

Comparison Between the Efficacy of Oblique Lumbar Debridement Using an Expandable Channel Combined With Posterior Percutaneous Internal Fixation and Traditional Anterior-Posterior Surgery for Single-Segment Lumbar Tuberculosis

Ann. Ital. Chir., 2025 96, 8: 1028–1038
<https://doi.org/10.62713/aic.3961>

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AIM: Lumbar tuberculosis can cause spinal instability and neurological deficits, often requiring surgery. Traditional anterior-posterior surgery is effective but highly invasive, leading to greater trauma and longer recovery. Minimally invasive techniques, such as oblique lumbar debridement with posterior percutaneous fixation, may reduce surgical damage and improve recovery. However, their efficacy remains unclear. This study compares this minimally invasive approach with conventional surgery to assess its feasibility as an alternative treatment.

METHODS: A retrospective analysis was conducted on 156 patients diagnosed with single-segment lumbar tuberculosis between July 2016 and October 2019. Patients were divided into a minimally invasive group (Min group, $n = 76$), treated with the oblique lumbar approach combined with Posterior Percutaneous Pedicle Screw Fixation (PPPSF), and a conventional Open group ($n = 80$). All patients received standard anti-tuberculosis therapy (isoniazid, rifampicin, pyrazinamide, and ethambutol) for at least two weeks preoperatively and continued for 10–12 months postoperatively, adjusted based on drug sensitivity testing. Nutritional support and bracing for three months post-surgery were also provided. Surgical and postoperative metrics were evaluated, including operative time, intraoperative blood loss, length of abdominal incision, postoperative drainage volume and postoperative hospital stay. Functional outcomes were assessed using the visual analogue scale (VAS) and Oswestry Disability Index (ODI), while serology markers such as erythrocyte sedimentation rate (ESR), C-reactive protein (CRP) and creatine phosphokinase (CPK) levels were measured. Radiographic parameters, including the Cobb angle and sagittal vertical axis (SVA), were also evaluated. Postoperative complications were also documented.

RESULTS: The Min group demonstrated significantly shorter operation time, smaller incisions, reduced blood loss, shorter hospital stays, and lower postoperative drainage and CPK levels compared to the conventional Open group ($p < 0.05$). There was no significant difference in VAS, ODI, ESR and CRP levels between the two groups at different times after surgery ($p > 0.05$). Radiographic assessments revealed no significant differences in the Cobb angle or SVA at any postoperative time point ($p > 0.05$). However, the Min group exhibited a significantly higher rate of Grade 1 spinal fusion (59 vs. 38 cases, $p < 0.05$). Although postoperative complications were lower in the Min group (14.5% vs. 18.8%), the difference was not statistically significant ($p = 0.474$).

CONCLUSIONS: Oblique lumbar debridement with PPPSF represents a viable alternative to traditional anterior-posterior surgery for single-segment lumbar tuberculosis, offering reduced surgical trauma and accelerated postoperative recovery.

Keywords: lumbar tuberculosis; minimally invasive; oblique lumbar debridement and reconstruction; posterior percutaneous pedicle screw fixation; clinical efficacy

Introduction

Spinal tuberculosis is the most common form of systemic osteoarticular tuberculosis, accounting for approximately 50% of osteoarticular tuberculosis cases, with lumbar tuberculosis comprising 22.8%–45% [1,2]. Although most patients respond favorably to systemic nutritional support and

appropriate anti-tuberculosis treatment [3], some may experience disease progression despite adequate medical management. This progression can lead to complications such as cold abscess formation, spinal instability, spinal cord or cauda equina compression, and kyphosis, which necessitate surgical intervention [4].

The primary objectives of surgical treatment for spinal tuberculosis include lesion debridement, spinal function reconstruction. Conventional surgical methods include anterior lesion removal with bone graft fusion and anterior screw-rod fixation, posterior spinal canal decompression with pedicle screw internal fixation, and combined anterior-posterior procedures [5,6]. The efficacy of these

Submitted: 14 January 2025 Revised: 18 February 2025 Accepted: 27 February 2025 Published: 10 August 2025

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approaches has been demonstrated in previous studies [7–10]. However, traditional open surgeries often require extensive tissue dissection, leading to significant surgical trauma and higher rates of complications such as venous bleeding and arterial thrombosis [11].

Recent advancements in spinal surgery techniques have facilitated minimally invasive treatments for lumbar tuberculosis management. Among these, oblique lumbar interbody fusion (OLIF) has gained popularity as a minimally invasive anterior lumbar fusion method, primarily for degenerative lumbar spine conditions [8,12]. Additionally, percutaneous pedicle screw fixation is the most common posterior minimally invasive internal fixation method [13]. This study aimed to evaluate the clinical efficacy of oblique lumbar debridement and reconstruction via an expandable channel combined with posterior percutaneous pedicle screw fixation for treating single-segment lumbar tuberculosis. A retrospective analysis was performed to compare the outcomes of this approach with those of traditional anterior-posterior combined surgery, focusing on surgical trauma, recovery time, and overall clinical outcomes.

Materials and Methods

Study Design and Participant Selection

This retrospective study analyzed the clinical data of 156 patients diagnosed with single-segment lumbar tuberculosis who underwent surgical treatment at Yongchuan Hospital of Chongqing Medical University between July 2016 and October 2019. To minimize selection bias, all eligible patients within this period who met the predefined inclusion and exclusion criteria were consecutively enrolled. The inclusion criteria were designed to ensure homogeneity in clinical characteristics, disease stage, and treatment protocols, thereby reducing potential confounding factors. Based on the surgical approach, patients were divided into the minimally invasive group (Min group, $n = 76$) and the Open group (Open group, $n = 80$). The Min group received oblique lumbar debridement and reconstruction via an expandable channel combined with posterior percutaneous pedicle screw fixation, while the Open group underwent conventional anterior-posterior combined surgery.

The study was conducted following the principle of the Declaration of Helsinki and was approved by the Ethics Committee of Yongchuan Hospital of Chongqing Medical University (YCKY2020-15). Written informed consent was obtained from all participants prior to enrollment. All surgical procedures were performed according to the relevant clinical guidelines and regulations.

Inclusion Criteria and Exclusion Criteria

Inclusion criteria: (1) Patients aged between 18 and 60 years diagnosed with single-segment lumbar tuberculosis involving the L1–L5 segments; (2) Patients with bone destruction, paravertebral abscess, kyphosis or spinal instability; (3) Patients with lesions confined to the anterior or mid-

dle column of the spine; (4) Patients with complete clinical follow-up data.

Exclusion criteria: (1) Patients with multi-segment lumbar tuberculosis; (2) Patients with tuberculosis involving the L5–S1 segment; (3) Patients with abscesses extending more than two spinal levels within the spinal canal; (4) Patients with psoas muscle hypertrophy; (5) Patients with recurrent lumbar tuberculosis; (6) Patients with severe coagulation disorders or cardiopulmonary insufficiency.

Preoperative Preparation

All patients underwent comprehensive preoperative examinations, including chest and lumbar spine X-ray, computed tomography (CT), and magnetic resonance imaging (MRI). Laboratory tests were conducted to measure erythrocyte sedimentation rate (ESR), C-reactive protein (CRP) and serum creatine phosphokinase (CPK) levels. X-ray imaging revealed vertebral instability, intervertebral stenosis, and local kyphosis. CT and MRI confirmed vertebral bone destruction confined to the lower 2/3 of the upper vertebra and the upper 1/3 of the lower vertebra. Cold abscesses in the perivertebral and vertebral canals were also identified in some cases.

All patients received preoperative bed rest and standard oral anti-tuberculosis treatment consisting of isoniazid 300 mg/day (Yongkang Pharmaceutical Co., Ltd., Beijing, China, Batch No. 20230415, 100 mg/tablet), rifampicin 450–600 mg/day (Guangdong Hengjian Pharmaceutical Co., Ltd., Jiangmen, China, Batch No. 20230522, 0.15 g/tablet, based on body weight), pyrazinamide 1500 mg/day (Shangyao Xinyi, Shanghai, China, Batch No. 20230318, 0.25 g/tablet), and ethambutol 750 mg/day (Chengdu Jinhua Pharmaceutical Co., Ltd., Chengdu, China, Batch No. 20230610, 0.25 g/tablet) for more than two weeks. Nutritional support, including high-protein and high-energy diets, was also administered. Surgery was scheduled when follow-up tests indicated a reduction in ESR to below 50 mm/h, normalization of CRP levels, and stable liver and kidney function parameters.

Surgical Methods

In the Min group, posterior percutaneous pedicle screw fixation was performed first: (1) After induction of general anesthesia and tracheal intubation, the patient was positioned prone on the operating table with a soft pillow under the chest and hips for support. The affected vertebrae were identified and marked on the body surface using C-arm fluoroscopy. (2) A small paraspinal incision (approximately 1.5 cm in length) was made, and a puncture needle was inserted into the pedicle under fluoroscopic guidance. A guide wire was advanced through the needle, which was then removed, leaving the guide wire in place. (3) Pedicle screws were subsequently inserted along the guide wire, and rods were placed using a rod guider. The nuts were securely tightened to correct spinal deformity and enhance

stability. (4) Each step was monitored and verified using C-arm fluoroscopy to ensure accuracy and stability.

Subsequently, oblique lumbar debridement and reconstruction were performed using an expandable channel: (1) The patient was repositioned laterally, and a 5-cm lateral abdominal incision was made. The skin, subcutaneous tissue, and abdominal oblique muscles were dissected layer by layer along the natural anatomical plane to expose the retroperitoneal space. (2) The psoas major muscle was retracted posteriorly, while major blood vessels were carefully mobilized anteriorly. A guide needle was inserted into the diseased intervertebral space using fluoroscopic guidance. (3) Dilation tubes were inserted sequentially along the guide needle to establish a working channel, which was subsequently expanded to provide an unobstructed surgical field. (4) Under a surgical microscope, necrotic tissue, diseased intervertebral discs, and caseous material were excised. A titanium cage filled with autologous bone grafts was implanted into the intervertebral space to facilitate reconstruction and maintain spinal stability. (5) Following thorough hemostasis, the incision was closed in layers, and a drainage tube was inserted.

In the Open group, posterior open internal fixation was performed first. After the administration of general anesthesia, the patient was positioned prone, and a midline posterior incision was made to expose the facet joints by dissecting the skin, subcutaneous tissue, and paravertebral muscles. Pedicle screws were implanted under C-arm guidance, followed by titanium rod placement and nut tightening to correct kyphosis. The patient was repositioned laterally, and a long oblique incision was made to access the lesion through the peritoneum by incising abdominal muscles and retracting the psoas major. The lesion was debrided, and the reconstruction followed the same steps as in the Min group.

Clinical Data Collection and Outcome Assessment

Baseline patient characteristics, including age, gender, body mass index (BMI), disease duration (in months), lesion segment, Frankel Grade, and follow-up duration, were collected to ensure the comparability between the two groups.

Surgical parameters included operative time, intraoperative blood loss, length of abdominal incision, postoperative drainage volume and postoperative hospital stay.

Inflammatory markers, including ESR and CRP levels, were measured preoperatively, at 3 days postoperatively, 3 months postoperatively, and at the final follow-up. Functional assessments included the visual analogue scale (VAS) and Oswestry disability index (ODI) measured preoperatively, 3 days postoperatively, 3 months postoperatively, and at the final follow-up. The VAS is a widely used tool for measuring pain intensity. It is scored on a scale of 0–10, where 0 represents “no pain” and 10 represents “worst pain imaginable” [14]. The ODI is a standardized questionnaire for evaluating disability related to lower back pathol-

ogy. It consists of 10 sections, each scored from 0 to 5, addressing activities such as lifting, walking, and sleeping. If all 10 questions are answered, the scoring method is: $\text{actual score}/50$ (maximum possible score) $\times 100\%$; if one question is not answered, the scoring method is: $\text{actual score}/45$ (maximum possible score) $\times 100\%$. The total score is expressed as a percentage, with higher scores indicating greater disability [15].

Radiographic assessments included the Cobb angle and sagittal vertical axis (SVA), measured preoperatively, 3 days postoperatively, 3 months postoperatively, and at the final follow-up. The Cobb angle quantifies spinal deformity by measuring the angle between the superior endplate of the uppermost affected vertebra and the inferior endplate of the lowest affected vertebra [16]. SVA is a key parameter for sagittal alignment, defined as the horizontal distance from the C7 plumb line to the posterior superior corner of the S1 vertebra. An SVA >5 cm indicates significant sagittal imbalance [17].

The Bridwell classification was used to evaluate spinal fusion quality at the final follow-up. This system classifies fusion outcomes into four grades: Grade 1, which indicates complete fusion with no radiolucency around the graft; Grade 2, indicating bone formation with minor gaps; Grade 3, which indicates incomplete fusion with radiolucency; and Grade 4, representing no fusion [18].

Postoperative complications such as neurological deterioration, bone graft absorption, vascular injury, peritoneal injury, poor wound healing, lower limb weakness, and numbness were analyzed.

Postoperative Treatment

Both the Min and Open groups received identical postoperative management. Postoperative management included routine antibiotic therapy, which was administered for 3 to 5 days to prevent infections. Resected necrotic tissue was sent for pathological examination, acid-fast staining, bacterial and tuberculosis culture, and drug sensitivity testing. Once the drainage tube was removed, patients were encouraged to mobilize using a supportive brace for three months. Standard anti-tuberculosis treatment (isoniazid, rifampicin, ethambutol, and pyrazinamide) was continued for 10 to 12 months, with regimen adjustments based on drug sensitivity results. Nutritional support was enhanced by providing high-protein and high-energy diets. Liver and kidney function, ESR, and CRP levels were regularly monitored. X-ray and CT imaging were performed at 3 days, 1 month, 6 months, and 1 to 2 years postoperatively.

Statistical Methods

Statistical analyses were performed using SPSS version 23 (IBM Corp, Armonk, NY, USA). The Shapiro-Wilk test was employed to assess the normality of quantitative data. Normally distributed data were presented as mean $\pm$ standard deviation (SD), while non-normally distributed data

Table 1. Baseline characteristics of patients in the Min and Open groups.

Variable	Min group (n = 76)	Open group (n = 80)	χ^2/t	p-value
Gender (men/women, n)	35 (46.1%)/41 (46.1%)	42 (52.5%)/38 (47.5%)	0.648	0.421
Age (years)	48.25 $\pm$ 6.30	47.71 $\pm$ 6.90	0.507	0.613
BMI (kg/m ²)	23.34 $\pm$ 1.78	23.17 $\pm$ 1.82	0.608	0.544
Disease duration (months)	2.2 $\pm$ 0.3	2.2 $\pm$ 0.3	0.789	0.431
Lesion segment (n)			0.836	0.658
L2–3	8 (10.5%)	12 (15.0%)		
L3–4	20 (26.3%)	22 (27.5%)		
L4–5	48 (63.2%)	46 (57.5%)		
Frankel grading (n)			0.450	0.799
C	15 (19.7%)	13 (16.3%)		
D	20 (26.3%)	20 (25.0%)		
E	41 (53.9%)	47 (58.8%)		
Follow-up time (months)	10.18 $\pm$ 2.51	10.61 $\pm$ 2.29	–1.116	0.266

Note: Frankel grading was used to evaluate neurological function: Grade C indicates motor function is present but not useful; Grade D indicates useful motor function; Grade E indicates normal motor and sensory function.

Data are presented as mean $\pm$ standard deviation (SD) for continuous variables and counts (%) for categorical variables. Group comparisons were conducted using independent *t*-tests for continuous variables and chi-square tests (or Yates' continuity correction when appropriate) for categorical variables. Statistical significance was set at $p < 0.05$. BMI, body mass index; Min group, minimally invasive group.

were expressed as median (interquartile range, IQR). For intra-group comparisons of normally distributed continuous variables, paired *t*-tests were used to evaluate differences between preoperative and postoperative time points. For comparisons of normally distributed data across multiple time points within the same group, repeated-measures one-way analysis of variance (ANOVA) was applied. Non-normally distributed continuous variables were compared using the Wilcoxon signed-rank test for intra-group analysis.

Inter-group comparisons were conducted using independent *t*-tests for normally distributed data and the Wilcoxon rank-sum test for non-normally distributed data. For categorical variables, frequencies (n) and percentages (%) were reported. Between-group comparisons were conducted using the chi-square test or, when necessary, Fisher's exact test for small sample sizes, and Yates' continuity correction was applied when appropriate. A two-sided *p*-value < 0.05 was considered statistically significant.

Results

Baseline Characteristics of Patients

A total of 156 patients were included in the study, with 76 in the Min group and 80 in the Open group. The Min group comprised 35 males and 41 females, with an average age of 48.25 $\pm$ 6.30 years (range: 38–59 years) and an average BMI of 23.34 $\pm$ 1.78 kg/m². The mean disease duration was 2.2 $\pm$ 0.3 months. The distribution of lesion segment was as follows: 8 patients at L2–3, 20 patients at L3–4, and 48 patients at L4–5. According to the Frankel grading system, 15 patients were classified as Grade C, 20 as Grade

D, and 41 as Grade E. The average follow-up time in this group was 10.18 $\pm$ 2.51 months.

In the Open group, there were 42 males and 38 females, with an average age of 47.71 $\pm$ 6.90 years (range: 38–59 years) and an average BMI of 23.17 $\pm$ 1.82 kg/m². The mean disease duration was 2.2 $\pm$ 0.3 months. Lesion segment were distributed as follows: 12 patients at L2–3, 22 at L3–4, and 46 at L4–5. 13 patients were classified as Grade C, 20 patients as Grade D, and 47 patients as Grade E. The average follow-up time was 10.61 $\pm$ 2.29 months.

Statistical analysis revealed no significant differences between the two groups in terms of age ($p = 0.613$), gender distribution ($p = 0.421$), BMI ($p = 0.544$), disease duration ($p = 0.431$), lesion segment ($p = 0.658$), Frankel Grade ($p = 0.799$), or follow-up time ($p = 0.266$) (Table 1).

Comparison of Surgical Outcomes Between the Two Groups

All patients in both groups successfully underwent surgical procedures. The Min group demonstrated significant advantages over the Open group in several key surgical parameters. As shown in Table 2, the operation time in the Min group was shorter (206.36 $\pm$ 6.55 min) compared to the Open group (221.9 $\pm$ 7.38 min, $p < 0.001$). The minimally invasive approach also resulted in a significantly smaller abdominal incision (7.29 $\pm$ 1.35 cm vs. 17.08 $\pm$ 2.09 cm, $p < 0.001$) and significantly lower intraoperative blood loss (157.43 $\pm$ 23.91 mL vs. 309.58 $\pm$ 39.45 mL, $p < 0.001$). Postoperative outcomes further favored the Min group, including a significantly lower postoperative drainage volume (209.91 $\pm$ 20.47 mL vs. 334.49 $\pm$ 30.28 mL, $p <$

Table 2. Surgical-related parameters in the two groups.

Variable	Min group (n = 76)	Open group (n = 80)	<i>t</i>	<i>p</i> -value
Operative time (min)	206.36 ± 6.55	221.90 ± 7.38	-13.889	<0.001
Intraoperative blood loss (mL)	157.43 ± 23.91	309.58 ± 39.45	-28.294	<0.001
Length of abdominal incision (cm)	7.29 ± 1.35	17.08 ± 2.09	-34.855	<0.001
Postoperative drainage volume (mL)	209.91 ± 20.47	334.49 ± 30.28	-30.239	<0.001
Postoperative hospital stay (days)	7.21 ± 1.41	10.05 ± 1.65	-11.523	<0.001

Note: Data are presented as mean ± SD ($\bar{x} \pm s$).

Table 3. Clinical outcomes in the two groups.

Indicator	Time point	Min group (<i>p</i> *)	Open group (<i>p</i> *)	<i>t</i>	<i>p</i> [#]
VAS	Pre-op	6.07 ± 0.88	6.01 ± 0.82	0.391	0.697
	3-days post-op	4.5 ± 1.60	4.86 ± 1.16	-1.618	0.108
	3-months post-op	3.08 ± 1.56	3.11 ± 1.51	-0.136	0.892
	Last follow-up	2.49 ± 1.51	2.79 ± 1.06	-1.431	0.155
ODI	Pre-op	76.67 ± 6.31	77.86 ± 5.29	-1.280	0.203
	3-days post-op	68.97 ± 6.32	69.74 ± 5.60	-0.800	0.425
	3-months post-op	59.07 ± 6.57	60.54 ± 7.41	-1.310	0.192
	Last follow-up	52.14 ± 7.13	53.05 ± 5.40	-0.891	0.375
ESR (mm/h)	Pre-op	41.51 ± 4.12	41.04 ± 4.47	0.674	0.501
	3-days post-op	45.07 ± 4.99	46.45 ± 5.69	-1.605	0.111
	3-months post-op	37.06 ± 5.01	38.39 ± 6.02	-1.485	0.139
	Last follow-up	37.74 ± 5.14	33.27 ± 6.20	-1.670	0.097
CRP (mg/L)	Pre-op	33.11 ± 3.56	32.41 ± 4.13	1.144	0.254
	3-days post-op	35.21 ± 5.84	36.34 ± 4.27	-1.385	0.168
	3-months post-op	30.45 ± 4.42	30.58 ± 4.53	-0.182	0.856
	Last follow-up	23.88 ± 5.08	24.87 ± 4.79	-1.251	0.213
CPK levels (U/L)		417.78 ± 27.75	843.27 ± 94.19	-38.677	<0.001

Note: Data are presented as mean ± SD ($\bar{x} \pm s$). Pre-op, preoperative; Post-op, postoperative; VAS, visual analogue scale; ODI, oswestry disability index; ESR, erythrocyte sedimentation rate; CRP, C-reactive protein; CPK, creatine phosphokinase. *p*[#] indicates comparison between groups at the same time point; *p** means comparison within the same group before and after surgery.

0.001), indicating less muscle injury. These findings collectively highlight the advantages of the minimally invasive approach in surgical efficiency and patient recovery.

Functional Recovery Assessments in Both Groups

The mean follow-up period was 10.18 ± 2.51 months in the Min group and 10.61 ± 2.29 months in the Open group (Table 1). As demonstrated in Table 3, there were no significant differences in preoperative VAS and ODI scores between the two groups ($p > 0.05$). Postoperatively, VAS scores significantly lower at each follow-up time point compared to preoperative values ($p < 0.05$). VAS scores progressively declined with increasing follow-up time, reflecting continuous improvements in pain. However, no significant differences in VAS scores were observed between the two groups at any postoperative time point ($p > 0.05$).

Similarly, ODI scores exhibited a consistent decline following surgery in both groups, with no significant differences at 3 days post-surgery, 3 months post-surgery, or at the last

follow-up ($p > 0.05$). However, both groups showed significant improvements compared to their preoperative scores ($p < 0.05$), indicating enhanced functional recovery. By the final follow-up, all patients in both groups had successfully returned to their preoperative occupations.

Comparison of Serum Indicators in Both Groups

The serum CPK level in the Min group was significantly lower than that in the Open group ($p < 0.001$). Inflammatory markers analysis revealed no significant differences in ESR or CRP levels between the two groups at baseline, 3 days post-surgery, 3 months post-surgery, or the final follow-up ($p > 0.05$). On postoperative day 3, both groups exhibited increased ESR and CRP levels compared to preoperative values. Over time, inflammatory markers showed a progressive decline, with significant reductions observed at the final follow-up ($p < 0.05$), indicating a resolution of inflammation in the later stages of recovery (Table 3).



Fig. 1. Radiographic imaging of lumbar tuberculosis (L1–2 segment) in a patient treated with the minimally invasive (Min) approach. (A) Preoperative computed tomography (CT) scan highlighting vertebral bone destruction and intervertebral space narrowing. (B) Preoperative magnetic resonance imaging (MRI) revealing spinal tissue damage and abscess formation. (C) Postoperative CT (3 days) illustrating successful placement of percutaneous pedicle screws and lesion debridement via an expandable channel. (D) Postoperative CT (1 year) confirming stable fusion with restored spinal alignment.

Radiographic Assessments in Both Groups

Radiographic evaluations indicated no significant differences between the two groups in terms of Cobb angle and SVA at any observed time point, suggesting that both approaches effectively maintained spinal alignment and sagittal balance ($p > 0.05$, Table 4). Notably, the fusion quality, assessed according to the Bridwell fusion grading system, was significantly superior in the Min group. The proportion of patients achieving Grade 1 spinal fusion was higher in the Min group (59 patients) compared to the Open group (38 patients, $p < 0.05$). These findings indicate superior fusion quality with the minimally invasive approach, which was further supported by the radiographic images in Fig. 1, illustrating successful spinal reconstruction and stabilization in both post-surgery groups.

Postoperative Complications in Both Groups

Postoperative complications were systemically analyzed and are presented in Table 5. Postoperative complications such as neurological deterioration, bone graft absorption, vascular injury, peritoneal injury, poor wound healing, lower limb weakness, and numbness were included in the analysis. The total complication rate was lower in the Min group (14.5%) compared to the Open group (18.8%), although this difference was not statistically significant ($p = 0.474$). Similarly, no statistically significant differences were observed between the two groups in the incidence of individual complications, including neurological deterioration ($p = 0.725$), bone graft absorption ($p = 0.964$), vascular

injury ($p = 0.964$), and other complications (all $p > 0.05$). Fisher's exact test was used for numbness, while the standard chi-square test was applied to compare total complication rates. The updated statistical results are reflected in Table 5.

Among the specific complications, neurological deterioration occurred in 2 patients in the Min group and 4 patients in the Open group. Bone graft absorption was reported in 2 patients in the Min group and 1 patient in the Open group. Vascular injury occurred in 2 patients in the Min group and 1 patient in the Open group. Peritoneal injury was observed in 3 patients in the Open group, while no cases were reported in the Min group. Poor wound healing was reported in 3 patients in each group. Additionally, numbness occurred in 1 patient per group, and lower limb weakness was observed in 1 patient in the Min group and 2 patients in the Open group.

Overall, these findings suggest that the minimally invasive approach is associated with slightly lower, albeit not statistically significant, postoperative complication rates compared to the open approach, with both surgical methods demonstrating comparable safety profiles.

Discussion

For spinal tuberculosis requiring surgical intervention, conventional surgical methods primarily include anterior lesion removal, bone grafting and fusion, and anterior screw-rod fixation; posterior decompression, debridement, and pedicle screw fixation; or a combination of anterior and poste-

Table 4. Radiographic assessments in the two groups.

Parameter	Time point	Min group	Open group	χ^2/t	p-value
Cobb angle	Pre-op	25.99 ± 2.08	26.10 ± 2.17	-0.333	0.740
	3-days post-op	27.97 ± 3.64	28.60 ± 2.68	-1.227	0.222
	3-months post-op	26.01 ± 3.42	26.61 ± 2.76	-1.206	0.230
	Last follow-up	24.49 ± 2.96	24.74 ± 2.88	-0.536	0.593
SVA (mm)	Pre-op	5.19 ± 0.82	5.32 ± 0.75	-1.025	0.307
	3-days post-op	4.62 ± 0.84	4.69 ± 0.77	-0.525	0.601
	3-months post-op	3.88 ± 0.75	4.08 ± 0.80	-1.585	0.115
	Last follow-up	3.29 ± 0.84	3.45 ± 0.84	-1.211	0.228
Bridwell	Grade 1	59 (77.32%)	38 (47.46%)	15.047	<0.001
	Grade 2	17 (22.68%)	42 (52.54%)		

Note: Data are presented as mean ± SD ($\bar{x} \pm s$) or the number of cases (n). SVA, sagittal vertical axis.

Table 5. Postoperative complications in the two groups.

Complication (n)	Min group (n = 76)	Open group (n = 80)	χ^2 (corrected chi-square/Fisher's exact)	p-value
Neurological deterioration	2 (2.6%)	4 (5.0%)	0.124	0.725
Bone graft absorption	2 (2.6%)	1 (1.3%)	0.002	0.964
Vascular injury	2 (2.6%)	1 (1.3%)	0.002	0.964
Peritoneal injury	0 (0%)	3 (3.8%)	1.258	0.262
Poor wound healing	3 (3.9%)	3 (3.8%)	0.000	1.000
Lower limb weakness	1 (1.3%)	2 (2.5%)	0.000	1.000
Numbness	1 (1.3%)	1 (1.3%)	0.000	1.000
Total (n, %)	11 (14.5)	15 (18.8)	0.513	0.474

Note: Data are presented as the number of cases (n) and percentage (%). The chi-square test was used for total complication rates with theoretical frequency ≥ 5 , Yates' continuity correction was applied for complication rates with theoretical frequencies between 1 and 5, and Fisher's exact test was used for complications with theoretical frequency < 1 , while the corrected chi-square test was applied for peritoneal injury, as its theoretical frequency was < 5 but ≥ 1 .

rior approaches [5,19]. The effectiveness of debridement and spinal reconstruction using these approaches has been well-documented in previous studies [9,20,21]. However, with advancements in surgical techniques, spinal surgery is increasingly shifting towards minimally invasive procedures, allowing faster recovery and earlier return to daily activities [22].

Various minimally invasive techniques for treating lumbar spinal tuberculosis have been explored in recent years. Ying *et al.* [23] reported success with anterior small incisions combined with posterior internal fixation, while Wang *et al.* [24] demonstrated that extreme lateral channel fixation combined with percutaneous posterior pedicle screw fixation yielded positive clinical outcomes. However, these methods require splitting the psoas major to access and debride the lesion, which may cause muscle injury and postoperative complications.

OLIF, first introduced by Li *et al.* in 2020 [25], represents a novel minimally invasive approach that accesses the posterior peritoneum through the natural lateral muscle space without splitting the psoas major muscle. This approach retracts the psoas muscle posteriorly and enables surgical manipulation via an expandable channel, offering the ad-

vantage of small incisions, minimal trauma, quick recovery, and comparable fusion rates; and it has been widely applied in treating lumbar degenerative diseases, such as disc herniation and spinal stenosis [26–29]. Percutaneous posterior minimally invasive pedicle screw fixation is widely used for thoracolumbar spine diseases, offering the advantages of a small incision and minimal muscle disruption, significantly reducing postoperative back pain [30,31]. Inspired by the OLIF approach, we adopted oblique lumbar debridement and reconstruction using an expandable channel, combined with posterior percutaneous pedicle screw fixation, to treat single-segment lumbar tuberculosis. Over an average of two-year follow-up, all patients achieved satisfactory clinical outcomes, demonstrating the feasibility and efficacy of this minimally invasive strategy.

In traditional open anterior-posterior combined surgeries, the incisions are typically longer, leading to greater tissue trauma. Zhang *et al.* [32] reported an average incision length of approximately 15.42 cm using the anterior approach, which is consistent with our finding of 17.08 cm in the Open group. The anterior approach involves the dissection of the external oblique, internal oblique, transverse abdominis, and psoas major muscles, while the posterior

approach requires detachment of multifidus muscles, vertical spines, and facet joints. These extensive dissections result in larger surgical incisions, greater trauma, scar formation, and loss of muscle function, contributing to longer recovery times and poorer postoperative outcomes.

In this study, the Min group exhibited an average anterior incision length of approximately 7.29 cm, significantly smaller than that observed in the Open group. The anterior procedure was performed directly through the natural muscle gap to the lesion, using an expandable channel, without cutting the psoas major muscle or disrupting spinal bony structures. Lesion debridement and bone grafting were performed under a microscope, enhancing visualization and precision. Posteriorly, each skin incision was approximately 1.5 cm, utilizing the space between the multifidus and erector spinae muscles, with subcutaneous rod placement to minimize muscle damage.

As a result, the Min group experienced less trauma compared to the Open group, as evidenced by reduced muscle injury and shorter operative times. These findings were further supported by the significantly lower postoperative CPK levels in the Min group, reflecting a lower degree of muscle injury. The minimally invasive approach also resulted in significantly lower intraoperative blood loss and postoperative drainage volume, which can be attributed to the smaller extent of muscle dissection and the use of a surgical microscope and expandable protective channels. The reduced muscle trauma, evidenced by lower CPK levels, highlights the clinical advantages of the minimally invasive approach, including reduced postoperative pain and a faster return to daily activities. Moreover, the minimally invasive approach demonstrated distinct benefits, including smaller incisions, reduced trauma, and faster recovery, making it a promising surgical option for treating spinal tuberculosis. However, the study primarily utilized VAS and ODI to evaluate functional outcomes, which may not comprehensively capture all aspects of patient recovery. Incorporating broader patient-reported outcomes measures (PROMs), such as the 36-Item Short Form Health Survey (SF-36) or Patient-Reported Outcomes Measurement Information System (PROMIS) in future studies could provide a more comprehensive assessment of postoperative recovery.

Additionally, further studies are needed to optimize the application of minimally invasive approaches in more complex cases, such as those involving multisegmental lesions, L5–S1 involvement, and hypertrophied psoas muscles. The development of specialized surgical instruments and tailored techniques for these scenarios could significantly improve clinical outcomes. Moreover, prospective multicenter studies with extended follow-up periods are essential to validate the long-term efficacy, durability, and safety of these minimally invasive approaches across diverse patient populations and clinical settings.

In this study, anterior lesion removal and bone grafting were performed under microscopic visualization, with posterior

screws ensuring three-column stabilization [33]. The anti-tuberculosis regimen was adjusted based on culture results, with a treatment duration of 1–1.5 years [34]. None of the patients included in this study exhibited drug-resistant tuberculosis, as only those with improved ESR and CRP levels following anti-tuberculosis treatment were included. Postoperatively, all patients experienced pain resolution, and their ESR and CRP levels returned to normal without significant differences between the two groups at the final follow-up.

The absence of statistically significant differences in ESR and CRP levels between the two groups suggests that these inflammatory markers primarily reflect the effects of systemic anti-tuberculosis therapy rather than the extent of intraoperative trauma. This observation aligns with previous study, which reported that ESR and CRP are broad inflammatory markers influenced by local tissue trauma and systemic infection [35]. Although the minimally invasive approach resulted in reduced operative trauma, the normalization of ESR and CRP levels may obscure subtle inflammatory differences during the early postoperative period. Future studies incorporating more specific biomarkers or advanced imaging modalities, could provide deeper insights into trauma-related inflammatory responses. The Min group achieved comparable long- and short-term clinical effects to the Open group, consistent with previous findings reported by Du *et al.* [33].

Radiographic assessments showed that both groups maintained spinal alignment and sagittal balance postoperatively, with no significant differences observed in Cobb angle or SVA between the Min and Open groups. Although the Min group exhibited slightly lower anterior lordosis at the final follow-up, the difference remained within the acceptable clinical range. Both surgical approaches achieved effective spinal fusion without evidence of screw loosening. Notably, the Min group demonstrated a significantly higher rate of Grade 1 spinal fusion, highlighting superior fusion quality compared to the Open group. These findings suggest that the minimally invasive approach is comparable to, or potentially superior to, the open approach in achieving spinal reconstruction and stabilization in patients with lumbar spinal tuberculosis.

The overall incidence of postoperative complications was low in both groups, with no statistically significant difference in the total complication rates between the Min and Open groups. Specific complications such as neurological deterioration, bone graft absorption, vascular injury, and peritoneal injury were relatively infrequent and comparable between the two groups. However, peritoneal injuries occurred exclusively in the Open group (3 cases, 3.75%), while no such cases occurred in the Min group. This difference is attributed to the distinct surgical technique employed: the minimally invasive approach utilizes a retroperitoneal pathway, bypassing direct manipulation of the peritoneum entirely, whereas the open technique re-

quires anterior exposure through the peritoneum, inherently increasing the risk of peritoneal trauma. These findings underscore one of the key advantages of the minimally invasive approach in reducing complications. In addition, minor complications, including poor wound healing, numbness, and lower limb weakness, were observed in both groups at similar frequencies. Notably, hip flexion weakness was reported in 1 patient in the Min group and 2 patients in the Open group, while numbness occurred in 1 patient from each group. All minor complications were managed conservatively and gradually resolved during follow-up, with no severe complications such as paralysis, massive hemorrhage, or postoperative infection observed in either group. These findings collectively confirm that the minimally invasive approach is as safe and feasible as the open approach, with comparable surgical risks.

Posterior percutaneous fixation was used to correct kyphotic deformity and restore stability, with screws intentionally avoided in lesion segments to minimize the risk of infection. Following successful anti-tuberculosis treatment, the screws were removed to preserve motor function. The minimally invasive surgical approach showed comparable or superior outcomes to conventional open surgery, maintaining spinal alignment, enhancing fusion quality, and reducing perioperative complications, highlighting its potential as a preferred surgical approach for lumbar tuberculosis. Despite the promising clinical outcomes observed in this study, several limitations must be acknowledged. First, the average follow-up period of approximately 10 months may be insufficient to comprehensively assess long-term outcomes and complications. Although no late-onset complications were observed during the follow-up period, this duration may not fully capture the durability of spinal fusion or the risk of late recurrence. Future studies with extended follow-up periods are needed to validate these findings and provide a more thorough evaluation of long-term clinical outcomes. Secondly, the retrospective design of this study at a single medical center may limit the generalizability of the findings to broader populations and diverse clinical settings. This limitation underscores the need for prospective, multicenter studies to confirm the reproducibility and reliability of the minimally invasive approach across various healthcare environments. Additionally, the adoption of minimally invasive techniques in resource-limited regions remains a significant challenge, as the oblique lumbar approach requires specialized equipment, trained personnel, and surgical infrastructure. Addressing these barriers will require international collaborations and the implementation of tailored training programs.

The relatively small sample size further constrains the statistical power of the study, potentially impacting the robustness of the conclusions drawn. Moreover, this study did not include patients with more complex conditions, such as L5–S1 lesions, large paravertebral abscesses, hypertrophied psoas major muscles, or multisegmental bone de-

struction, which may present additional surgical challenges. The safety and efficacy of the minimally invasive approach in these more complicated cases remain unexplored. Future studies should investigate the application of minimally invasive techniques in more complex cases and assess the feasibility of developing specialized surgical instruments to address these anatomical variations.

Conclusions

In conclusion, oblique lumbar debridement and reconstruction using an expandable channel combined with posterior percutaneous pedicle screw fixation for single-segment lumbar tuberculosis demonstrated clinical efficacy comparable to traditional anterior-posterior combined surgery. However, the minimally invasive approach offers reduced trauma, faster recovery, and superior fusion quality, presenting distinct clinical advantages. While these findings are promising, further validation through large-scale clinical trials, multicenter studies, and patient-specific evaluations is required.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

LLH, ZZL, JY designed this study. ZZL, LLH and JYZ collected the data. ZZL, JY, JYZ and LLH analyzed the data. LLH was the major contributor in writing the manuscript. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Yongchuan Hospital of Chongqing Medical University (YCKY2020-15). Written informed consent was obtained from all participants prior to enrollment. All surgical procedures were performed according to the relevant clinical guidelines and regulations.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

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