CLINICAL ARTICLE

Application of Oblique Lateral Interbody Fusion in Treatment of Lumbar Spinal Tuberculosis in Adults

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Objective: The purpose of the present paper was to evaluate the safety and clinical efficacy of mini-open retroperitoneal oblique lumbar interbody fusion (OLIF) for the treatment of lumbar spinal tuberculosis.

Methods: A total of 115 patients who suffered from lumbar spinal tuberculosis from June 2014 to December 2017 were included in this research. A total of 59 patients underwent OLIF and percutaneous pedicle screw fixation (OLIF group) and 56 patients underwent the anterior-only approach (anterior-only group). All patients were followed up for at least 24 months. Operation time, blood loss, and rate of complications were used to assess the safety of these two techniques. The visual analog scale (VAS) and the Oswestry disability index (ODI) were used to evaluate the relief of neurological and functional symptoms. The erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) were measured to investigate the activity and recurrence of spinal tuberculosis. The Cobb angle, the sagittal vertical axis of the spine (SVA), the pelvic tilt (PT), the sacral slope (SS), the pelvic incidence (PI), and postoperative Frankel classification were also used to assess the efficiency of the spine deformity correction and the recovery of long-term neurological function.

Results: Most patients were successfully treated with OLIF and the anterior-only technique and attained satisfactory clinical efficiency during the 24-month follow-up period. In the perioperative period, the mean operative time (154.68 ± 23.64 min, $P < 0.001$), the mean blood loss (110.57 ± 87.67 mL, $P < 0.001$), and the mean hospital stay (9.55 ± 3.62 days, $P < 0.001$) of the OLIF group were all significantly lower than in the anterior-only group (172.49 ± 25.67 min, 458.56 ± 114.89 mL, and 14.89 ± 3.89 days, respectively). A total of 10 patients (16.95%) experienced complications in the OLIF group, including neurological injury, segmental artery and iliac vein lacerations, peritoneal injury, instrument failure, and infection of incisions; this rate of complications was lower than in the anterior-only group (37.50%, $P = 0.013$). Regard to spinal deformity correction, the Cobb angle ($9.42° \pm 1.72°$, $P = 0.032$), the SVA (2.23 ± 1.07 cm, $P = 0.041$), the PT ($14.26° \pm 2.37°$, $P = 0.037$), and the SS ($39.49° \pm 2.17°$, $P = 0.042$) of the OLIF group at last follow-up were all significantly different when compared to the anterior-only group ($14.75° \pm 2.13°$, 3.48 ± 0.76 cm, $18.58° \pm 1.45°$, and $36.78° \pm 1.96°$, respectively). The VAS and the ODI of the OLIF group at 1 week postoperatively (3.15 ± 0.48, 21.85 ± 3.78, $P = 0.032$, 0.037) and at the last follow-up (2.12 ± 0.35, 16.70 ± 5.25, $P = 0.043$, 0.035) were both lower than for the anterior-only group (5.18 ± 0.56, 29.83 ± 5.42 and 3.67 ± 0.62, 20.68 ± 6.23). The Frankel classification was improved for both OLIF and anterior-only patients; however, there were 35 cases (59.32%) classified as Frankel grade E in the OLIF group and 22 cases (39.29%, $P = 0.021$) in the anterior-only group

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Conclusion: The OLIF surgical technique for single lumbar (L_2–L_5) spinal tuberculosis is less invasive, has lower complication rates, and is more efficient than the anterior-only approach. However, the long-term effects of this surgical technique still need to be explored.

Key words: Anterior-only approach; Complication; Lumbar; Oblique lateral interbody fusion; Spinal tuberculosis

Introduction

Tuberculosis (TB) is a major infectious disease that endangers global human health. According to the World Health organization (WHO), there were approximately 10 million people worldwide infected with TB and approximately 1.24 million patients died of TB in 2018[1]. China has a high TB burden. The dangers of TB are not confined to pulmonary issues: TB can spread to extra-pulmonary tissues through the blood system and lymphatic system (e.g. lymphoid TB, renal TB, and bone and joint TB). Secondary pulmonary TB most frequently occurs in the vertebral body and in joints, and approximately 50% occurs in lumbar vertebrae, especially in immunocompromised people and elderly patients[2]. The clinical symptoms of lumbar spinal TB are commonly inconspicuous in the early stages; however, with the proliferation of *Mycobacterium tuberculosis*, paraspinal abscesses, bony destruction, kyphosis, and even paraplegia can occur. Most spinal TB can be cured with standard antituberculosis chemotherapy; however, if neurological deficits and spinal deformity occur with spinal TB, surgery is necessary[3].

Many published studies have confirmed the effectiveness of surgical treatment for lumbar spinal TB using anterior, posterior, or anterior–posterior internal fixation after focal clearance and interbody fusion[4–6]. However, all these surgical approaches are associated with a series of problems[7–9]: (i) clearance of lesions and restoration of stability cannot be achieved simultaneously; (ii) extensive and complex injuries of perifocal tissue and incision; (iii) a high rate of complications, such as spinal cord injury, failure of interbody fusion, incision infection, and localized abscesses. All these negative factors not only increase healthcare costs and the financial burden for families and societies but also impact the physical and psychological health of patients. "The End TB Strategy" of the WHO is aiming to decrease the incidence and mortality rate of TB and to reduce the financial costs of TB for patients' family[10]. Therefore, while surgery is generally effective for lumbar spinal TB, exploring more minimally invasive operative approaches is necessary.

In recent three years, oblique lateral interbody fusion (OLIF), as a minimally invasive and safe surgical technique, has been widely used to treat progressive disease of the lumbar spine by lumbar intervertebral fusion[11, 12]. This technique was first proposed by Mayer *et al.*[13] in 1997 and was officially named "OLIF" by Silvestre *et al.*[14] in 2012. This technique involves fully utilizing the retroperitoneal intermuscular space and inserting a retractor. Application of this technique results in less blood loss, faster recovery, and a lower probability of nerve injury. In terms of its learning curve, it is detail-oriented and can be easily applied by spine clinicians. Considering the advantages of OLIF, it could be an effective surgical approach to cure lumbar spinal TB. In theory, the lumbar and abdominal regions can potentially provide access to the posterior spine and the abdomen down to the symphysis pubis, which makes it possible to remove the lesion and complete internal fixation simultaneously in the lateral position. However, this technique has rarely been applied by spine surgeons to treat lumbar spinal TB.

Based on the background above, the purpose of this study was: (i) to observe whether the OLIF technique could been applied to treat lumbar spinal TB; (ii) to evaluate the focus clearance effect and lumbar interbody fusion rate of the OLIF technique; and (iii) to synthetically assess the safety and mid-term to long-term therapeutic effects of the OLIF technique.

Methods

Inclusion and Exclusion Criteria

The inclusion criteria were as follows: (i) patients diagnosed with lumbar spinal TB by X-ray, CT, and MRI; (ii) patients who had undergone operative treatment with OLIF or the anterior-only approach; and (iii) patients who had undergone a minimum of 24 months of follow-up.

The exclusion criteria were: (i) patients with multi-segmental spinal TB; (ii) patients who were long-term bed-ridden or had a variety of underlying diseases, including cardiovascular and cerebrovascular diseases, diabetes mellitus, tuberculous pleurisy, and renal or liver disfunction; and (iii) patients with a medical history of congenital spinal deformity or lumbar surgery.

Subjects

We retrospectively reviewed the medical records of patients who had undergone surgical treatment between June 2014 and June 2017. A total of 115 consecutive patients were included in this study and followed up for 24 months (average, 23.90 ± 4.21 months). A total of 59 patients (the OLIF group) underwent OLIF surgery and 56 patients (anterior-only group) underwent the anterior-only approach. The levels infected by TB included L_2–L_3 in 24 patients, L_3–L_4 in 38 patients, L_4–L_5 in 45 patients, and L_5–S_1 in 8 patients. The initial symptoms of all patients were lower back pain and loss of nerve function in the spinal cord accompanied by low-grade fever, massive fatigue, and night sweats. The neurological status of all patients was evaluated using the

Frankel classification and was intact in all patients (B: 4 cases; C: 39 cases; D: 67 cases, E: 5 cases). Kyphosis also occurred in 23 patients with 15°–52° (average, 26.12° ± 8.92°) Cobb angle. There were no statistically significant differences between the demographic profiles of the two groups studied ($P > 0.05$). All patients needed to undergo standard quadruple antituberculosis (isoniazid + rifampicin + pyrazinamide + ethambutol) before the operation and 2–4 weeks later. The study protocol was approved by the Medical Ethical Committee of Fudan University (20200120031).

Surgical Procedures

Anesthesia and Position

All the operations were performed with patients in a lateral position under general anesthesia.

Approach and Exposure

Oblique lumbar interbody fusion. The operation was performed based on the standard procedure described by Sato *et al.*[15] and Abe *et al.*[16]. Patients were placed in the lateral decubitus position on their right side, and the target guide pin was inserted in the disk space under fluoroscopic guidance. Presence of a scoliosis does not affect the side of surgical approach. A 5-cm skin incision was made 6 to 10 cm anterior to the mid-portion of the marked disc. The surgical team approached the retroperitoneal space through blunt dissection and mobilizing the peritoneum anteriorly to expose the anatomical oblique lateral corridor. The affected vertebra, pus, dead bones, tuberculous bud tissue, and caseous necrotic material could then be clearly seen. When the lesions were completely removed, saline solution was used to fully wash the operation field, followed by autologous iliac bone implantation. After the intervertebral fusion, the pedicle screw–rod internal fixation system or pedicle screws and plates was used to stablize spine[17]. All key procedures of the OLIF approach are presented in Fig. 1.

Anterior-only approach. First, the exposed pathologic and adjacent vertebral body were exposed through extraperitoneal soft tissue. Second, when the infective lesions were revealed, a curette could be used to radically clear the anterolateral and intervertebral tuberculous abscess, caseous necrosis, and necrotic bone. Third, 3% hydrogen peroxide solution, 0.9% sodium chloride, and isoniazid were alternately used to wash the tuberculous focus. Fourth, bone graft from autogenous iliac crest was implanted, and then pedicle screws and anterior titanium plates were used for internal fixation. Finally, a drain tube was placed for continuous drainage of lumbar fluid.

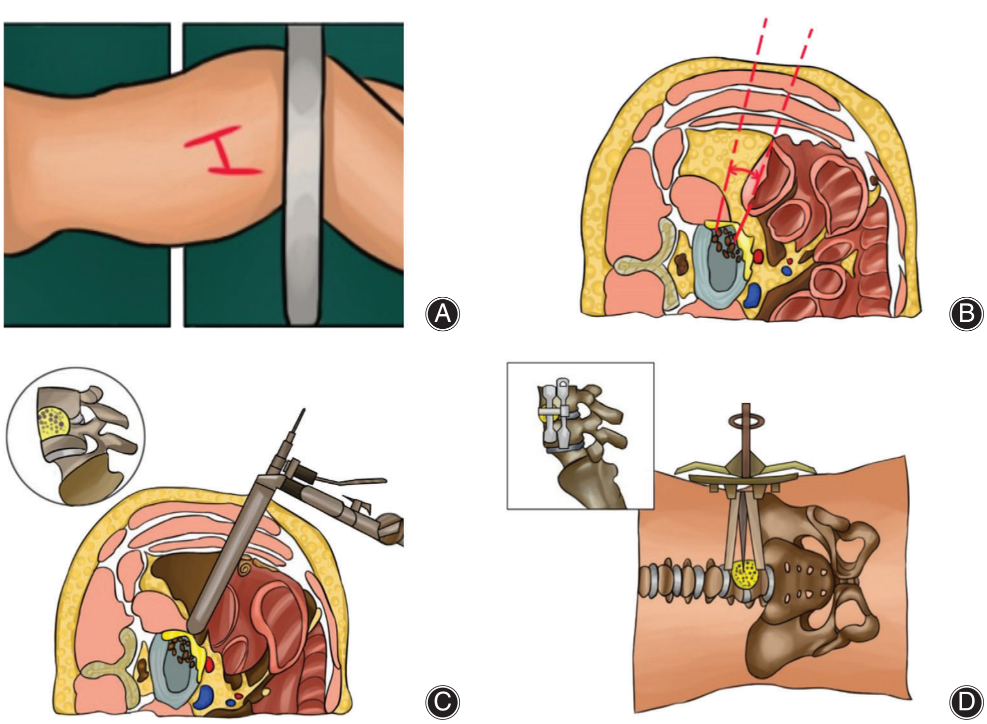

Fig 1 Surgical procedures of the oblique lumbar interbody fusion (OLIF) technique. (A) The patient was placed in right lateral decubitus position, and a 5-cm transverse incision was made at the left lower quadrant. (B) The musculus obliquus externus and internus abdominis, the musculus transversus abdominis, and the retroperitoneal fat along the retroperitoneal intermuscular space were bluntly dissected. (C) The sequential dilators and the retractor were placed under the guidance of X-ray, and the infective focus was cleared completely with a curet and reamer. (D) Autologous iliac bone was implanted into the intervertebral space, and then pedicle screws and plates were implanted into the anterolateral of the adjacent vertebral body to reconstruct spine continuity and stability.

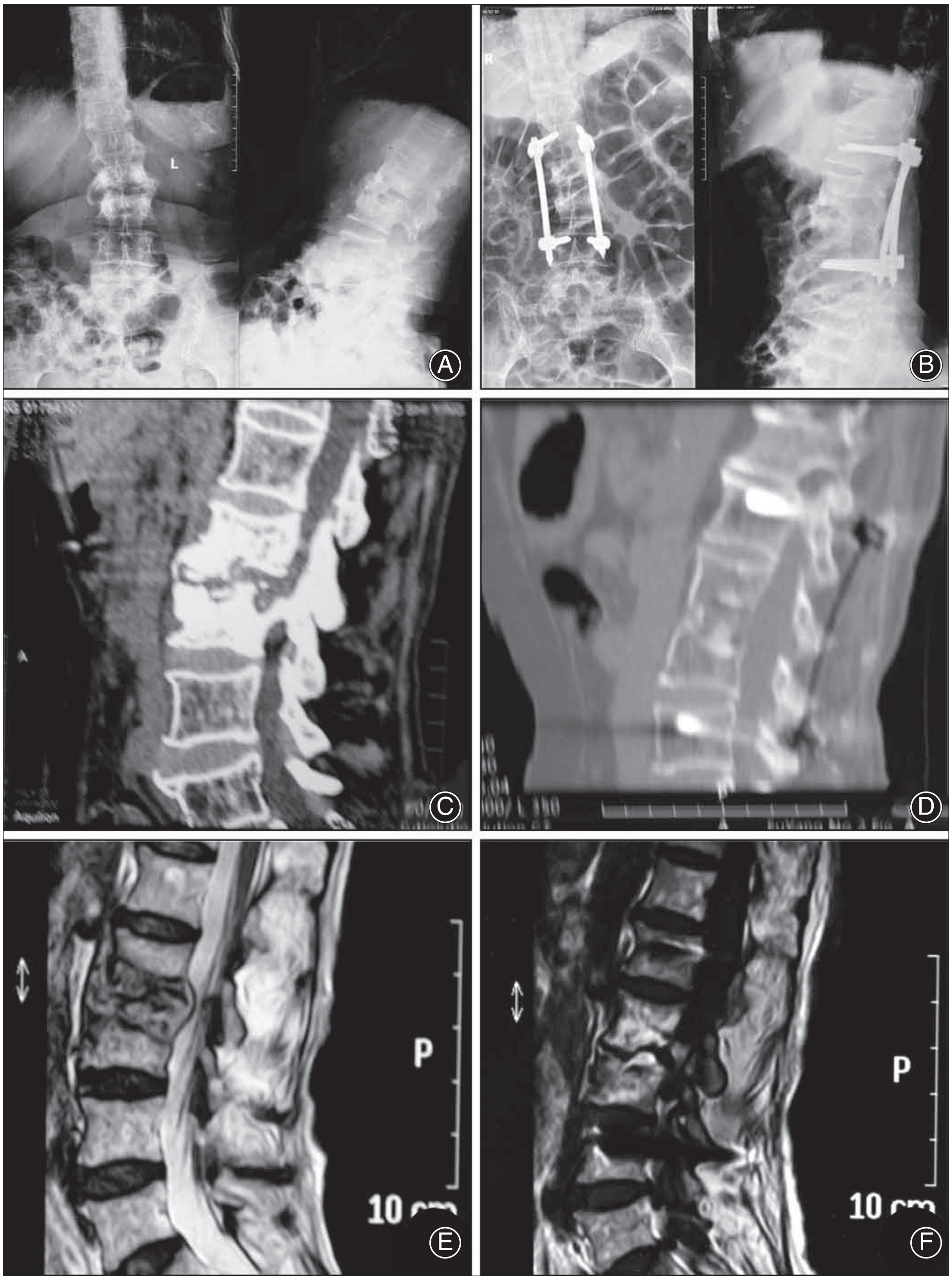

Fig 2 A 44-year-old woman with tuberculosis of L_2–L_3 had triple chemotherapy for 26 months. (A, C, and E) Preoperative radiographic data, showing the infective lesions located at L_2–L_3, and that the anterior and middle column of vertebral body had been severely damaged, with compression of the spinal cord and lumbar scoliosis. (B, D, and F) The postoperative radiographic data of 2-year-follow-up, which indicated that the vertebral body of L_2–L_3 has been fused by the OLIF technique with the pedicle screw–rod internal fixation system; infective lesions have been almost cleared and lumbar deformity has also been corrected to some extent.

Evaluation of Outcomes

Evaluation of Operative Outcomes and Complications
The intraoperative indexes were prospectively recorded, including operative time and blood loss. The kinds and numbers of complications were carefully recorded, including neurological injury, segmental artery and iliac vein lacerations, peritoneal injury, instrument failure, and infection of incisions. The length of hospital stay was also documented.

Evaluation of Follow-up Indexes

Visual Analog Scale
The visual analog scale (VAS) was used to assess the degree of pain of patients in the two groups. The VAS scoring system was self-completed by patients. Patients marked the location on the 10-cm line corresponding to the amount of pain they experienced: 0 represents no pain and 10 the most severe pain.

Oswestry Disability Index

Oswestry disability index (ODI) is a principal condition-specific outcome measure used in assessing the daily routine of patients with spinal diseases. The ODI scoring system consists of 10 sections: present pain intensity, personal life care, lifting, walking, sitting, standing, sleeping, sex life, social life, and traveling. There are six statements in each section, and each section is scored on a scale of 0–5. If all 10 sections are completed, the score is calculated as follows: total score out of total possible score × 100. If one section is missed (or not applicable), the score is calculated as: (total score/(5 × number of questions answered)) × 100%. In the ODI scoring system, 0%–20% is considered mild dysfunction; 21%–40% is moderate dysfunction; 41%–60% is severe dysfunction; and 61%–80% is considered as disability. For cases with a score of 81%–100%, the patient is either long-term bedridden or exaggerating the impact of pain on their life.

C-reactive Protein and Erythrocyte Sedimentation Rate

The erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) are two inflammatory markers in blood; they are used to monitor the activity of spinal TB during the follow-up period in this study.

Spinal Deformity Correction

In assessing the operative effect of OLIF and the anterior-only technique, the Cobb angle is used to evaluate the severity of scoliosis and the sagittal vertical axis (SVA) is used to evaluate whether the spine is out of balance. Because of the importance of the three-dimensional structure and the morphological parameters of the pelvis for sagittal balance of the spine, pelvic tilt (PT), sacral slope (SS), and pelvic incidence (PI) are also used to evaluate the ability of OLIF to compensate for spine imbalance.

Frankel Spinal Cord Injury Classification

The Frankel spinal cord injury classification is commonly used to evaluate the neurological function of sensory and motor after spinal injury. Based on motor and sensory performance, there are five grades: (A) no sensory or motor function; (B) incomplete sensory but no motor function; (C) motor function of partial muscles is preserved but not below the injury level; (D) incomplete motor function is preserved below the neurological level, and patients can walk on crutches; and (E) sensory and motor function are normal. Frankel classification was applied to assess the operative effect of OLIF and the anterior-only approach in the treatment of lumbar spinal TB.

Statistical Method

All data analysis and statistics were processed using SPSS 21.0 (IBM, Armonk, NY, USA). Patient characteristics, ESR, CRP, spinal deformity correction indexes, VAS, and ODI were expressed as means and standard deviations. One-way analysis of variance or Student's *t*-tests were used to compare differences between groups. The rate of complications and Frankel classification were presented as numbers and ratios. The χ^2-test was applied to analyze differences between groups. $P < 0.05$ was defined as a significant difference.

Results

General Results

All patients received adequate preoperative preparation and postoperative management. Preoperative clinical data and follow-up times of patients in the two groups were not significantly different ($P > 0.05$, Table 1). However, there were significant differences in intraoperative and postoperative indicators between these two groups. The mean operative time (154.68 ± 23.64 min, $P < 0.001$), mean blood loss (110.57 ± 87.67 mL, $P < 0.001$), and

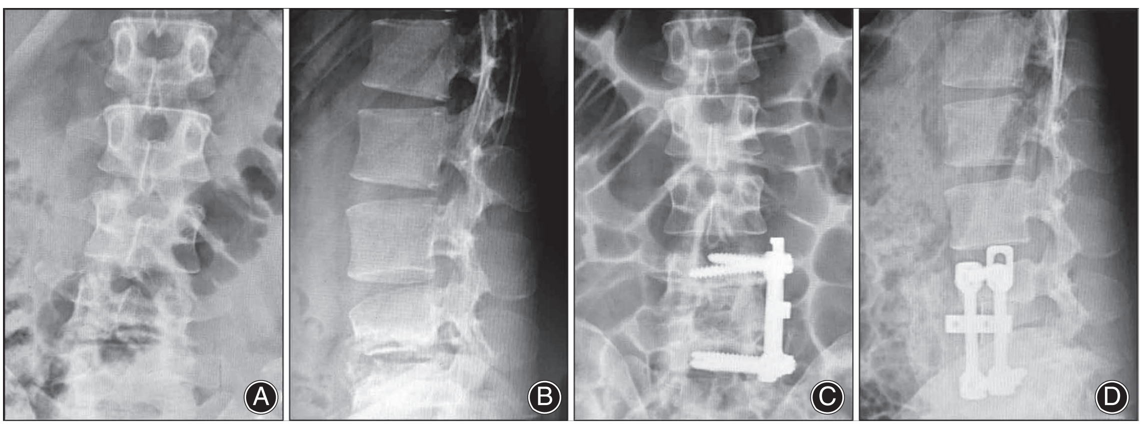

Fig 3 A 53-year-old man with tuberculosis of L_4–L_5 had triple chemotherapy for 30 months. (A and B) Preoperative X-ray images, which demonstrated that the infective lesions were located at L_4–L_5, and the edge of the L_4 and the superior border of the L_5 vertebral body had been severely damaged with mild deformity of the spinal column. (C and D) Postoperative X-ray images, which showed that the infective focus had been cleared, the location of the autogenous iliac crest and internal fixation were reasonable, and the spinal deformity had been corrected to some extent.

TABLE 1 Perioperative characteristics of patients

	Oblique lateral interbody fusion		Anterior-only		
Variable	Mean	SD	Mean	SD	*P*-value
Age (year)	42. 87	15. 42	40.45	16.79	0.589
Disease course (month)	10.64	5.43	11.23	4.67	0.557
Symptom duration (year)	2.13	1.62	2.07	1.76	0.496
Antituberculosis drugs use time (year)	4.82	2.59	5.02	2.71	0.428
Follow-up duration (month)	23.89	3.96	23.91	4.21	0.572
Preoperative Cobb angle (°)	26. 39	3. 18	25.85	4.17	0.635
Operation time (min)	154.68	23.64	172.49	25.67	<0.001
Blood loss (mL)	110.57	87.67	458.56	114.89	<0.001
Hospital stays (day)	9.55	3.62	14.89	3.89	<0.001

SD, standard deviation.

mean hospital stays (9.55 ± 3.62 days, $P < 0.001$) of the OLIF group were all significantly different compared to the anterior-only group (172.49 ± 25.67 min, 458.56 ± 114.89 mL, and 14.89 ± 3.89 days, respectively) (see Table 1). This highlighted that OLIF can absolutely clear TB focus with more minimal invasive.

C-Reactive Protein and Erythrocyte Sedimentation Rate

During the surgery, infective focus was cleared as much as possible by OLIF or the anterior-only approach. Following surgery, erythrocyte sedimentation rate (ESR) and c-reactive protein (CRP) were measured to evaluate TB lesion clearance effect, and monitor the recurrence. The ESR and CRP in the OLIF group were, respectively, decreased from 57.68 ± 16.55 mm/h and 35.67 ± 13.88 mg/L preoperatively to 8.79 ± 3.19 mm/h and 7.72 ± 3.63 mg/L at the last follow-up, with a mean drop of 48.89 and 27.95 (P = 0.008; 0.012) (Table 2). In the anterior-only group, ESR and CRP were, respectively, decreased from 56.92 ± 15.96 mm/h and 36.45 ± 11.17 mg/L preoperatively to 8.32 ± 3.02 mm/h and 7.53 ± 3.01 mg/L at the last follow-up, with a mean drop of 48.60 and 28.92 (P = 0.015; 0.009) (Table 2). However, there was no prominent difference between these two groups at each follow-up time point.

TABLE 2 Change of ESR and CRP of each group during the follow-up (mean ± SD)

Variable	Oblique lateral interbody fusion	Anterior-only	*P*-value*
ESR (mm/h)			
Preoperation	57.68 ± 16.55	56.92 ± 15.96	0.523
2 weeks after surgery	24.76 ± 8.23†	23.67 ± 9.58†	0.612
6 months after surgery	10.29 ± 3.26‡	9.56 ± 3.37‡	0.417
The last follow up	8.79 ± 3.19	8.32 ± 3.02	0.478
CRP (mg/L)			
Preoperation	35.67 ± 13.88	36.45 ± 11.17	0.634
2 weeks after surgery	17.19 ± 4.26†	17.02 ± 5.21†	0.578
6 months after surgery	8.34 ± 3.79‡	8.45 ± 4.05‡	0.723
Last follow up	7.72 ± 3.63	7.53 ± 3.01	0.696

* Compared to anterior-only group.; † Compared to preoperation, $P < 0.05$.; ‡ Compared to 2 weeks after surgery, $P < 0.05$.; CRP, c-reactive protein; ESR, erythrocyte sedimentation rate.

Spinal Deformity Correction

Cobb angle

According to Table 3, the Cobb angle of all patients decreased after surgical treatment. In the OLIF group, the Cobb angle at last follow up was 9.42° ± 1.72°, which was significantly lower than preoperatively, 26.39° ± 3.18° (t = 6.35, $P < 0.05$); in the anterior-only group, the Cobb angle at last follow up was 14.75° ± 2.13°, which was also significantly lower than preoperatively, 25.85° ± 4.17° (t = 5.68, $P < 0.05$). Compared with the anterior-only group at last follow up, the Cobb angle of the OLIF group was much lower (t = 3.59, P = 0.032). A representative case is shown in Fig. 2 of a 44-year-old female patient with L2-L3 tuberculosis and scoliosis.

Sagittal Vertical Axis

The sagittal vertical axis (SVA) of all patients was decreased by surgery (see Table 3). In the OLIF group, the SVA at last follow up was 2.23 ± 1.07 cm, and it was significantly lower than preoperatively, 5.39 ± 2.16 cm (t = 3.19, $P < 0.05$); in the anterior-only group, the SVA at last follow up was 4.48 ± 0.76 cm, and it was also significantly lower than preoperatively, 3.48 ± 0.76 cm (t = 2.73, $P < 0.05$). Compared with the anterior-only group at last follow up, the SVA of the OLIF group was much lower (t = 2.49, P = 0.041). Another representative case is shown in Fig. 3 of a 53-year-old male patient with L4-L5 tuberculosis.

Pelvic Tilt

The pelvic tilt (PT) of all patients was decreased (see Table 3). In the OLIF group, the PT at last follow up was 14.26° ± 2.37°, and it was significantly lower than

TABLE 3 Spinal deformity correction of oblique lumbar interbody fusion (OLIF) and anterior-only approach at the last follow-up time (mean ± SD)

	Oblique lateral interbody fusion		Anterior-only		
Variable	Preoperation	Last follow up	Preoperation	Last follow-up	*P*-value *
Cobb angle (°)	26.39 ± 3.18	9.42 ± 1.72 †	25.85 ± 4.17	14.75 ± 2.13 †	0.032
SVA (cm)	5.39 ± 2.16	2.23 ± 1.07 †	5.47 ± 2.55	3.48 ± 0.76 †	0.041
PI (°)	56.42 ± 2.07	53.14 ± 1.45 †	56.02 ± 3.13	54.08 ± 2.02 †	0.863
PT (°)	28.64 ± 3.63	14.26 ± 2.37 †	29.12 ± 4.18	18.58 ± 1.45 †	0.037
SS (°)	34.67 ± 3.41	39.49 ± 2.17 †	34.85 ± 3.28	36.78 ± 1.96 †	0.042

* Compared to anterior-only group at last follow up.; † Compared to preoperation, $P < 0.05$.; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; SVA, sagittal vertical axis.

preoperatively, 28.64° ± 3.63° ($t = 5.81$, $P < 0.05$); in the anterior-only group, the PT at last follow up was 18.58° ± 1.45°, and it was also significantly lower than preoperatively, 29.12 ± 4.18 ($t = 4.68$, $P < 0.05$). Compared with the anterior-only group at last follow up, the PT of OLIF group was much lower ($t = 3.75$, $P = 0.037$).

Sacral Slope

The sacral slope (SS) of all patients was increased (see Table 3). In the OLIF group, the SS at last follow up was 39.49° ± 2.17°, and it was significantly higher than preoperatively, 34.67° ± 3.41° ($t = 3.17$, $P < 0.05$); in the anterior-only group, the SS at last follow up was 36.78° ± 1.96°, and it was also significantly higher than preoperatively, 34.85° ± 3.28° ($t = 4.28$, $P < 0.05$). Compared with the anterior-only group at last follow up, the SS of the OLIF group was much higher ($t = 3.52$, $P = 0.042$).

Pelvic Incidence

The pelvic incidence (PI) of all patients was increased (see Table 3). In the OLIF group, the PI at last follow up was 53.14 ± 1.45°, and it was significantly lower than preoperatively, 56.42 ± 2.07° ($t = 3.38$, $P < 0.05$); in the anterior-only group, the PI at last follow up was 54.08 ± 2.02°, and it was also significantly lower than preoperatively, 56.02 ± 3.13 ($t = 2.89$, $P < 0.05$). However, there was no significant difference between these two groups in PI at last follow up ($t = 2.01$, $P = 0.863$).

TABLE 4 Visual analog scale (VAS) score and Oswestry disability index (ODI) score for the two group patients at each time point of follow up (mean ± SD)

Variable	Oblique lateral interbody fusion	Anterior-only	*P*-value*
VAS			
Preoperation	7.85 ± 0.79	7.63 ± 0.86	1.732
Postoperative 1 week	3.15 ± 0.48 †	5.18 ± 0.56 †	0.032
The last follow-up	2.12 ± 0.35 ‡	3.67 ± 0.62 ‡	0.043
ODI (%)			
Preoperation	54.56 ± 6.71	55.15 ± 7.18	1.853
Postoperative 1 week	21.85 ± 3.78 †	29.83 ± 5.42 †	0.037
The last follow-up	16.70 ± 5.25 ‡	20.68 ± 6.23 ‡	0.035

* Compared with anterior-only group.; † $P < 0.05$, compared to preoperation.; ‡ $P < 0.05$, compared to 1 week postoperatively.; ODI, Oswestry disability index; VAS, visual analog scale.

Visual Analog Scale

According to the visual analog scale (VAS), the pain was significantly relieved by surgical therapy (see Table 4). In the OLIF group, the average VAS score was 7.85 ± 0.79 preoperatively and decreased to 3.15 ± 0.48 ($t = 10.16$, $P < 0.001$) and 2.12 ± 0.35 ($t = 5.29$, $P < 0.05$) at 1 week postoperatively and at last follow-up, respectively; in the anterior-only group, the average VAS score was 7.63 ± 0.86 preoperatively and decreased to 5.18 ± 0.56 ($t = 7.82$, $P < 0.01$) and 3.67 ± 0.62 ($t = 4.32$, $P < 0.05$) at 1 week postoperatively and at last follow up, respectively. Compared with the anterior-only group at 1 week postoperatively and at last follow up, the VAS of the OLIF group was much lower ($t = 3.76$, $P = 0.032$; $t = 2.92$, $P = 0.043$).

Oswestry Disability Index

According to the ODI, the neurological deficits were significantly improved (see Table 4). In the OLIF group, the average ODI score was 54.56 ± 6.71 preoperatively and decreased to 21.85 ± 3.78 ($t = 12.68$, $P < 0.001$) and 16.70 ± 5.25 ($t = 8.92$, $P < 0.01$) at 1 week postoperatively and at last follow up, respectively; in the anterior-only group, the average ODI score was 55.15 ± 7.18 preoperatively and decreased to 29.83 ± 5.42 ($t = 15.64$, $P < 0.001$) and 20.68 ± 6.23 ($t = 9.58$, $P < 0.01$) at 1 week postoperatively and at last follow up, respectively. Compared with the anterior-only group at 1 week postoperatively and at last follow up, the ODI of the OLIF group was much lower ($t = 6.96$, $P = 0.037$; $t = 5.12$, $P = 0.035$).

TABLE 5 The Frankel classification of all patients at preoperation and at the last follow up (OLIF group/anterior-only group)

		Frankel classification (last follow up)				
Frankel classification (preoperation)	*n*	A	B	C	D	E
A	0/0	0/0	0/0	0/0	0/0	0/0
B	2/2	0/0	0/0	0/1	1/1	1/0
C	19/20	0/0	0/0	1/6	6/11	12/3
D	35/32	0/0	0/0	4/1	12/14	19/17
E	3/2	0/0	0/0	0/0	0/0	3/2

Note: There was no significant difference between the OLIF group and the anterior-only group at preoperation, $P > 0.05$. Compared to the anterior-only group, significant difference was observed at the last follow up, $P = 0.021$. OLIF, oblique lumbar interbody fusion.

TABLE 6 Intraoperative and postoperative complications of oblique lumbar interbody fusion (OLIF) and anterior-only fusion, *n* (%)

Variable	Oblique lateral interbody fusion	Anterior-only	χ^2	*P*-value
Neurological injury	2 (3.39%)	9 (16.07%)	-	-
Vascular injury	1 (1.69%)	4 (7.14%)		
Instrument failure	1 (1.69%)	2 (3.57%)		
Peritoneal injury	0	2 (3.57%)		
Incision infection	2 (3.39%)	4(7.14%)		
Lower limb weakness and numbness	4 (6.78%)	0		
Total complications	10 (16.95%)	21(37.50%)	6.162	0.013

Frankel Classification

The Frankel classification of all patients improved with these two surgical techniques. In the OLIF group, 35 cases (59.32%) were classified as Frankel grade E, while in the anterior-only group there 22 cases (39.29%) were classified as Frankel grade E at the last follow up ($P = 0.021$, Table 5).

Complications

Complications occurred intraoperatively and postoperatively (Table 6). The total rate of complications in the OLIF group (10 cases, 16.95%) was significantly lower than in the anterior-only group (21 cases, 37.50%) ($P = 0.013$). In the OLIF group, there were 2 cases (3.39%) of neurological injury, with one presenting as transient thigh/psoas numbness and the other as spinal nerve injury; there was 1 case (1.69%) of vascular injury and 1 case (1.69%) of surgical instrument failure; after surgery, 4 patients (6.78%) experienced lower limb weakness and numbness and 2 patients (3.39%) had surgical site infection. In the anterior-only group, 9 patients (16.07%) had neurological injuries, 4 patients (7.14%) experienced vascular injuries, there were 2 cases (3.57%) of breakage of the lateral interbody fusion cage, 2 cases (3.57%) of peritoneal injury, and 4 cases (7.14%) of wound infection, 1 of which underwent reoperation after surgery. For the above complications, some specific measures were used to help patients to recover, including debridement dressing, neurotrophic treatment, vascular repair, symptomatic treatment, and rehabilitation training. Fortunately, these complications were all resolved.

Discussion

Spinal TB is most common in thoracic and lumbar vertebrae, and is often associated with instability, deformity, neurological deficit, or paraplegia. Although triple chemotherapy (isoniazid, rifampicin, and ethambutol or pyrazinamide) treatment can be recommended[18], it cannot completely clear the vertebral body infection and paravertebral abscesses and reestablish spinal stability. To date, multiple surgical techniques have been applied to treat spinal lumbar TB, including anterior-only, posterior-only, and anterior–posterior approaches[19–21].

The anterior-only approach is widely applied to treat spinal thoracic and lumbar TB. The advantage of this approach is that it provides a wide surgical field, which can assure a radical clearance of infection and decompression of the spinal cord during the operation. Internal fixation with a titanium mesh cage and a nail–stick system can be applied over the same period[16]. However, the shortcomings are also obvious. A relatively broader space is usually necessary to place the cage or autogenous iliac bone, which means that the anterior-only approach cannot be applied for multi-segmental spinal TB. On the other hand, it is hard to ensure strong internal fixation of the vertebral interbody, resulting in a high rate of instrument failure (3.57% in this research).

Although the posterior-only approach can clear part of the infective lesion, it necessitates the destruction of posterior column structures, especially the supraspinal ligaments and interspinal ligaments[22]. The anterior–posterior approach is another method for treating spinal thoracic and lumbar TB, which combines the advantages of anterior-only and posterior-only approaches. The surgical indications are more extensive, but it requires two surgical incisions and changes in patient position, and the rate of complications is also higher than for the two abovementioned methods[23].

Since it was first reported in 2012, OLIF has been used to treat degenerative spondylolisthesis, lumbar kyphosis, lumbar scoliosis, and L_5–S_1 isthmic spondylolisthesis[24]. However, this is the first time that OLIF has been used to treat lumbar TB, and in our opinion, it has its own advantages during surgery and in postoperative recovery. The objectives of surgical treatment of spinal TB are infective removing infective focus and restoring stability[20], which were all well achieved by OLIF in this research. On the one hand, both OLIF and the anterior-only approach could clear the vertebral body infection. However, the anterior-only approach is much higher risk and complex, with the danger of vascular, organ, lymphatic vessel, and nerve injuries during the anatomic dissection. There was a 26.79% complication rate as a result of the dissection in patients who underwent the anterior-only approach, which was much higher than for OLIF (11.86%). The reason for this phenomenon may be that the OLIF approach can make full use of the space of the retroperitoneal abdominal aorta and the anterior edge of the psoas, which drastically reduces the risk of injury to the vessels, organs, and nerves. OLIF and the anterior-only approach have been used in other spinal diseases and similar conclusions have been reached[25-27]. OLIF and the anterior-only approach could successfully reconstruct the spinal stability of all patients through bone grafting and internal fixation. However, there were some differences between these two techniques. To reestablish spinal stability, the pedicle screw–plate is usually placed in front or one side of the vertebral bodies in the anterior-only technique, which not only leads to a higher risk of instrument or interbody fusion failure but also to uneven stress on both sides of the vertebral body lesions. Nevertheless, internal fixation instruments were placed behind the vertebral canal when infective focus was cleared by OLIF, and OLIF can provide strong fixation of vertebral body lesions. The results of this research coincidentally revealed that the rate of instrument failure in OLIF (1.69%) is much lower than in the anterior-only approach (3.57%). In terms of correction of spinal deformity, we found that compared to the anterior-only approach, OLIF also had advantages in improving the Cobb angle, SVA, PT, and SS, and the reduction in the Cobb angle was much more obvious at follow up. This could be related to the position of internal fixation and the extent of damage around of the vertebral body lesions. The surgical field for the anterior-only approach is very narrow, and the soft tissue around the adjacent vertebral bodies has to be dissected to make space to insert the internal instruments. Meanwhile, the position of the internal fixation may lead to a stress concentration during the postoperative recovery. Lee *et al.*[28] (2007) reported a similar phenomenon. However, OLIF just cleared the focus and the depression of the spinal cord with a 3–5 cm skin incision, and the internal instruments were placed behind the spinal canal. In addition, OLIF largely improved the neurological dysfunction of patients, and we found that the VAS, the ODI, and Frankel grade of patients who underwent OLIF were all superior to those for the anterior-only approach, which is likely due to the reduced tissue damage during the operation. Some intraoperative indicators also reveal this phenomenon.

All these data above showed that OLIF can be applied to treat lumbar spinal TB, and it is much more minimally invasive and efficient than the anterior-only approach. The advantages of OLIF in treating lumbar spinal TB are similar to those in treating other spinal diseases[29–31] Although OLIF has been widely used[32–35], we still need to emphasize some key points (that may have been mentioned in treating other diseases) regarding the treatment of lumbar spinal TB: (i) patients with single segment of spinal TB may be the most suitable for OLIF, and two segments at most; (ii) violent pulling of the psoas should be avoided and incision of the front edge of the psoas is advised when it is hard to establish a working channel; (iii) removing the left 12th rib can be considered when it is hard to expose L_{1-2}; and (iv) it is better to use intraoperative neuroelectrophysiological monitoring to avoid unnecessary injury of the spinal cord.

Conclusion

Although there are several surgical techniques applied to treat patients with lumbar spinal TB, many challenges remain. In this study, we first attempted to apply OLIF to treat lumbar (L_2–L_5) spinal TB. It was determined that OLIF is a safe and effective approach for treating lumbar spinal TB because of its lower rate of complications, better correction of deformity, and greater improvement of nerve function. However, the limitations of this research are also obvious. The present study had a small sample size and short follow-up time, so some uncertainty remains about the use of OLIF for spinal TB, especially regarding the mid-term and long-term therapeutic effects and potential complications.

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