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Research Article

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Application of Oblique Lumbar Interbody Fusion augmented with lateral vertebral screw for Adjacent Segment Disease: a retrospective study

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Abstract

Purpose: To evaluate the radiographic and clinical outcomes of oblique lumbar interbody fusion (OLIF) augmented with lateral vertebral screw fixation as revision surgery in adjacent segmental disease (ASD) treatment compared to transforaminal lumbar interbody fusion (TLIF) reoperation.

Methods: A retrospective study was conducted in the orthopedic department of Dushu Lake Hospital affiliated to Suzhou University from January 2019 to June 2023. Thirty patients with ASD underwent single segmental OLIF augmented with lateral vertebral rod-screw fixation, and another thirty-two individuals had extended TLIF surgery as a revision surgery. All patients' baseline conditions were evaluated. The duration of the operation, intraoperative blood loss, and length of hospital stay were compared between the two groups. Radiographic and clinical outcomes were also evaluated by intervetebral disc height (IDH),

intervetebral foraminal height (IFH), intervetebral foraminal area (IFA), cross-sectional area of the spinal canal (CSA), thickness of ligmentum flavum (TL), Oswestry Disability Index (ODI), and visual analog scale (VAS).
Results: The duration of operation (63.06 ± 8.02 ***min*** vs. 150.30 ± 7.20 ***min***, respectively; $\boldsymbol{P}<0.001$) and intraoperative blood loss (66.66 ± 13.15 ***ml*** vs. 311.10 ± 40.83 ***ml***, respectively; $\boldsymbol{P}<0.001$) were significantly lower than those in the TLIF group. The hospital stay (6.03 ± 0.61 days vs. 12.91 ± 0.73 days, respectively; $\boldsymbol{P}<0.001$) was also significantly shorter than that in the TLIF group. Both groups have shown a significant decrease in ODI and VAS scores after the procedure ($\boldsymbol{P}<0.001$). But the ODI scores (11.93 ± 5.03 vs. 15.44 ± 3.65; $\boldsymbol{P}=0.0018$) and VAS (back and leg) were lower in the OLIF group at last follow-up. In the OLIF group, all radiographic parameters have improved after the surgery.
Conclusion: OLIF augmented with lateral vertebral rod-screw fixation may have been found to be a safer, faster, and more effective way to treat ASD based on our early clinical and radiographic outcomes of this study.

Keywords: Oblique lumbar interbody fusion, Transforaminal lumbar interbody fusion, Adjacent-segment disease, Degenerative lumbar spondylolisthesis

1 Introduction

Degenerative lumbar spondylolisthesis (DLS) is defined as the superior vertebral body sliding forward relative to the inferior vertebral body due to lumbar degeneration, while excluding any defects in the vertebral arch[1]. With the development of surgical technique and the advancement of cognition of the concept of 'segmental stability', the treatment of DLS evolved from facet joint fusion to lumbar interbody fusion. Transforaminal lumbar interbody fusion (TLIF) has gradually emerged as the leading procedure that decompresses the neural elements followed by osseous union of affected spine segments in the treatment of DLS conditions[2]. However, as the local stiffness changes in the fusion segment, the adjacent lumbar disk may share an excessive load to offset. Consequently, this could result in deterioration of the lumbar disc adjacent to the fused region[3]. A large percentage of researchers may be confused by the concept of 'adjacent segment degeneration' and 'adjacent segment disease'. Both have been used to describe the pathology at the adjacent level rather than at the primary fusion segments. The term "adjacent segment degeneration" (ASDeg) should be explained as radiographic changes in an adjacent segment to a previous fused level that may not correlate with clinical findings. Although the term "adjacent segment disease" (ASDis) refers to the emergence of pain or numbness that is correlated with radiographic changes in the spinal region adjacent to a previous spinal fusion[4]. ASDeg may gradually transfer to ASDis, which in most cases requires surgical intervention. A cohort study reported that the revision surgery rate for ASDis occurred in 13% of procedures at a mean time of 43 months (range, 2.3 to 162 months)[5]. Risk factors for the development of ASD present complexity. Risk factors are mainly categorized into two aspects related to either the patient or the surgeon. Articles have reported that risk factors include age, sex, obesity, fusion without instrumentation, adjacent

facet joint damage , long fusion length, and sagittal balance impairment. [6, 7]. As is known to all, it is crucial for surgeons to restore the surgical intervertebral space height and segmental lordosis to improve overall lumbar lordosis (LL) in treating lumbar degenerative disease[8, 9]. However, It still remains controversial for surgeons to choose which approach to use to treat ASD patients most efficiently. This is mostly due to the fact that different procedures can result in diverse biomechanical impacts on the surgical segments.

Oblique lumbar interbody fusion (OLIF) surgery has been gradually accepted in recent decades[10, 11]. It's efficacy for the management of degenerative lumbar disease has been recognized as equivalent to traditional TLIF or PLIF in several studies. However, it still remains unclear whether OLIF is superior to TLIF or PLIF in ASD treatment. In this study, we have chosen the OLIF procedure as our first choice to deal with the ASD condition. Despite the preservation of the lumbar posterior structure in OLIF surgery, some researchers argue that relying solely on the use of "large cage" may not be sufficient[12–14]. Considering the aforementioned issue, we have introduced the lateral vertebral rod screw as a supplementary fixation, which resides in the neutral position relative to the stand-alone OLIF and the OLIF with bilateral pedicle screw fixation, providing sufficient instant segmental stability for the fusion segment. We also compare the radiographic and clinical outcomes of TLIF and OLIF as revision surgeries in ASD treatment. We suppose that OLIF with lateral vertebral crew would result in better clinical and radiological outcomes than TLIF.

2 Materal And Methods

2.1 Study Design

A retrospective study was conducted in the orthopedic department of Dushu Lake Hospital affiliated to Suzhou University from January 2019 to June 2023. Clinical data were obtained and analyzed after approval was granted by the Medical Ethics Committee of Dushu Lake Hospital ($No.2019010$) on January 14, 2019. All surgeries were performed by two experienced spine surgeons. Two independent senior radiologists independently assessed all perioperative images and the final result was the average of their measuring values.

2.2 Patient Demographics

Patients who were included in this study had to meet specific criteria: having single-level 'symptomatic ASD' with failed conservative treatment for over 3 months; being between 18 and 80 years old; having MRI images show lumbar stenosis, lumbar segmental instability, or mild to moderate degenerative spondylolisthesis (gradeI or II) in adjacent segments as opposed to the primary surgical segments; having undergone primary lumbar fusion treatment for degenerative diseases; insisting on follow-up of at least 12 months after revision surgery. "Symptomatic ASD" means that there were clinical symptoms and signs attributed to the adjacent segment of a previously treated spinal level. The study excluded patients with lumbar disc protrusion or herniation,

severe degenerative spondylolisthesis (grade III or IV), severe osteoporosis, and primary fusion surgery for non-degenerative conditions such as trauma, tumor, infection, or inflammation.

There were 62 patients who met the above criteria and were enrolled in the study. All of them underwent standard transforaminal lumbar interbody fusion (TLIF) or posterior lumbar interbody fusion (PLIF) during their primary surgery for lumbar stenosis, lumbar degenerative disc herniation, or lumbar degenerative spondylolisthesis. 30 of the enrolled patients underwent single-segmental OLIF augmented with lateral vertebral rod-screw fixation, and 32 individuals received TLIF surgery as revision surgery with extended fusion at the adjacent level.

2.3 Surgical Technique

2.3.1 OLIF group

The patient was positioned on their right side and adjusted on the surgical table to form a 'lumbar bridge'. Before surgery, X-ray check was used to check the position of the target intervertebral space, then adjusted the surgical bed to place it perpendicular to the ground on the lateral view and to position the spinous process centrally between both pedicles on the anteroposterior view (AP view). The incision was then marked based on the X-ray. A 4 cm skin incision was made in the left lateral abdominal region, which was centered on the target segment to be exposed. The incision ran parallel to the long axis of the trunk and was located 4 cm in front of the projection of the front rim of the vertebra. The external oblique, internal oblique, and transverse abdominal muscles were then bluntly dissected sequentially using vascular forceps and fingers. The retroperitoneal space was exposed by gently mobilizing the peritoneum and its contents to abdominal direction.

The assistant surgeon retracted the psoas muscle dorsally using a long, blunt retractor. The sympathetic chain and ureter were then covered with moist gauze and pulled forward, along with the peritoneal contents. Several long retractors were positioned on the abdominal side to expose the lateral surface of the disk. A 2.0 mm K-wire was then inserted into the disk, and an X-ray check was performed to verify the center of the disk on the lateral side. Then the 'OLIF 25 retractor system' (Clydesdale Spinal System, Medtronic, Inc., Minneapolis, MN, USA) was mounted and following the direction of the K-wire and we adjusted the tubular retractor until a clear view of surgical site was guaranteed. After performing a subtotal discectomy, a test mold was placed and confirmed by X-ray examination to ensure proper size and placement. Ultimately, after thorough preparation of the bone graft bed, a properly sized cage filled with allograft bone and osteogenic substances was correctly inserted, with X-ray confirmation of standard anteroposterior (AP) and lateral fluoroscopic views. It ought to be noted to that, when dealing the L4-5 segment, the tubular retractor should be removed prior to the insertion of the cage. If this precaution is not taken, there could be a potential for misplacement of the cage due to the obstruction of the iliac crest, which could result in damage to the upper endplate of the L5 vertebra. The OLIF interbody cages (Clydesdale Spinal System, Medtronic, Inc., Minneapolis, MN, USA), which are made of polyetheretherketone (PEEK), were used in various sizes, including

heights ranging from 9–13 mm, lengths of 40, 45, and 50 mm, and lordosis options of 0 or 8 degrees. After the cage was inserted, a custom blunt long pedicle finder was inserted slightly caudally and cephaladally (less than 5 degrees) at the points that were the center of the anterior and posterior margins of the vertebrae, as well as 0.5 cm to the superior and inferior endplates, respectively. We checked the primary nail tracks with ball-tip probe to make sure that there were no breaches on the vertebral wall then placed the 'markers'. The X-ray was used to verify the orientation of the inserted 'markers' before proceeding to prepare the secondary nail tracks. After that two multi-axial pedicle screws (Medtronic, Inc., Memphis, TN, USA) were inserted into the vertebrae, the titanium rod was cut to the appropriate length to connect the two screw tails. For all patients, the incisions were closed in a layered fashion (Fig. 1).

2.3.2 TLIF group

The patient was placed in a prone position and a mid-line incision was made to expose the previous fixators and the levels to be decompressed. A standard TLIF technique was performed at the adjacent segment for laminectomy, intervertebral space preparation, and insertion of a PEEK cage (Medtronic, Inc., Memphis, TN, USA) filled with autograft bone. The intervertebral space height and the nerve root loosening were double checked in all patients in this group. The initial rods and pedicle screws were removed, and then new bilateral pedicle screw-rod system (Medtronic, Inc., Memphis, TN, USA) for the adjacent segment was installed for internal fixation (Fig. 2). For all patients, silicon drainage tubes were placed and the incisions were closed in a layered fashion. After surgery, we would remove the drainage tube two days after surgery.

All patients within two groups to bear weight after three days and require them to wear a lumbar brace for three months. .

2.4 Radiographic and clinical Evaluation

We have adopted 3.0 T magnetic resonance imaging (MRI) scans (Philips Medical Corp., Best, Netherlands) for perioperative evaluation. To identify the disc space intervals at the surgical site, an axial localizing sequence was employed. At each level, four slices were acquired with a slice thickness of 3.0-mm and a 1.0-mm interval between each slice. The $T2$-weighted images were presented using the following parameters: repetition time, 3800 ms; echo times, 102 ms; matrix, 416$*$224; excitations, 4; and field of view, 20 cm. The acquired images were then displayed and measured in the local digital image processing software DU (DUi, suchow, China) .

The measurement of the cross-sectional area of the spinal canal (CSA) at the surgical level was carried out using a graphic cursor to accurately capture the outline of the spinal canal. The thickness of the ligamentum flavum (TL) was determined by the average of the measurements of the longest dimension on both sides (Fig. 3**a**). The CSA of spinal canal, TL were measured on a $T2$-weighted image of lumbar MR scans collected preoperatively and at the final follow-up.

The intervertebral disk height (IDH), intervertebral foraminal height (IFH), and intervertebral foraminal area (IFA) were measured on the lateral lumbar radiography

perioperatively at the studying segment (Fig. 3**b**). The IDH was determined by calculating the average height between the anterior and posterior rims of an intervertebral space. The IFH refers to the distance of the line connecting the highest and lowest points on the two adjacent pedicles' rims. The IFA was surrounded by a cursor in order to capture the boundary of the intervertebral foramen.

The presence of soft tissue calcification in the central and foraminal areas, which has an impact on the efficacy of indirect decompression after OLIF surgery, was verified through preoperative computed tomography[15].

The patients' general and neurological conditions and surgical outcome were evaluated at hospitalization (preoperative conditions), 4 weeks after surgery, 8 weeks after surgery, and the last follow-up using the Owestry disability index (ODI) and visual analog scale (VAS) for back and prominent leg pain.

2.5 Statistical Analysis

We conducted the Fisher exact test, χ^2 test or 2-sample z-test were used to compare the variables between the OLIF and TLIF groups. Unpaired t tests were used to compare outcomes between preoperative and postoperative measurements. P$<$ 0.05 was considered statistically significant. Statistical analysis was performed using SPSS software, version 18.0 (IBM Corp., Armonk, New York, USA).

3 RESULTS

3.1 Demographic Variables

Between January 2020 and November 2023, our retrospective study enrolled a total of 62 patients. The OLIF group consisted of 30 patients, while the TLIF group had 32 patients. In the OLIF group, 30 patients underwent OLIF augmented with lateral vertebral screw fixation, while 32 patients in the TLIF group underwent standard posterior TLIF with extended bilateral pedicle screw fixation. Regarding the baseline of the enrolled patients in both groups, the age, sex, BMI, BMD, level of ASD and follow-up period (Table. 1).

3.2 Clinical Outcomes

The OLIF group outperformed the posterior TLIF group in regards to operative time, blood loss, and length of hospital stay. The OLIF group had a significantly shorter operative time compared to the TLIF group. (63.06 ± 8.02 min vs. 150.30 ± 7.20 min, respectively; $P = 0.000$). The OLIF group had significantly lower blood loss (66.66 ± 13.15 ml) compared to the TLIF group (311.10 ± 40.83 ml; $P = 0.000$). The hospital stay for the OLIF group was 6.03 ± 0.61 days, while it was 12.91 ± 0.73 days for the TLIF group. ($P = 0.000$) (Table. 2).

The OLIF group outperformed the TLIF group in both ODI score and VAS pain score. Specifically, the OLIF group saw an improvement in ODI score from 66.27 ± 9.45 before the operation to 11.63 ± 5.31 at the final follow-up, with a significant difference ($P = 0.000$). At the last follow-up, the ODI scores were lower in the OLIF group compared to the TLIF group (11.93 ± 5.03 vs. 15.44 ± 3.65; $P = 0.0018$). The

VAS back pain score in OLIF significantly improved from 8.07 ± 1.29 preoperatively to 1.47 ± 0.94 at final follow up with a significant difference ($P = 0.000$). The OLIF group also exhibited a significantly lower VAS back pain score compared to the posterior approach group at each follow up time point respectively (4w-post: 5.67 ± 1.27 vs. 6.69 ± 1.60, $P = 0.0275$; 8w-post: 2.87 ± 0.63 vs. 3.60 ± 1.07, $P = 0.0075$; final follow-up: 1.47 ± 0.94 vs. 2.06 ± 0.88, $P = 0.0487$). The VAS leg pain score in OLIF also showed a substantial drop, from preoperative: 8.07 ± 1.29 to final follow-up: 1.47 ± 0.94, P=0.000. VAS leg pain in the OLIF group was lower compared to the TLIF group at final follow-up (1.13 ± 0.63 vs. 1.63 ± 0.79; $P = 0.0345$) (Fig. 4)

3.3 Radiographic outcomes

The radiographic parameters were significantly improved pre- and post-operatively in the OLIF group, which was also comparable to those of the TLIF. In OLIF group, the IFH was significantly improved after surgery (14.80 ± 1.23 mm vs. 19.51 ± 1.30 mm; $P = 0.000$). The TL was also significantly thinner postoperatively than preoperatively in OLIF group (3.94 ± 1.13 mm vs. 2.82 ± 0.91 mm; $P = 0.000$). The IDH in OLIF group was 8.70 ± 1.23 mm preoperatively, which was significantly lower than 13.22 ± 1.03 mm postoperatively ($P = 0.000$). The postoperative CSA value was 137.21 ± 24.49 mm^2 in the OLIF group, which was significantly larger than 107.44 ± 28.38 mm^2 preoperatively ($P = 0.000$). Furthermore, the IFA value in the OLIF group postoperatively was larger than preoperatively (28.54 ± 3.21 mm^2 vs. 17.59 ± 2.25 mm^2; $P = 0.000$). All radiographic outcomes, including IFH, TL, IDH, CSA, and IFA, were comparable between the two groups after surgery ($P = 0.000$). (Fig. 5)

4 DISCUSSION

As modern society developed, lumbar disc degeneration presented a rejuvenation trend; therefore, there has been a steady increase in the number of lumbar fusion surgeries, leading to an increase in the appearance of ASD as a long-term post-lumbar fusion pathology[16–18]. Risk factors consist of multilevel constructs and nonunion of previous surgical segment[19, 20]. The imbalance of the spine in the sagittal or coronal planes also accelerates the degeneration of adjacent segments[21]. Older and male patients would also have a higher incidence of ASD, derived from pre-existing facet or disk degeneration. With the increasing prevalence of ASD, spine surgeons are encountering a rising number of patients who require treatment.

The first and foremost challenge that surgeons face is whether or not the ASD can be managed non-surgically. As the clinical protocol indicates, like primary lumbar pathology, all patients with ASD should not doubt receive conservative treatment before considering surgery[22]. However, non-invasive treatment is often limited in its effectiveness when used alone. Thus, surgeons' experience and patients' determination are the basis of treatment guidance for ASD[22].

When it comes to surgical treatment, various surgical methods have been reported in the literature for ASD procedures, including decompression combined with fusion extension, decompression combined with artificial disc replacement, or simple decompression[23–25]. The choice of those surgical methods mainly depends

on the various pathologies related to ASD, such as kyphosis, segmental instability, disk collapse, spondylolithesis, or lumbar stenosis caused by hypertrophied ligamentum flavum. Among all methods, TLIF has gradually become one of the mainstream procedures for degenerative lumbar disease (DLS) and been adopted by most spine surgeons as revision surgery. Because TLIF can not only achieve nerve root decompression but also simultaneously provide immediate segmental stability through fusion. Patients who underwent extented TLIF or PLIF on the adjacent segment could have experienced substantial pain relief and enhanced quality of life after a minimum follow-up period of 2 years[26–28]. But conventional TLIF or PLIF for adjacent segmental fusion usually involves dissecting the scar tissue around the nerve structure, or dura mater. After the decompression and fusion, extended rod-crew fixation is required to restore the lumbar spine stability, which can lead to significant destruction for the paraspinal muscles and extensive soft tissue dissection[24]. In addition, scar tissue may hinder the anatomical landmarks, which to a certain extent increases the risk of dural tears or nerve damage during pedicle screw insertion. [29]. Despite the shortcomings mentioned above, the most suitable approach should largely depend on the specific pathology involved in ASD in each case. In our study, the 30 patients with ASD who have received revision surgery enrolled presented adjacent segmental spondylolithesis, instability, and stenosis in the adjacent caudal or cephalic segment; thus, decompression and fusion were recommended.

The central idea of the traditional posterior approach may have been refined to include complete decompression along with the restoration of the original structural stability or an extended construct[30, 31]. Thus, there have been alternative approaches in the literature suggested to overcome those drawbacks. Aichmair et al. conducted a two-center study, in which they have adopted stand-alone lateral lumbar interbody fusion (LLIF) for ASD treatment to overcome shortcomings including removal of parts of primary instruments, excessive soft tissue impingement, etc. However, they have also drawn the conclusion that standalone LLIF is associated with a narrower spectrum of adverse effects, and posterior instrumentation may be necessary to increase segmental stability[32]. Compared to traditional surgery, minimally invasive LLIF could have been a viable choice for the treatment of ASD. It is a complete novel approach to the target level, which could entirely avoid the primary incision and invasion of the posterior column structure. Above all, we may infer that the minimally invasive lateral interbody fusion for ASD could achieve satisfactory clinical and radiographic improvement. Park et al. and Palejwala et al. reported a stand-alone LLIF for treatment of ASD[33, 34]. Du et al. conducted the LLIF with unilateral pedicle screw fixation[35]. All the above-listed research has reported promising clinical and radiographic results after LLIF was applied in ASD treatment[33–35]. However, there may be a certain risk of lumbar plexus nerve damage in LLIF surgery by directly dissecting the psoas muscle. Kotwal et al. found that nerve damage-related transient thigh pain was the most frequent complication seen in LLIF[36]. To prevent the aforementioned complication, oblique lateral interbody fusion (OLIF) was gradually implemented.

OLIF is a modified version of the LLIF approach for minimally invasive anterolateral lumbar interbody fusion, originally introduced by Mayer in 1997[37]. Unlike lateral lumbar interbody fusion, the OLIF approach reduces the risk of lumbar plexus nerve

injury by accessing the target disc through the potential gap between the abdominal major vessels and the psoas. OLIF can also reserve posterior structures and does not invade the spinal canal, which greatly reduces complications such as dural tears and destruction of paraspinal muscles. By using this method, an experienced surgeon can conveniently and minimally invasively employ a large cage to restore the IDH or IFH while also achieving a high fusion rate between the vertebrae. This ultimately leads to a well-aligned spine[38]. OLIF has already gained a good reputation for effectively treating degenerative conditions in the lumbar spine[39–41].

Several of those studies have also demonstrated the promising results of the application of OLIF in treating ASD[42–44]. Zhang et al. compared the OLIF coupled with facet joint fusion with PLIF for revision of caudal adjacent segment disease after primary posterior lumbar fusion, and they concluded that OLIF is superior to PLIF in terms of reduced blood loss, shorter hospital stay, and lesser complications[42]. Zhu et al. have compared stand-alone OLIF with PLIF in the revision of ASD. They also reported similar results[43]. Park et al. made a similar comparison between OLIF and TLIF in treating ASD. They came to the conclusion that OLIF could have become a good alternative to TLIF when revision surgery is considered[44]. In our study, we have incorporated the anterolateral vertebral screw in OLIF surgery as an auxiliary fixation, which prevents damage to the posterior bony structure and paraspinal muscles while providing sufficient stability needed for adjacent fusion level. The classic case done by us could be seen in fig.1. Furthermore, we found that this approach achieved a plausible clinical outcome in the follow-up, which was consistent with previous studies[45, 46]. By introducing a large cage, indirect decompression was guaranteed, which could be verified with post-operative spinal plain film or a CT scan. Within our study, the OLIF group has shown better intervertebral height restoration with superiority in IDH, IFH, and IFA parameters. In addition, the blood loss of 66.66 ± 13.15 ml, the operation time of 63.06 ± 8.02 min and the hospital stay of 6.03 ± 0.61 days have indicated that OLIF could benefit patients a lot and enable fast recovery. Due to the absence of the para-spinal muscle injury in the OLIF group, we have naturally observed that the OLIF group had lower VAS scores for back pain compared to the TLIF group at both 4 weeks and 8 weeks and final follow-up after the surgery. The VAS leg pain score in the OLIF group also prevailed over that in the TLIF group at final follow-up, which probably attributes to the avoidance of direct nerve root manipulation or traction in the OLIF group[47]. The keystone in OLIF surgery could be summarized as 'indirect decompression', which means that there should be no need to perform laminectomy and fusion and extent the primary construct as standard extented posterior TLIF or PLIF do. Thus, CSF leakage could be avoided, and posterior spinal elements (facet joint capsules, paraspinal muscles) and primary fixations would remain intact. Moreover, the patients' SL and global LL after surgery could be improved, which may have a lot of benefits for spine sagittal alignment[46]. However, in our experience, ASD cases present nerve root symptoms, disk herniation, lateral recess, or severe spinal stenosis. OLIF alone may not be sufficient compared to the direct decompression in traditional PLIF or TLIF procedure[48]. Thus, patients for the OLIF group should be carefully specified.

The duration of the operation, the estimated amount of blood loss, and the degree of muscle injury in OLIF revision surgery could differ based on surgical proficiency, particularly for novices[48]. Hence, we have also provided surgical videos for technical improvement. First, preoperative fluoroscopic checking and table adjustment: The C-arm should be positioned vertical and horizontal to the ground, then adjust the surgical bed until the surgical intervertebral space is vertical on the lateral view and the spinous process centered on the anterior-posterior (AP) view; Second, a safe and fast way from skin to disk surface: special, customized long retractors are crucial to pull the psoas muscle dorsally and pulling the detrimental structures such as the ureter, plexus nerve, and abdominal blood vessels ventrally. Allow for the insertion of a K-wire into the middle point of the lateral side of the disk. In our experience, these two processes would allow us to install the working channel and insert the cage correctly and securely. Third, but not least, we would like to introduce a maneuver called posterior longitudinal ligament dislodgement (PLLD), which refers to removing as much posterior annulus fibrosus as possible to thoroughly depressurize the PLL when preparing the bone graft bed. Only by doing so is spinal canal enlargement guaranteed.

A major concern regarding the application of OLIF coupled with vertebral screw fixation is that the force to maintain intervertebral space height may not be enough for the correction of spondilolithesis and mechanical stability for fusion. As is known to all, indirect decompression produced by OLIF restores DH and prolongs the hypertrophied ligamentum flavum. Compared to stand-alone OLIF, supplementary anterolateral vertebral screws could, to some extent, provide a support force that reduces the interface stress between cage and bony endplate and promotes the fusion process. Furthermore, the vertebral screw may not be sufficient to generate the pull-back force needed to counteract the forward tendency in spondylolithesis[49]. Moreover, the improper cage size and accidental damage to the endplate may cause the cage to subside, leading to nonfusion. Ziang et al. have found that the higher cage subsidence in standalone OLIF surgery may be correlated with imprecise measurement of cage height and overcorrection in the sagittal plane[50]. Kotheeranurak et al. performed a multi-factor logistic regression analysis, and found that higher cage height had the strongest association with subsidence, while other risk factors, including age>60 years, BMD<-2.5 and severe multifidus muscle fatty degeneration[51]. We may conclude that cage subsidence is complicated and multifactorial. In our study, we observed Grade I cage subsidence in two cases in their last follow-up. However, the preoperative radicular pain of both patients was relieved, and bony fusion was observed on CT scans. Further, we have found that it took less time to achieve bony fusion for OLIF than for PLIF or TLIF. This could be related to the semi-rigid fixation used in OLIF, as compared to the traditional rigid posterior construct. The semi-rigid fixation allows for slight movement at the interface between the cage and bony endplate, which facilitates the bony fusion process. Therefore, we believe that combining OLIF with vertebral screw fixation could be a concise and highly efficient surgery, providing sufficient indirect decompression for achieving segmental stability and yielding good clinical outcomes.

There are several limitations to our study. First, in this study, we employed reconstructed CT scans to identify the fusion between lumbar vertebrae. Nevertheless, it

would be advantageous to extend the follow-up period beyond 2 years, as any potential nonfusion would become more noticeable from a clinical perspective or through radiographic examination over prolonged time periods. Second, the statistical significance level was defined as 0.05 in our study, especially in those subjective self-reported data used to evaluate clinical outcomes. Type II error may occur due to slight variations in the population (δ), significant differences among individuals (SD), and a limited sample size. Therefore, extensive clinical trials with multiple centers, large sample sizes, randomized selection, and long-term follow-up are urged demanded in the future. Last but not least, additional in-vivo biomechanical tests or finite element analysis are required to confirm the validity of constructs in two groups, considering the intricate structure of the revision surgery for ASD.

5 CONCLUSION

This preliminary study suggests that the utilization of lateral vertebral screws could potentially serve as a secure and efficient alternative augmentation in OLIF surgery for the treatment of ASD following a previous lumbar fusion procedure. Comparing with traditional posterior TLIF or PLIF, OLIF showed similar results in terms of self-reported outcomes and more competitive results regarding pre- and postoperative radiographic improvement. OLIF surgery is a minimally invasive procedure that demands a steep learning curve; thus, surgeons with rich experience in lumbar anterior and lateral surgery would be more interested in OLIF for the treatment of lumbar ASD disease.

Declarations

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- Conflict of interest/Competing interests (check journal-specific guidelines for which heading to use)
- Ethics approval
  The studies involving human participants were reviewed and approved by the institutional review board of Dushu Lake Hospital affiliated to Soochow University ($No.$2019010), and all methods were performed in accordance with the Declaration of Helsinki.
- Consent to participate
- Consent for publication
- Availability of data and materials
  The original contributions presented in the study are included in the article/-Supplementary material, further inquiries can be directed to the corresponding authors.
- Code availability
- Authors' contributions

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	TLIF (n=32)	OLIF (n=30)	P
Age(years)	52.94 ± 7.32	53.40 ± 7.56	0.8075
Sex(M/F)	18/14	14/16	0.6115
BMI(kg/m^2)	21.07 ± 1.71	20.73 ± 1.41	0.4024
BMD	1.49 ± 1.19	1.91 ± 1.71	0.0683
Preoperative diagnosis			0.0968
Spondylolisthesis			
I	7	8	
II	12	4	
Segmental instability	8	7	
Recurrent stenosis	6	11	
Level of ASD			0.5882
L2-3	8	7	
L3-4	10	10	
L4-5	14	13	
follow-up (weeks)	23.13 ± 4.17	22.87 ± 4.72	0.8198

Table 1 Demographics of the enrolled patients

	TLIF	OLIF
Operative time (min)	150.30 ± 7.20	63.06 ± 8.02 *
Blood loss (ml)	311.10 ± 40.83	66.70 ± 13.15 *
Hospital stay (days)	12.91 ± 0.73	6.03 ± 0.61 *

Table 2 general operative statistics. *****, P <0.05 when compared to TLIF group

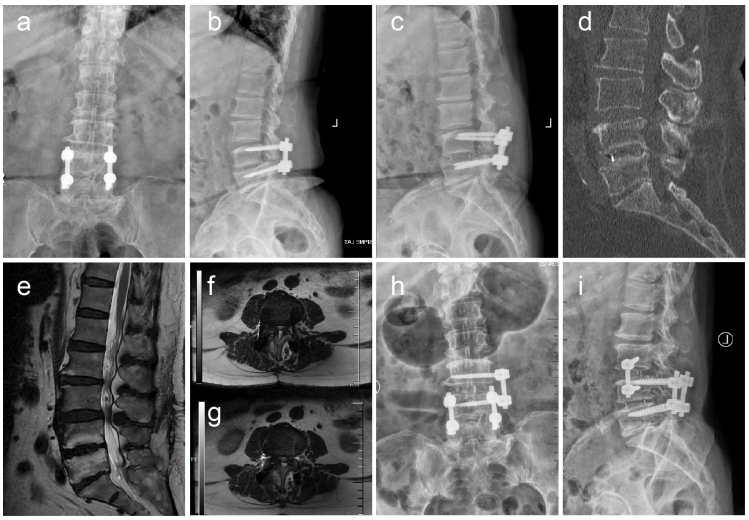

Fig. 1 Images obtained from a 78-year-old woman who had L4-5 transforaminal lumbar interbody fusion surgery 6 years ago. She complained of lower back and bilateral leg pain for 6 month, while the pain could be reliefed during rest. The lumbar spinal AP (anterior-posterior), lateral view (**a, b**) and over-extension view (**c**) have shown segmental instability at L3-4 after L4-5 TLIF; Lumbar spinal sagittal CT reconstruction view (**d**) has shown no evident calcification at the L3-4 intervertebral disc; Preoperative Lumbar spinal MRI images (**e, g, f**) have shown lumbar stenosis at L3-4 level; The patient have undergone L3-4 OLIF augmented with lateral vertebral screws and postoperative lumbar spinal AP and lateral view (**h, i**) have shown satisfied realignment of lumbar spine. The patient's lower back and bilateral leg pain improved immediately after revision surgery.

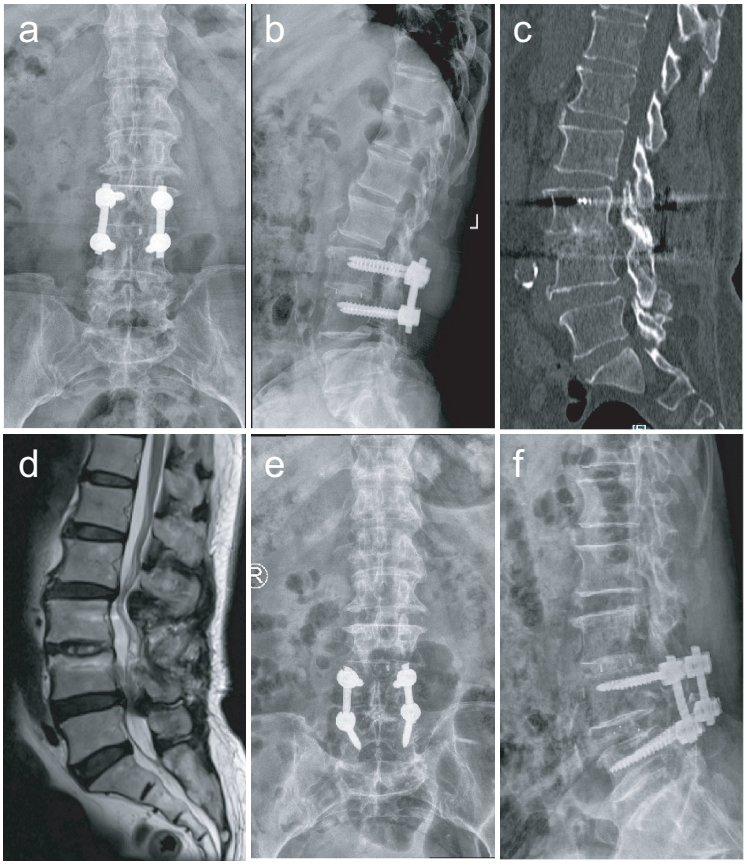

Fig. 2 Images obtained form female patient, 70 years old, had experienced lower back pain for 1 year, which had worsened with right leg radicular pain for 5 months. Both lower back and leg pain could be improved while at rest. The patient had undergone L3-4 transforaminal lumbar interbody fusion (TLIF) 8 years ago. The preoperative lumbar spinal AP (anterior-posterior), lateral view (**a, b**) have shown primary L3-4 TLIF fixators; The sagittal CT reconstruction (**c**) have indicated complete fusion at L3-4 level and no obvious calcification was observed at L4-5 intervertebral disc; the lumbar MRI (**e**) have shown L4-5 lumbar stenosis; The patient underwent L3-4 internal fixators were removed and L4-5 TLIF surgery. The postoperative AP and lateral view (**f, g**) of the lumbar spine have shown appropriate position of internal fixators. The patient's preoperative symdrome were improved instantly after the revision surgery.

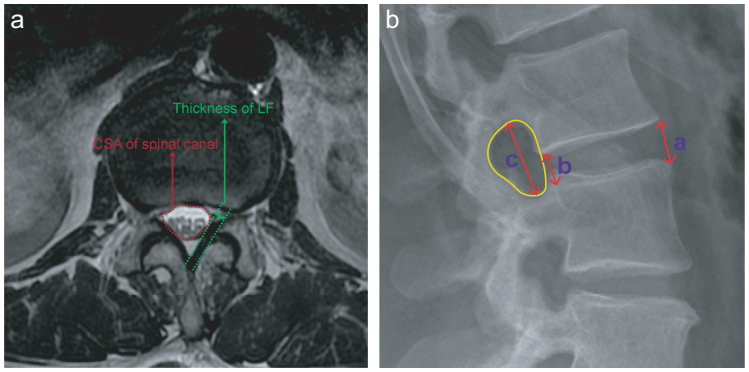

Fig. 3 **a** the cross section area (CSA) of spinal canal (red dashed line and arrow) and thickness of ligmentum flavum, TL (green dashed line and arrow) were measured at the mid-disc level of the axial sequence using $T2$weighted MRI. **b** the intervetebral disk height (IDH) equals the average value of line a + line b, the height of the intervertebral foramen (IFH) is represented by line c, and the area within the region bounded by the yellow line is the intervertebral foramen (IFA) were measured on lateral radiography.

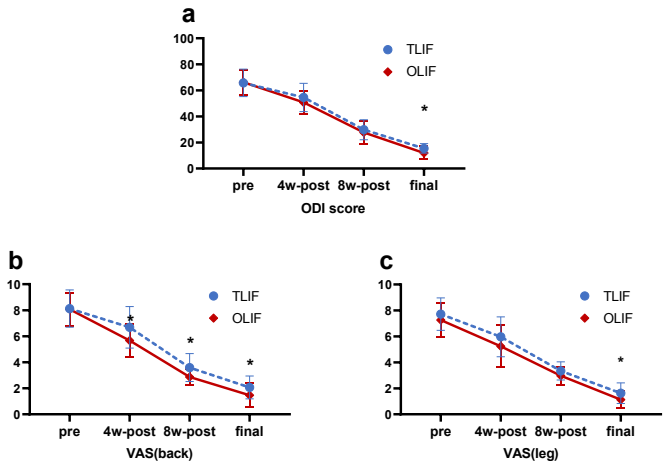

Fig. 4 **a** ODI scores of the two groups preoperatively, 4 weeks postoperatively, 8 weeks postoperatively and at the final follow-up. **b** VAS back pain scores between two groups preoperatively, 4 weeks postoperatively, 8 weeks postoperatively and at the final follow-up. **c** VAS leg pain scores between two groups preoperatively, 4 weeks postoperatively, 8 weeks postoperatively and at the final follow-up. *****, $P<0.05$ when compared to TLIF group. pre: preoperative; 4w-post: 4 weeks after surgery; 8w-post: 8 weeks after surgery; final: final follow up.

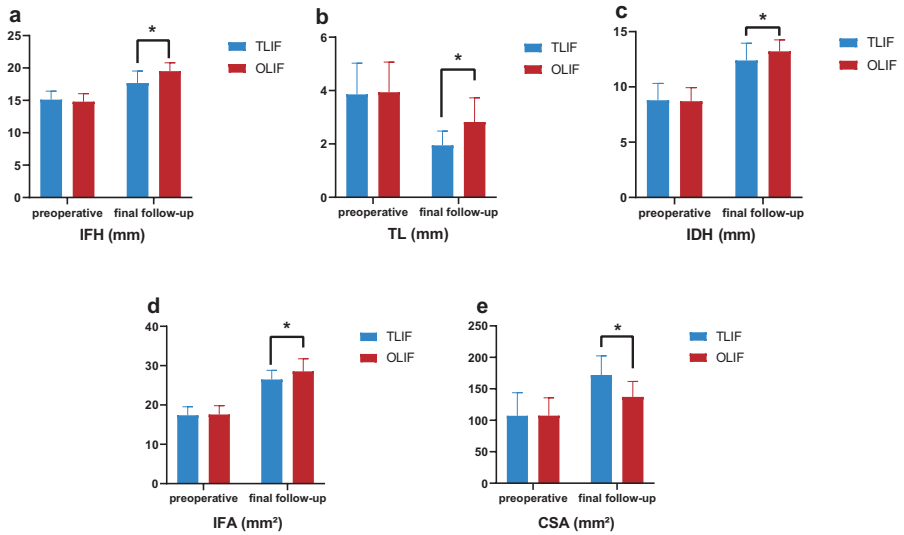

Fig. 5 **a** IFH, **b** TL, **c** IDH, **d** IFA, and the **e** CSA of spinal canal within the two groups preoperatively and postoperatively. *, $P<0.05$ when compared with the OLIF group