

Comparison of clinical outcomes achieved with oblique lateral interbody fusion with or without supplementary instrumentation in patients with single-level lumbar degenerative disease

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Abstract

Background

Oblique lateral interbody fusion (OLIF) is applied often to treat degenerative disc disease in the lumbar spine. Stand-alone OLIF prevents morbidities associated with supplemental fixation and is less expensive. However, it remains controversial whether stand-alone OLIF is sufficient to avoid subsidence for single-level diseases. Additionally, bilateral pedicle screw (BPS) and bilateral transfacet screw (BTS) fixation are well-established posterior fixation methods that can offer improved biomechanical stability. But the comparison of clinical outcomes of OLIF with and without supplementary instrumentation is lack.

Methods

We retrospectively examined 20 patients who underwent single-level stand-alone OLIF for symptomatic lumbar degenerative disease at L1–L5 (SA group). Groups of patients treated with OLIF plus BPS (n = 20, BPS group) or BTS (n = 20, BTS group) were matched for age, sex, diagnosis, operative level, body mass index, and bone mineral density. The disk height index (DHI), segmental lordotic (SL) angle, and lumbar lordotic (LL) angle were measured preoperatively and at 3 days and 6 months postoperatively. Clinical outcomes were evaluated.

Results

Significant disc height loss was observed in all groups, but was greater in the SA and BTS groups than in the BPS group at the 6-month follow-up. The SL and LL angles were not affected in any group. The operative time was significantly less in the SA group, and the estimated blood loss was significantly higher in the BPS group. At 6 months post-surgery, improvements in clinical outcomes were evident in all groups, but the VAS (back pain), JOA, and ODI scores were worse in the SA group than in the other groups.

Conclusions

Stand-alone OLIF was associated with greater subsidence and poorer clinical outcomes compared with OLIF plus supplementary instrumentation. The addition of BTS did not decrease the degree of subsidence, but provided clinical outcomes comparable to those achieved with BPS.

Introduction

Oblique lateral interbody fusion (OLIF) is a minimally invasive retroperitoneal surgical procedure commonly used for treating degenerative disease in the lumbar spine[1, 2]. The OLIF procedure was first described in 1997[3, 4] and evolved from techniques such as direct (extreme) lateral transpsoas interbody

fusion (DLIF or XLIF) and anterior lumbar interbody fusion (ALIF). During OLIF, the disc space is accessed from the space between the psoas and major vessels of the abdomen without splitting the psoas muscle. The OLIF technique aims to avoid the major vascular/visceral injuries that occur during ALIF; the paraspinal/soft tissue trauma that occurs during transforaminal lumbar interbody fusion, posterior lumbar interbody fusion, and posterolateral fusion; and the lumbar plexus nerve injuries that occur during DLIF and XLIF. The reported benefits of OLIF include decreased blood loss, improved postoperative pain due to less muscle retraction and smaller incisions, a reduced infection rate, a shorter length of hospital stay, an increased disc space height, a higher fusion rate, and avoidance of the need for further surgery[5, 6].

The efficiency of OLIF is partly due to the extension–distraction moment arm applied to the anterior and middle columns of the spine. The resultant ligamentotaxis and restoration of disc height can indirectly decompress the spinal canal and neuroforamina and alter the spinal alignment to relieve claudication, radicular symptoms, and back pain[7]. Graft subsidence into one or both of the adjacent vertebral bodies may compromise this indirect decompression and correction of the lumbar lordotic curvature, causing the return of symptoms, new-onset back pain, neurological deficits, and, in more severe cases, fracture of the vertebral body itself[8–10]. In the multicenter survey involving 155 patients, Abe et al. observed a subsidence rate of 18.7% that resulted in the need for reoperation in 1.9% of patients[11].

Stand-alone OLIF prevents morbidities associated with supplemental fixation and is less expensive. However, without posterior column support, the rates of interbody cage subsidence and restenosis may be increased[12]. Liu et al. suggested that OLIF with a cage alone may be insufficient to provide adequate stability for 3 or more levels of fusion, which could contribute to subsidence[13]. To the best of our knowledge, it remains controversial whether stand-alone OLIF is sufficient for the single-level condition[14, 15]. A variety of lateral and posterior fixation methods are available to supplement OLIF with varying capabilities to restrict range of motion (ROM)[13, 16]. Bilateral pedicle screw (BPS) fixation is a common technique that can offer improved biomechanical stability in all directions[17]. BPS is associated with a slight, but significant increase in complications due to the risk of screw malpositioning and wound healing problems and is relatively more expensive[18]. Bilateral transfacet screw (BTS) fixation is a common and well-established posterior fixation method[19]. Biomechanical studies have demonstrated that the equivalent stiffness of the BTS technique is comparable to that of the BPS technique[20, 21]. BTS also provides reliable and safe results, including symptom relief and a low complication rate[22]. Thus, the research supports that percutaneous BTS is an attractive surgical alternative for treating single-level spinal fusions. In the present study, we used these two techniques for supplemental fixation in patients undergoing OLIF.

The present study aimed to determine stand-alone OLIF could provide satisfactory clinical outcomes for patients with lumbar degenerative diseases treated using single-level fusion and to compare the radiographic and clinical outcomes after stand-alone OLIF with those achieved using OLIF with BPS or BTS as supplementary instrumentation.

Materials And Methods

Patients and indications

This retrospective study examined the patients who underwent single-level OLIF at L1–L5 in Beijing Ji Shui Tan Hospital between January 2018 and April 2020. The inclusion criteria were as follows: (1) symptomatic lumbar degenerative disease refractory to conservative treatments, (2) degenerative changes mainly concentrated in one segment of the lumbar spine with no or mild degeneration on the adjacent level, and (3) lack of facet fusion, severe lumbar stenosis, developmental lumbar stenosis and free disc fragment/facet cyst in imaging, and an improvement in low back and/or leg pain of greater than 50% during rest. The exclusion criteria were as follows: (1) lumbar degenerative scoliosis, (2) Meyerding II degenerative spondylolisthesis or above, (3) lumbar instability caused by neoplasm, infection or trauma, (4) multi-level lumbar spinal fusion, (5) prior surgery in the lumbar region, and (6) severe osteoporosis (quantitative computed tomography [QCT] value $< 50 \text{ mg/cm}^3$). Twenty stand-alone OLIF patients (SA group) who met the inclusion and exclusion criteria were ultimately recruited for the study. Then 20 patients matched for age, sex, diagnosis, operative level, body mass index, and bone mineral density (BMD) were selected as a control group from 121 patients who underwent OLIF with BPS (BPS group), while 20 patients for another control group were selected from 38 patients who underwent OLIF with BTS (BTS group). There was no statistical difference between the selected and non-selected patients in age, sex, diagnosis, operative level, body mass index, and BMD in the BPS group and BTS group (Table 1). QCT was performed to assess patients' BMD preoperatively. Postoperative data were collected on day 3 and at 6 months after surgery.

Table 1

Demographic data of the SA, BPS, and BTS groups of patients who underwent OLIF for single-level lumbar degenerative disease

Parameter	Group			P
	SA (n = 20)	BPS (n = 20)	BTS (n = 20)	
Age (years)	62.90 ± 9.24	65.95 ± 7.63	65.35 ± 9.24	0.509
Male-to-female ratio	8:12	8:12	6:14	0.750
Diagnosis				
LS	7	8	9	0.812
LSCS	13	12	11	
Operative level				
L2/3	0	0	2	0.364
L3/4	2	1	3	
L4/5	18	19	15	
BMI (kg/m ²)	25.18 ± 3.57	24.58 ± 2.65	24.76 ± 2.97	0.820
BMD (mg/cm ³)	89.22 ± 25.42	87.74 ± 24.96	84.08 ± 33.15	0.838
Values are mean ± standard deviation (SD) or as otherwise indicated.				
SA, stand-alone; BPS, bilateral pedicle screw; BTS, bilateral transfacet screw; BMI, body mass index; BMD, bone mineral density; LS, lumbar spondylolisthesis; LSCS, lumbar spinal canal stenosis.				

Surgical techniques

All procedures were performed by three senior spine surgeons who had experience in the OLIF procedure. The choice of surgical techniques for a certain patient was based on the experience and preference of the surgeons, because there is no definitive consensus regarding the optimal supplementary instrumentation.

OLIF procedure

After general anesthesia intubation, the patient was placed in the lateral decubitus position, and fluoroscopy was performed to identify the target intervertebral disc. A 6-cm skin incision was made in the lateral abdominal region parallel to the iliac crest. The abdominal muscles were dissected sequentially with a muscle-splitting approach. The retroperitoneal space was then accessed by blunt dissection, and the peritoneal content was mobilized anteriorly. The space between the psoas major and the aorta was bluntly dissected using fingers. After exposure of the target intervertebral disc and the lateral side of the adjacent vertebral body, fluoroscopy was performed to confirm the proper level before proceeding with interbody fusion, and the tubular retractor system was docked. The intervertebral disc was removed, and

both the endplates were prepared for cage insertion. Subsequently, an OLIF polyetheretherketone cage of appropriate size (Clydesdale Spinal System, Medtronic, 18-mm width, or Oracle system, Synthes, 22-mm width) filled with allograft synthetic bone materials containing bone morphogenetic protein (BMP) was inserted, and the optimal position was confirmed using fluoroscopy. Finally, the abdominal muscle planes were closed sequentially without placement of a drainage catheter.

Robot-assisted percutaneous BPS/BTS procedures

The patient was placed in the prone position after the OLIF procedure. Robot-assisted procedures were performed using the TiRobot system (TINAVI Medical Technologies, Beijing, China). The patient tracker was percutaneously anchored at the spinal process. An alternative method was used for the BTS procedure in some patients. Preparation and draping were done at the beginning, and the patient was kept in the lateral decubitus position after OLIF cage insertion. The patient tracker was percutaneously anchored at the iliac crest.

Fluoroscopic images produced by the C-arm (ARCADIS Orbic 3D C-arm, Siemens Medical Solutions, Erlangen, Germany) were transferred to the robotic workstation. After the preoperative planning of pedicle screw instrumentation using the TiRobot workstation, the robotic arm was instructed to move to the chosen trajectory. When the accuracy of guidance was less than 0.5 mm and became stable, a tiny incision over the trajectory was made. The guiding cannula was inserted into the incision at the distal end of the robotic arm until the bony surface was touched. Then, the guiding pin held by a drill bit was placed along the guiding cannula to the optimal depth. A fluoroscopic re-scan by the C-arm was performed, and the position of the guiding pin was evaluated. Once optimal positioning of the guiding pin was confirmed, the pilot hole was tapped, followed by insertion of cannulated pedicle screws or cannulated Herbert screws. Afterward, the positions of screws were evaluated and confirmed using fluoroscopy. The incisions were closed without drainage.

On the first day after the operation, patients were asked to perform out-of-bed activities with the help of a lumbar brace. Also, all patients were required to wear the lumbar brace for 3 months postoperatively.

Radiologic analysis

Radiologic outcomes were assessed by collecting anteroposterior and lateral radiographs at 3 days and 6 months postoperatively. The disc height was expressed according to the disc height index (DHI), based on the method of Inoue from standing lateral radiographs[23]. The DHI was calculated as the mean of the anterior, middle, and posterior disc heights, divided by the sagittal diameter of the overlying vertebral body at the midvertebral level. The segmental lordotic (SL) angle was defined as the angle between the superior endplate of the upper vertebra and the inferior endplate of the lower vertebra at the corresponding level. The global lumbar lordotic (LL) angle was defined as the angle between the upper endplate of the L1 vertebra and the upper endplate of the S1 vertebra (Fig. 1).

Clinical assessment

The operating time, estimated blood loss, and height, length, and width of the OLIF cage were recorded. Before surgery and at the 6-month follow-up, self-assessment of disability and pain was provided by patients using the Oswestry Disability Index (ODI), Japanese Orthopaedic Association (JOA) scoring system, and Visual Analog Scale (VAS) for back/leg symptoms. Any intraoperative and postoperative complications were also recorded.

Statistical analysis

The χ^2 -test and Fisher exact test were used to evaluate between-group differences in gender, diagnosis, operative level, complication, and the height, length, and width of the OLIF cage. One-way analysis of variance (ANOVA) was used to identify differences among the groups for age, BMI, BMD, DHI, SL, LL, operative time, estimated blood loss, VAS score, JOA score, and ODI score. Differences in variables across the three time points of the study were identified by paired *t*-tests for DHI, SL, LL and the VAS, JOA, and ODI scores. The independent-samples *t*-test was used to evaluate the differences in operative time and estimated blood loss in subgroups of the BTS group. Statistical analysis was performed using SPSS (version 21.0; SPSS, Chicago, IL, USA). The level of statistical significance was set as $P < 0.05$.

Results

Radiographic outcomes

In all three groups, the DHI was improved immediately after surgery and then deteriorated significantly by the 6-month follow-up (Table 2). Other than a significant decrease in the SL angle from 3 days to 6 months postoperatively in the SA group ($P = 0.047$), no changes in the SL and LL angles were observed in any group over the course of the study (Table 2).

Table 2
Radiographic outcomes of patients in the SA, BPS, and BTS groups

Parameter	Group			P
	SA (n = 20)	BPS (n = 20)	BTS (n = 20)	
DHI				
PreOp	0.23 ± 0.06	0.22 ± 0.07	0.22 ± 0.07	0.792
3d	0.36 ± 0.06	0.36 ± 0.05	0.34 ± 0.05	0.416
<i>P</i>	0.000*	0.000*	0.000*	
Δ3d-PreOp	0.12 ± 0.06	0.14 ± 0.05	0.12 ± 0.05	0.441
6m	0.30 ± 0.06	0.33 ± 0.04	0.29 ± 0.03	0.002*
<i>P</i>	0.000*	0.002*	0.000*	
Δ6m-3d	-0.05 ± 0.04	-0.03 ± 0.03	-0.05 ± 0.04	0.024*
SL				
PreOp	16.16 ± 5.08	15.37 ± 9.25	10.28 ± 9.97	0.063
3d	16.47 ± 5.11	17.27 ± 8.26	12.59 ± 7.48	0.091
<i>P</i>	0.743	0.206	0.100	
Δ3d-PreOp	0.31 ± 4.19	1.90 ± 6.49	2.32 ± 6.00	0.499
6m	14.65 ± 5.02	16.59 ± 8.57	11.99 ± 8.79	0.172
<i>P</i>	0.047*	0.397	0.452	
Δ6m-3d	-1.82 ± 3.82	-0.68 ± 3.52	-0.60 ± 3.50	0.497
LL				
PreOp	41.68 ± 14.17	41.59 ± 16.15	34.42 ± 18.73	0.285
3d	38.79 ± 12.71	39.71 ± 15.68	36.94 ± 11.07	0.799
<i>P</i>	0.242	0.221	0.314	
Δ3d-PreOp	-2.89 ± 10.71	-1.89 ± 6.66	2.52 ± 10.90	0.176

Values are mean ± standard deviation (SD).

SA, stand-alone; BPS, bilateral pedicle screw; BTS, bilateral transfacet screw; DHI, disc height index; SL, segmental lordosis; LL, lumbar lordosis.

PreOp, preoperation; 3d, 3 days after operation; 6m, 6 months after operation; Δ3d-PreOp, the difference between preoperation and 3 days after operation; Δ6m-3d, the difference between 3 days and 6 months after the operation.

Group				
6m	42.33 ± 12.60	41.67 ± 15.90	38.74 ± 11.40	0.670
<i>P</i>	0.081	0.096	0.129	
Δ6m-3d	3.54 ± 8.57	1.96 ± 5.00	1.81 ± 5.08	0.645
Values are mean ± standard deviation (SD).				
SA, stand-alone; BPS, bilateral pedicle screw; BTS, bilateral transfacet screw; DHI, disc height index; SL, segmental lordosis; LL, lumbar lordosis.				
PreOp, preoperation; 3d, 3 days after operation; 6m, 6 months after operation; Δ3d-PreOp, the difference between preoperation and 3 days after operation; Δ6m-3d, the difference between 3 days and 6 months after the operation.				

The changes in DHI, SL angle, and LL angle (Δ DHI, Δ SL, and Δ LL) were compared among the three groups. No significant differences in the Δ SL and Δ LL values were found, and no significant difference in the Δ DHI value from before surgery to 3 days after surgery was observed. However, from 3 days to 6 months after surgery, the values for the degree of graft subsidence (Δ DHI) in the SA and BTS groups were significantly greater than that in the BPS group (Table 2). Notably, the Δ DHI values during this time for the SA and BTS groups did not differ significantly.

Clinical outcomes

The operative time was significantly less in the SA group than in the other two groups ($P = 0.000$), and the estimated blood loss volume was significantly higher in the BPS group than in the SA and BTS groups ($P = 0.004$; Table 3). No significant differences in the height, length, and width of the OLIF cage were observed among the three groups.

Table 3
Operation details for patients in the SA, BPS, and BTS groups

Group				
Parameter	SA (n = 20)	BPS (n = 20)	BTS (n = 20)	P
Operative time (min)	117.75 ± 34.16	182.75 ± 41.88	207.00 ± 52.10	0.000*
Estimated blood loss (mL)	60.00 ± 22.00	95.00 ± 32.04	81.00 ± 39.19	0.004*
Height of cage (mm)				
10	2	3	1	0.597
12	4	3	5	
13	3	8	7	
14	8	5	4	
15	3	1	3	
Length of cage (mm)				
45	2	6	1	0.206
50	6	7	9	
55	12	7	10	
Width of cage (mm)				
18	14	16	11	0.272
22	6	4	9	
Values are mean ± standard deviation (SD) or as otherwise indicated.				
SA, stand-alone; BPS, bilateral pedicle screw; BTS, bilateral transfacet screw.				

In the BTS group, surgery was performed in the prone position for 9 patients and in the lateral decubitus position for 11 patients. The operative time did not differ between these subgroups, nor did the estimated blood loss (Table 4).

Table 4
Operation details for patients in subgroups of different positions in the BTS group

Subgroup			
Parameter	Prone (n = 9)	Lateral decubitus (n = 11)	P
Operative time (min)	220.00 ± 49.75	196.36 ± 53.86	0.326
Estimated blood loss (mL)	77.78 ± 26.35	83.64 ± 48.43	0.749
Values are mean ± standard deviation (SD).			

All patients experienced significant improvements in the VAS score for back pain, the VAS score for leg pain, the JOA score, and the ODI score by 6 months after surgery compared with those before surgery. The changes in these scores (Δ VAS back pain, Δ VAS leg pain, Δ JOA and Δ ODI) from before surgery to 6 months after surgery were compared among the three groups. The improvement in the VAS score for back pain was significantly less in the SA group than in BPS and BTS groups, as were the JOA score and ODI score. The improvements in the VAS score for back pain, JOA score, and ODI score were similar in the BPS and BTS groups. The improvement in the VAS score for leg pain did not differ among the three groups (Table 5).

Table 5
Clinical outcomes of patients in the SA, BPS, and BTS groups

Parameter	Group			P
	SA (n = 20)	BPS (n = 20)	BTS (n = 20)	
VAS score (back pain)				
PreOp	4.43 ± 2.16	5.05 ± 1.99	6.00 ± 2.88	0.117
6m	1.55 ± 2.28	1.00 ± 1.09	0.83 ± 1.14	0.333
<i>P</i>	0.000*	0.000*	0.000*	
Δ6m-PreOp	2.88 ± 2.09	4.05 ± 2.13	5.18 ± 2.76	0.012*
VAS score (leg pain)				
PreOp	5.43 ± 2.38	6.00 ± 2.22	5.63 ± 2.90	0.765
6m	1.13 ± 2.21	0.40 ± 1.14	0.65 ± 1.42	0.378
<i>P</i>	0.000*	0.000*	0.000*	
Δ6m-PreOp	4.30 ± 2.36	5.60 ± 2.28	4.98 ± 2.94	0.279
JOA score				
PreOp	11.20 ± 2.95	9.70 ± 4.79	10.10 ± 2.71	0.401
6m	22.20 ± 5.93	27.90 ± 2.15	26.90 ± 2.75	0.000*
<i>P</i>	0.000*	0.000*	0.000*	
Δ6m-PreOp	11.00 ± 4.94	18.20 ± 5.36	16.80 ± 3.64	0.000*
ODI score				
PreOp	42.12 ± 7.67	49.21 ± 9.69	44.10 ± 11.86	0.073
6m	12.63 ± 13.98	7.44 ± 7.18	7.65 ± 8.63	0.209
<i>P</i>	0.000*	0.000*	0.000*	
Δ6m-PreOp	29.49 ± 12.01	41.77 ± 12.85	36.45 ± 14.52	0.017*
Values are mean ± standard deviation (SD).				
SA, stand-alone; BPS, bilateral pedicle screw; BTS, bilateral transfacet screw; VAS, visual analog scale; JOA, Japanese Orthopaedic Association; ODI, Oswestry Disability Index; PreOp, preoperation; 6m, 6 months after operation; Δ6m-PreOp, difference between preoperation and 6 months after operation.				

Complications included psoas weakness, left thigh numbness, paralytic ileus, sympathetic dysfunction, and superficial wound infection (Table 6). No patients required reoperation during the 6-month follow-up. The incidence of complications did not differ significantly among the three groups.

Table 6
Complications experienced by patients in the SA, BPS, and BTS groups

Complication	Group			P
	SA (n = 20)	BPS (n = 20)	BTS (n = 20)	
Psoas weakness	1	1		
Left thigh numbness	2	3	3	
Paralytic ileus	1			
Sympathetic dysfunction		1	1	
Superficial wound infection			1	
Total	4	5	5	1.000
Values are number of patients.				
SA, stand-alone; BPS, bilateral pedicle screw; BTS, bilateral transfacet screw.				

Discussion

Subsidence is a common complication following various lumbar interbody fusion surgeries[24] and a matter of great concern for OLIF in particular, as the surgery relies primarily on indirect decompression achieved by restoration of disc height and sagittal alignment[5]. The reported incidence of subsidence with OLIF has ranged from 4.4–21.6%[25]. The development of subsidence is considered to be a multifactorial process, and studies have investigated several potential risk factors, including low BMD, disc space overdistraction, insufficient cage width, construct length, endplate violation, use of osteobiologics, and supplemental fixation[9, 26–32]. Inconsistent results likely resulting, at least in part, from a lack of a uniformity in the methodology used to measure and report subsidence have made it difficult to understand this radiological phenomenon[7, 10, 33, 34]. In the present study, subsidence was defined as any compromise of either endplate due to the cage and was recorded based on specific numeric measurements of cage settling, which can easily be discerned and measured radiographically. Based on the conclusion of previous studies that subsidence is an early postoperative event that does not progress significantly beyond 3 months postoperatively[10, 35], we used postoperative 6 months as the last follow-up date. Over-distraction is an important factor for subsidence; however, to the best of our knowledge, there has been no standard for this issue until now. In the present study, we compared the changes in disc height before and immediately after the operation, which showed that there was no statistical difference, so as to make cage subsidence comparable between the three groups.

Among the patients in the present study, the OLIF procedure was an effective method for restoring disc height, regardless of the fixation pattern used, which was consistent with the results of previous studies[36–38]. In all three groups, loss of disc height had occurred by 6 months after surgery. Notably, in one previous study, subsidence was reported as an expected occurrence rather than a complication[35].

However, the subsidence in the BPS group was significantly less than that in either of the other two groups, indicating that supplementary fixation and a specific pattern can help to avoid a loss in disc height. In recent decades, the use of supplemental fixation in OLIF has been the subject of ongoing debate. Previous studies showed that a sufficiently distracted intervertebral space following discectomy can be stabilized for multidirectional movement by tension forces of the residual annulus and ligaments[14, 39, 40]. Also, the authors supporting stand-alone OLIF have stated that it avoids the morbidity associated with supplemental screw fixation and is less expensive. Conversely, Fogel et al. reported that a stand-alone cage decreased the ROM by only about 23% compared with the normal spine and significantly increased the anterior-posterior (interbody) displacement in a L4-L5 spondylolisthesis cadaver model[41]. Liu et al. used a finite element model to evaluate the biomechanics of three-level lateral interbody fusion with and without supplementary instrumentation and found that stand-alone lateral interbody fusion could not provide adequate ROM restriction, whereas lateral cages with bilateral pedicle screw and rod fixation provided favorable biomechanical stability[13]. Additionally, stand-alone OLIF generated significantly higher endplate stress than did OLIF with supplementary instrumentation, which may increase the risk of cage subsidence. Nevertheless, their results can only be applied to multilevel fusion. Whether supplementary instrumentation should be applied to prevent subsidence in single-level OLIF remains controversial. Malham et al. proposed that patients with one- or two-level disease, normal bone density, and no obvious instability were candidates for stand-alone OLIF[7]. In contrast, in the present study, the subsidence in the SA group was significantly greater than that in the BPS group at the 6-month follow-up, indicating that stand-alone OLIF may not be sufficient for maintaining disc height even in single-level disease, which is consistent with the result of Choi and Sung[35].

Bilateral pedicle screws represent the biomechanical gold standard for adjunct stabilization[30, 42]. However, studies have reported greater blood loss and longer operative time for OLIF with supplementary BPS compared with stand-alone OLIF due to the requirement of additional posterior surgery[39, 43]. These results were consistent with our findings. As a traditional method for posterior fixation, BTS has several advantages over BPS, such as fewer incisions, being minimally invasive, having less influence on the adjacent segments, and less cost, as only two screws are used at each spinal segment[44]. In the present study, the operative time tended to be shorter when the operation was performed with patients in the lateral decubitus position versus the prone position, but the difference was not significant, probably due to the small sample sizes of the subgroups. Previous studies have demonstrated that BTS provides equivalent stiffness against segmental movements compared with BPS[20, 44]. Chin et al. even showed that BTS offers greater stability than pedicle screws in the motion of flexion[21]. However, in the current study, the subsidence rates of the BTS and SA groups were similar and significantly higher than that of the BPS group, indicating that although additional BTS can make the overall construct stiffer, this construct is unlikely to achieve more resistance to axial compression than stand-alone OLIF. The screw placement was done under the guidance of the TiRobot system. Previous studies at our center have demonstrated a high accuracy of BPS and BTS with assistance by this robotic system[45, 46], and thus, accuracy was not a concern in this study.

It is well established that improper sagittal alignment of the spine results in inefficient energy use and maximizes muscle tension due to exhaustive bracing and spine instability, contributing to adjacent-level disease[47, 48]. In a review of 12 retrospective and 2 prospective studies including 1266 levels in 476 patients, Costanzo et al. showed that lateral interbody fusion is effective when the lumbar lordosis and sagittal balance correction goals were less than 10° and 5 cm, respectively, but the results for sagittal balance restoration using the technique were inconsistent[49]. Chen et al. compared the alteration and maintenance of SL and LL in lateral interbody fusion with and without supplementary fixation[39]. They found that lateral interbody fusion alone and with supplementary fixation could increase the post-operative SL and LL angles, but BPS could maintain the LL angle but not the SL angle for 2 years after surgery. In the present study, OLIF with or without supplemental fixation improved the SL angle to 0.3°~2.3° on average, with no significant difference among the groups. At the 6-month follow-up though, the reduction in the SL angle was significant only in the SA group. Overall, research to date has produced inconsistent findings regarding local and global sagittal balance restoration after OLIF, and further studies are needed to address this issue.

The questionnaire-based clinical outcomes in our cohort showed significant improvements in symptoms and function at 6 months after surgery compared with preoperative values, regardless of the fixation pattern, which was consistent with previous studies[6, 50, 51]. The change in the VAS score for leg pain did not differ among the three groups, indicating that indirect decompression can be achieved and maintained by the stand-alone technique. However, the improvements in the VAS score for back pain, the JOA score, and the ODI score were worse in the SA group compared with the other two groups. Back pain and related disability may have resulted due to the instability caused by the lack of posterior column support. In a finite element analysis, stand-alone OLIF generates significantly higher endplate stress compared with that of supplemental instrumentation, which results in an increase in the risk of cage migration and development of clinical symptoms[13]. Our results confirm this limitation of the SA technique. Interestingly, although BTS cannot offer more resistance to subsidence compared with stand-alone OLIF, the symptomatic and functional improvement with BTS were better. These findings were consistent with other studies that investigated the clinical outcomes with BTS as supplementary fixation for lumbar interbody fusion and observed promising results[22, 52]. This can be explained by the additional stability provided by the transfacet screws. In a study of the effect of supplemental BTS on the stability of stand-alone ALIF under physiologic compressive preloads, Phillips et al. found that the stand-alone cage is likely to be less stable and supplemental BTS can enhance the stability of the motion segment, particularly during conditions of low compressive preloads[53]. Moreover, the results of our study also indicated no obvious correlation between subsidence and clinical outcomes. This is consistent with the results of previous studies comparing subsidence to final clinical outcomes in which no clear relationship was observed[12, 54, 55]. Marchi et al. graded subsidence and proposed that high-grade subsidence (> 50% into the vertebral endplates) could lead to persistent back pain or radiculopathy and a need for revision surgery[10]. Similar results were reported by Tempel et al., who reported a strong correlation between subsidence grade and the risk of revision surgery[55]. Because the sample size of the

current study was small, we did not grade the subsidence. A further prospective, randomized, and controlled study is needed to clarify the correlation between subsidence grade and clinical outcomes.

Because of the novelty of OLIF, there is a paucity of data regarding its complications. In a multicenter study including 155 patients, Abe et al. reported a complication incidence of 29.5%[11], and a systematic review reported 1.5% intraoperative and 9.9% postoperative complications among 1453 patients treated with OLIF[5]. A recent analysis of OLIF-related complications identified only 20 research studies of sufficient quality and relevance, and reported overall combined rates of 5.7% for postoperative psoas weakness, 8.7% for thigh numbness, and 3.3% for paralytic ileus[25]. These rates were similar to those in the present study (psoas weakness 3.3%, thigh numbness 13.3%, and paralytic ileus 1.7%), in which the overall complication rate was 23.3%. These complication rates did not differ significantly among the groups, but these findings should be interpreted with caution due to the relatively small sample sizes.

A major limitation of this study was its retrospective design. Additionally, the study was a single-center study with a small sample size. Although we matched the patients according to main parameters, complex baseline differences may have been confounding factors for clinical and radiographic outcomes among the groups. Differences between surgeons could be a potential confounding factor in this study, because the surgeries were performed by three senior spine surgeons. Although all three surgeons had received standardized training for the OLIF procedure and implemented standardized surgical maneuvers, and there was no statistical difference between the numbers of cases in the different treatment groups for the three surgeons, this confounding factor cannot be completely ruled out. Another limitation was the lack of dynamic radiographic evaluation at the 6-month follow-up. Thus, no conclusions regarding instability or union can be made. Ideally, fusion status should be assessed by CT scan at one year after surgery. Future studies should focus on the stability status after OLIF rather than subsidence only.

Conclusions

The stand-alone OLIF procedure was associated with greater subsidence and poorer clinical outcomes compared with OLIF plus supplementary BPS. The addition of BTS to OLIF could not decrease the degree of subsidence, but provided comparable clinical outcomes to OLIF with BPS. Therefore, BTS could be considered as a substitute for BPS as supplemental fixation with OLIF.

Abbreviations

BMD: bone mineral density; BMI: body mass index; QCT: quantitative computed tomography; OLIF: oblique lateral interbody fusion; ODI: Oswestry Disability Index; VAS: Visual Analog Scale; JOA: Japanese Orthopedic Association; DHI: disk height index; SL: segmental lordosis; LL: lumbar lordosis; SA: stand-alone; BPS: bilateral pedicle screw; BTS: bilateral transfacet screw.

Declarations

Ethics approval and consent to participate

All procedures performed in this study were planned and conducted in accordance with the ethical standards of the Institutional and National Research Committees and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards, and approved by the medical ethics committee of Beijing JiShui Tan Hospital [ethical approval number: 202004-01].

Consent for publication

Informed consent was obtained from all individual participants involved in the study.

Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to the data is confidential patients' data but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

(I) Conception and study design: ZL and WT; (II) provision of study materials or patients: ZL, YQS and QY; (III) collection and assembly of data: JYW, MXF and JNL; (IV) data analysis and interpretation: ZL and WT. All authors read and approved the final manuscript.

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Figures

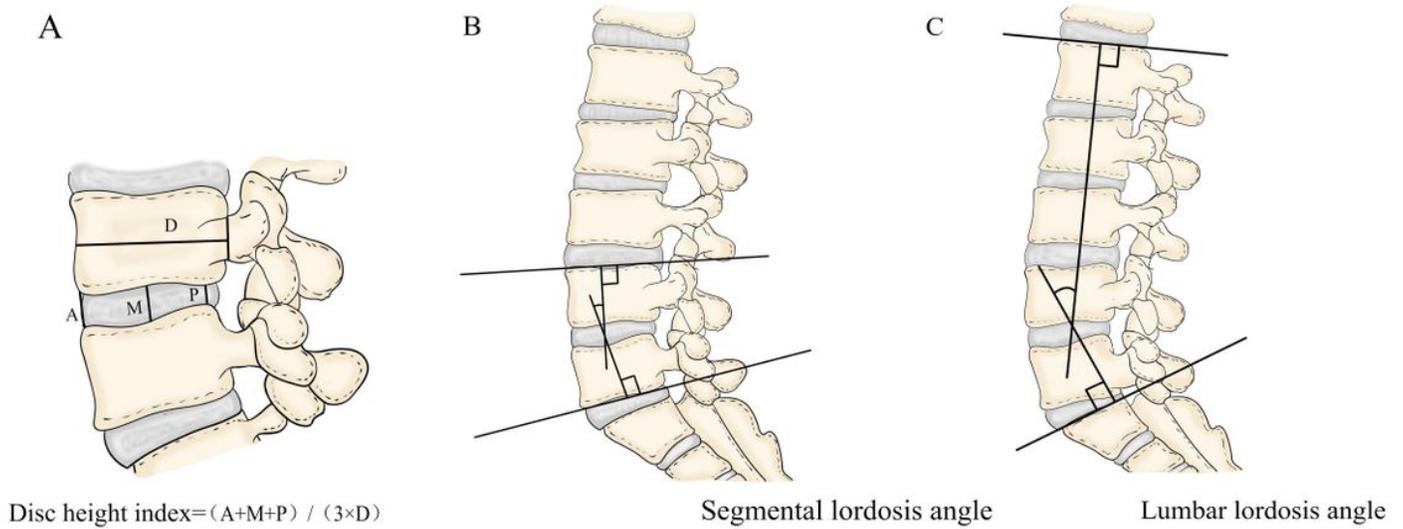


Figure 1

A. The DHI was measured on standing neutral lateral radiographs, as an average of the anterior (A), middle (M), and posterior (P) disc heights normalized by the sagittal diameter (D) of the overlying vertebral body at the mid-vertebral level. B. The SL angle was defined as the angle between the superior end plate of the upper vertebra and the inferior end plate of the lower vertebra at the corresponding level. C. The LL angle was defined as the Cobb angle formed between the upper end plate of L1 vertebra and the upper end plate of S1 vertebra.