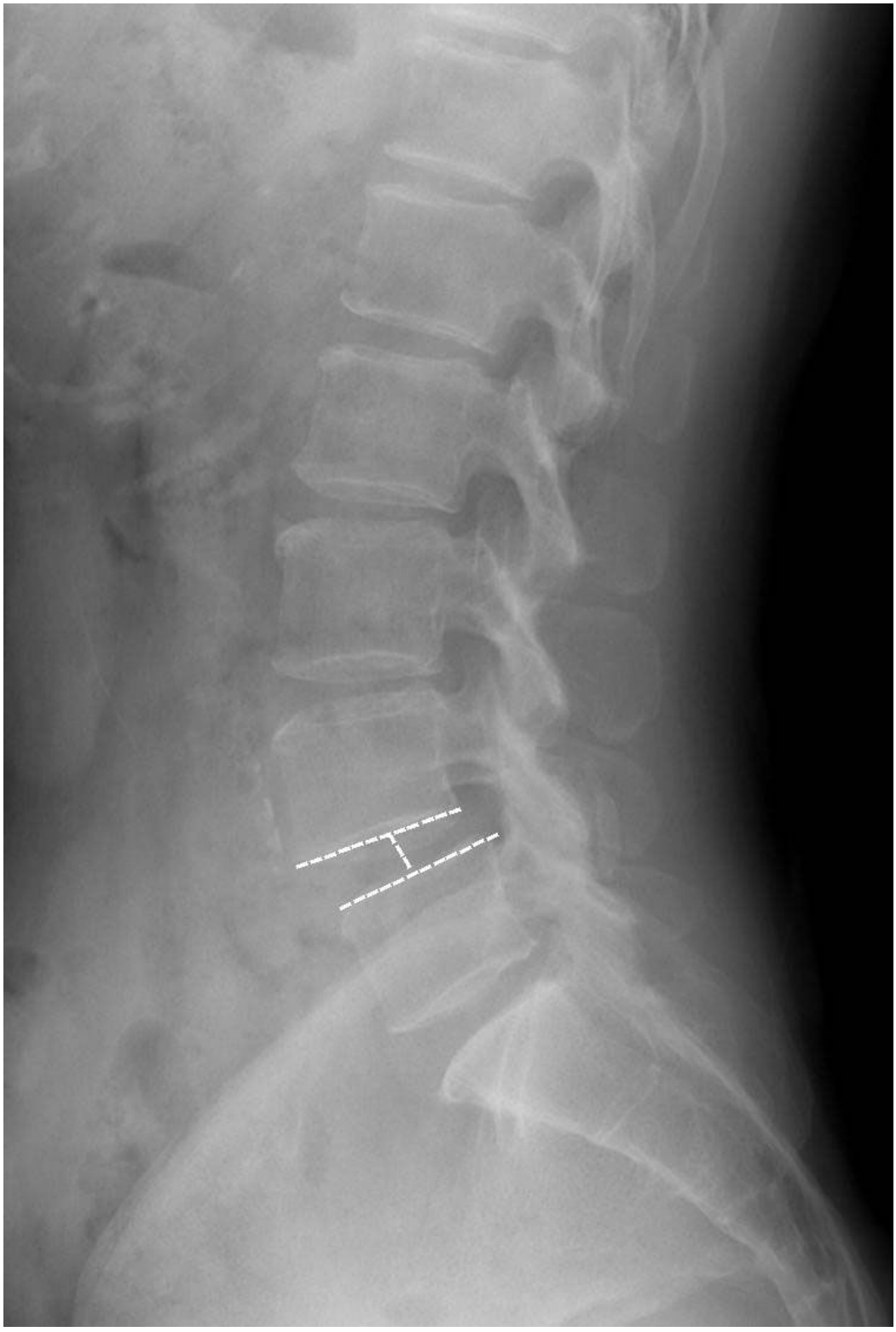

Figure 1

Disc height was measured at the midpoint of spinal column on plain standing lateral radiography.

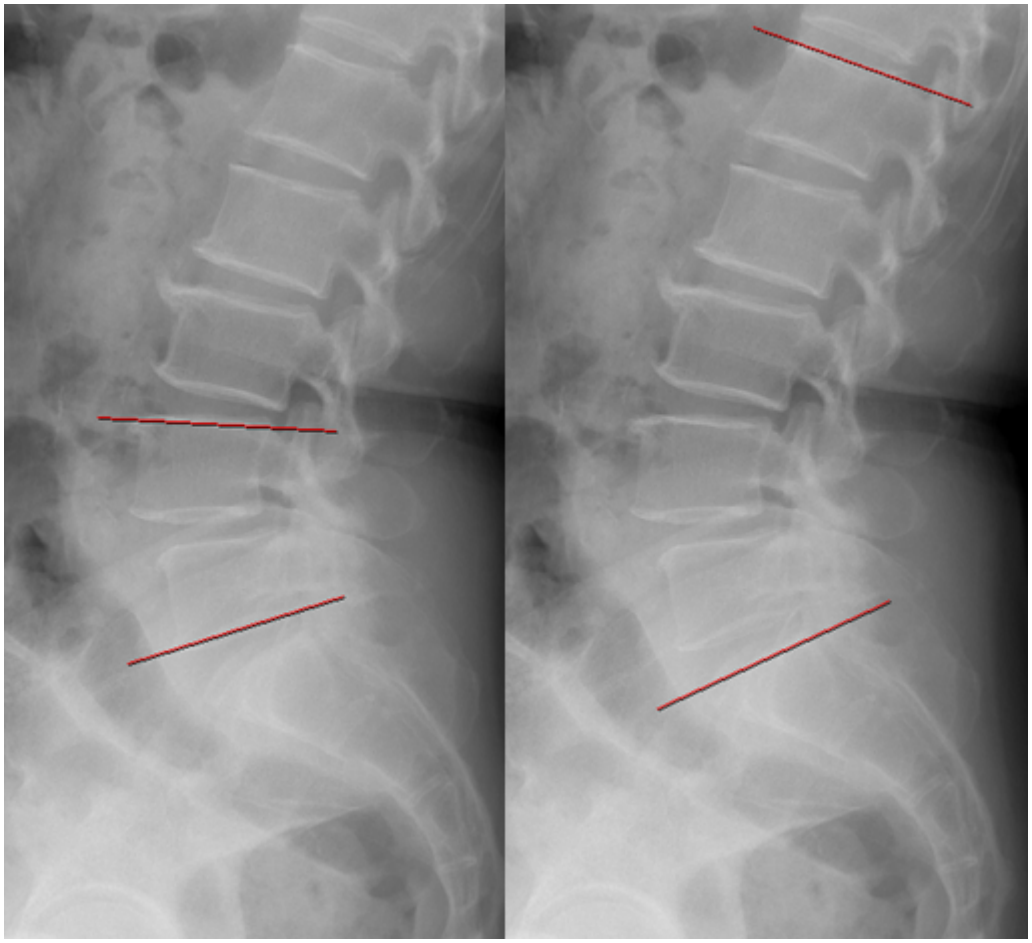

Figure 2

Segmental lordotic angle and lumbar lordotic angle.

A. The segmental lordotic angle was measured between the upper endplate of the cranial side of the vertebral body and the lower endplate of the caudal side of the vertebral body for the operating level. B. The lumbar lordotic angle was measured between the upper endplate of the L1 vertebral body and the upper endplate of the S1 vertebral body.

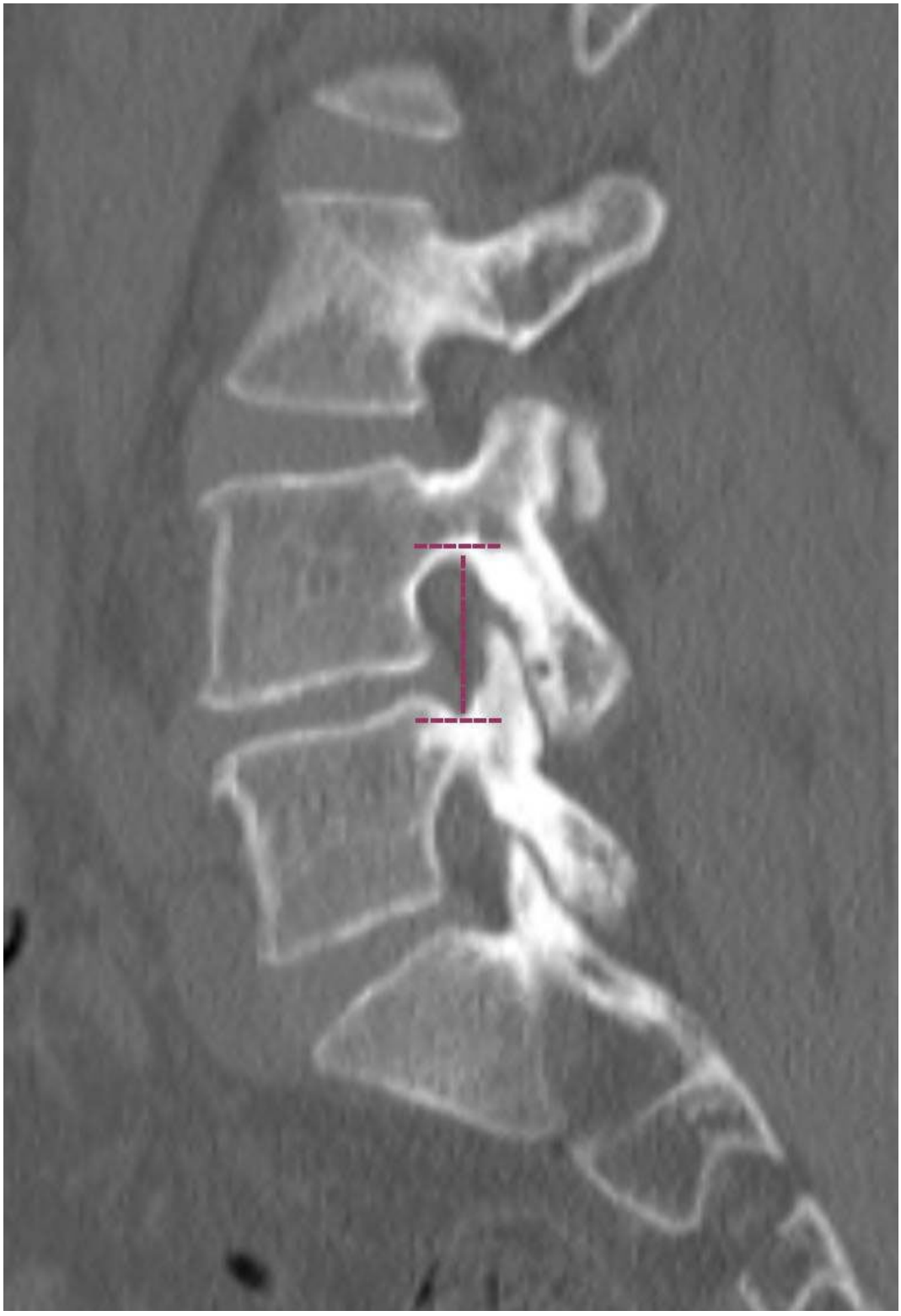

Figure 3

Foramen height was measured between the lower pedicle arch of the cranial side vertebral body and the upper pedicle arch of the caudal side vertebral body.

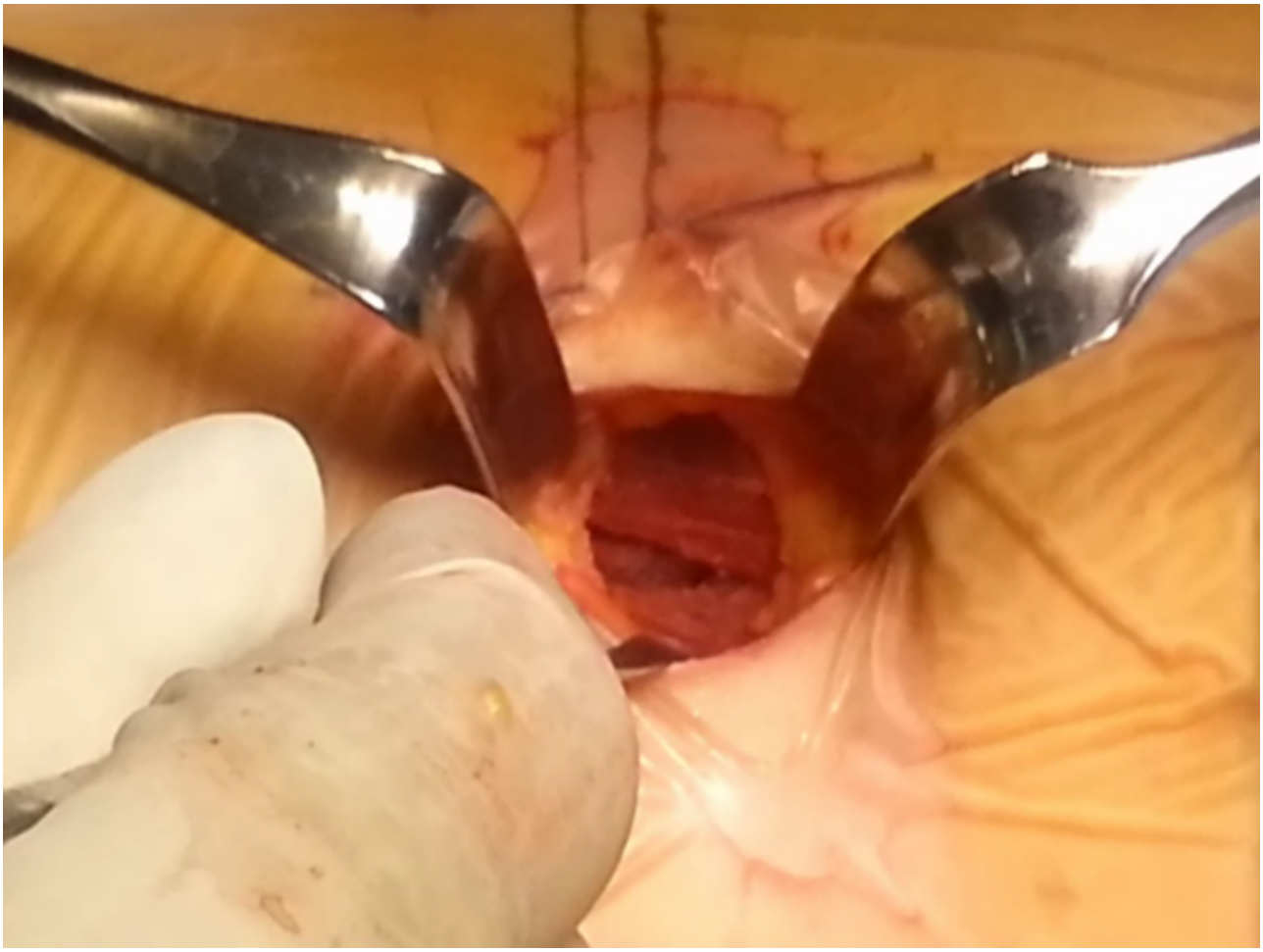

Figure 4

2.5-3 cm skin incision was made in projection of the target segment and parallel to external oblique muscle fibers.

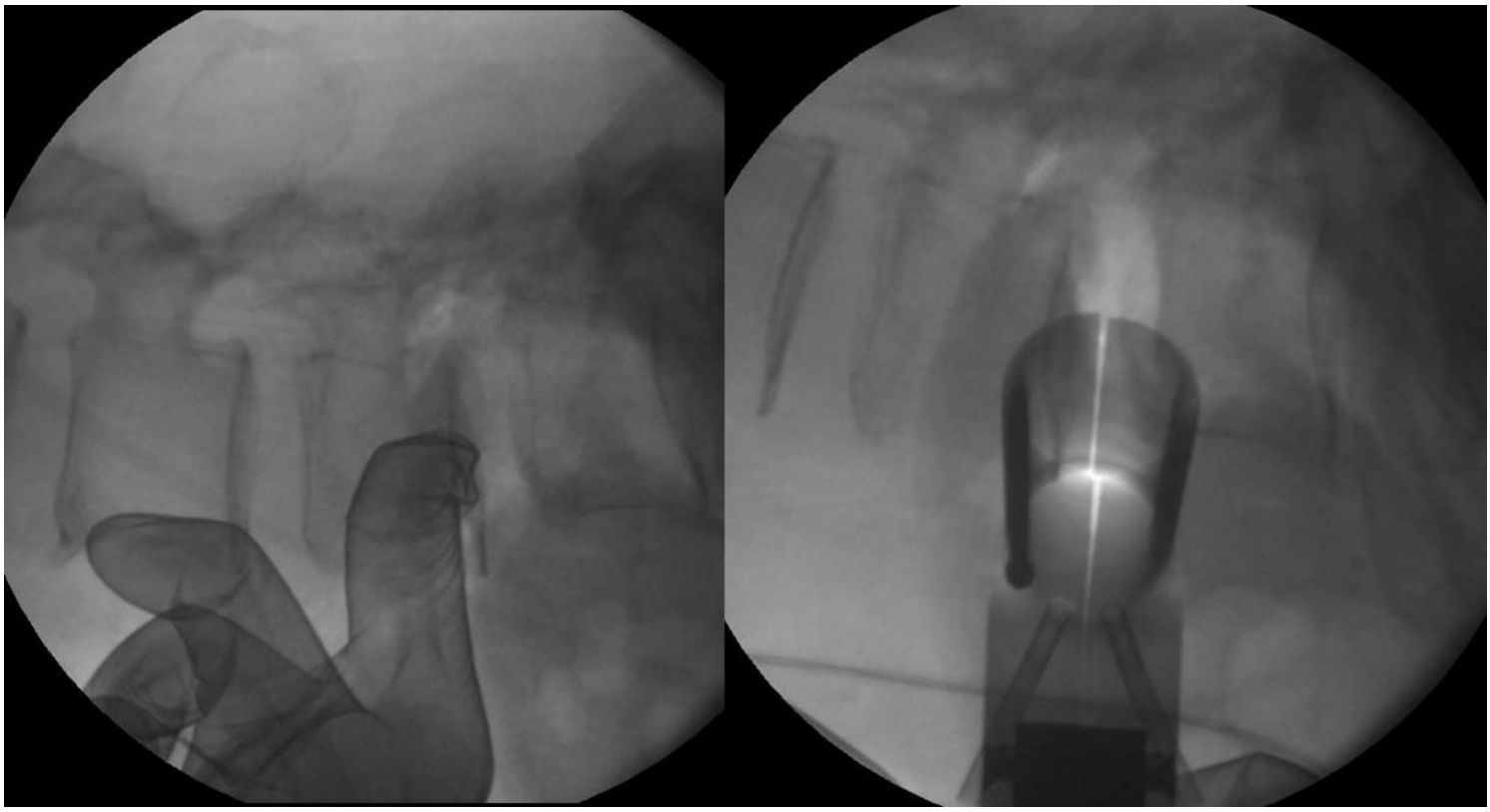

Figure 5

The psoas muscle was dissected with index finger and tubular retractor system was docked in the targeting disc level.

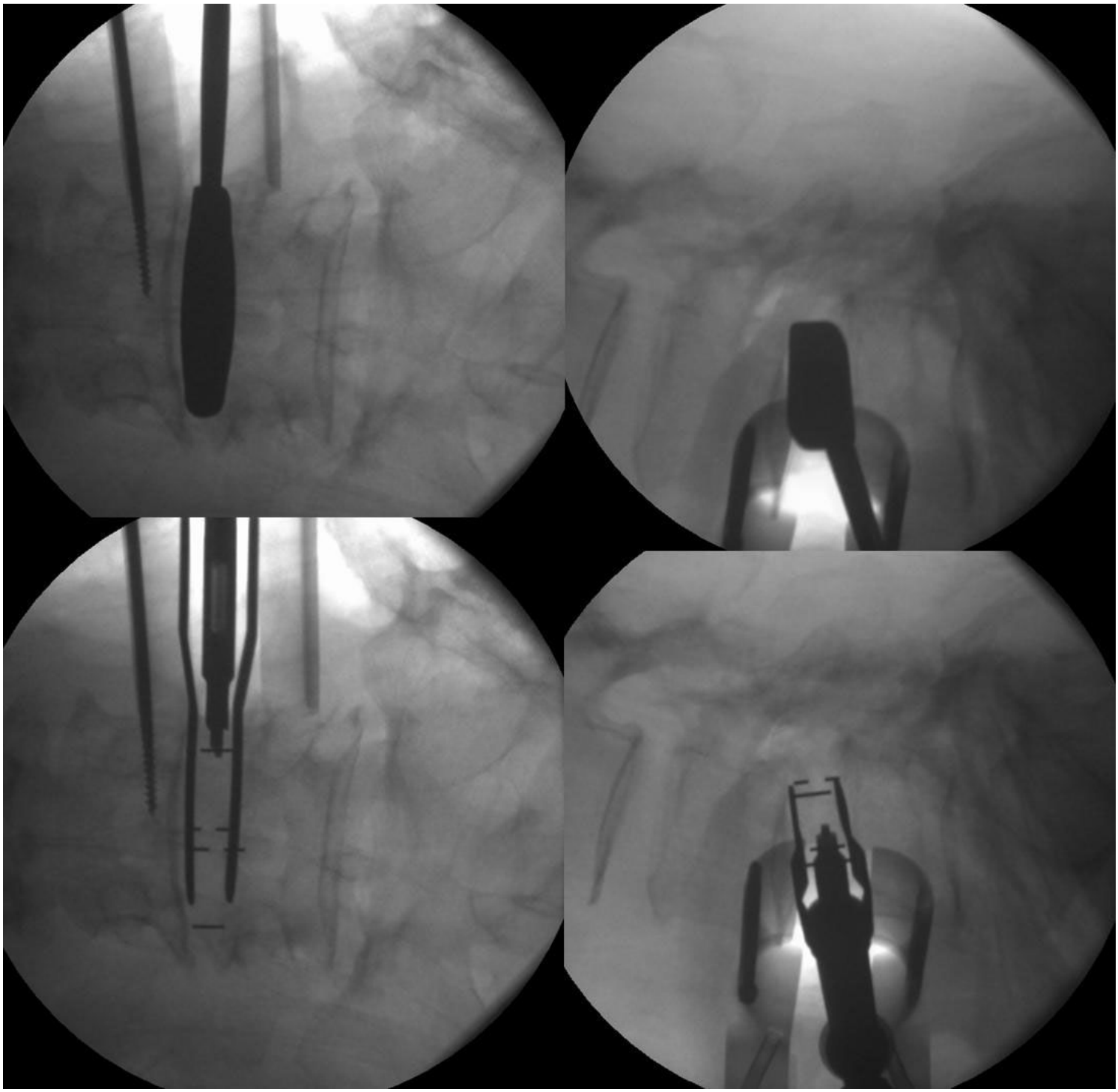

Figure 6

Vertebral endplates were prepared and cage packed with graft bone was inserted to the disc space.