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Comparison of two surgical approaches in treating children with thoracolumbar junction tuberculosis: a multicenter study

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Abstract

Objectives We conducted a multicenter retrospective analysis to compare the clinical outcomes and complications associated with the posterior-anterior and posterior-only approaches in treating Thoracolumbar Junction (TLJ) Tuberculosis (TB) in children aged 3–10 years.

Methods Herein, 52 TLJ TB patients (age range = 3–10 years; mean age = 6.8 ± 2.2 years; females = 22; males = 30) treated with debridement, fusion, and instrumentation were recruited from two hospitals in China between May 2008 and February 2022, and their clinical data were reviewed retrospectively. Among them, 24 group A patients and 28 group B patients underwent the posterior-anterior and posterior-only approaches, respectively. The two groups were assessed for surgical time, blood loss, hospitalization duration, operative complications, inflammatory indicators, Visual Analog Scale (VAS) scores, Oswestry Disability Index (ODI) scores, kyphosis angles, and neurologic functions. Results or differences with $P < 0.05$ were considered statistically significant.

Results The average follow-up period was 37.5 ± 23.3 months. Compared to group A patients, group B patients exhibited significantly lower surgical time, blood loss amount, time it took to stand, and hospitalization duration, as well as fewer complications. Notably, the Erythrocyte Sedimentation Rate (ESR) and C-Reactive Protein (CRP) values of patients in both groups returned to normal one year post-surgery. Furthermore, compared to the preoperative values, patients' VAS and ODI scores, as well as neurological functions and kyphosis angles, were significantly improved postoperatively and at the final follow-up, but with no statistically significant differences between the two groups. Moreover, there was no internal fixation failure or TB recurrence, and all patients exhibited solid bone fusion at the last follow-up.

Conclusion For pediatric TLJ TB involving no or at most two segments, both posterior-anterior and posterior-only approaches could effectively remove lesions and decompress the spinal cord, restore spinal stability, correct kyphosis, and prevent deformity deterioration. Nonetheless, the posterior-only approach can more effectively shorten the surgical time, reduce related trauma and complications, and promote rapid recovery, making it a safer and highly preferable minimally invasive approach.

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Keywords Posterior-Anterior, Posterior-only, Children, Thoracolumbar Junction Tuberculosis, Kyphosis

Introduction

Tuberculosis (TB), a historical infectious disease with a global footprint, remains the world's second leading cause of death [1]. China is one of the countries with a high TB incidence and prevalence, accounting for ~7.1% of all cases worldwide [1]. Spinal TB, the predominant type of extrapulmonary TB, often presents with vertebrae destruction, necrotic bone, abscesses, and spinal cord compression. The Thoracolumbar Junction (TLJ) region, the transition zone between the relatively fixed thoracic and flexible lumbar vertebrae, which encompasses the T10-L2 vertebrae, is frequently involved in TB. Unlike adult TB patients, pediatric TB patients tend to suffer more severe and extensive vertebral destruction and paravertebral abscesses due to a richer periphyseal blood supply and lax paravertebral fascia [2]. Consequently, the kyphosis and neurological damage secondary to pediatric TLJ TB may be more severe, significantly impacting children's appearance, cardiopulmonary function, and Quality of Life (QoL) [3, 4].

Although standardized chemotherapy could be employed to address some spinal TB cases, it may be ineffective in relieving nerve compression and correcting kyphosis. Notably, TB primarily affects the anterior spinal column, leaving the accessory intact. Due to the imbalance between the anterior and posterior structures, even a mild kyphosis may persistently worsen as the spine grows [5]. In this regard, surgical intervention could be critical in managing pediatric spinal TB, especially in cases with complications such as severe bone destruction, spinal instability, pathological dislocation, extensive abscesses, nerve compression, and spinal deformities. Hitherto, multiple surgical procedures have been used to treat pediatric spinal TB, including the anterior-only, anterior-posterior, posterior-anterior, and posterior-only approaches. Notably, single anterior arthrodesis without posterior instrumentation has been shown to be less effective in arresting kyphosis progression, limiting its clinical application [6, 7]. Consequently, the posterior instrumentation + anterior debridement/fusion and posterior-only approaches are currently the mainstay interventions in managing spinal TB. However, it remains unclear which of the aforementioned surgical approaches is superior in treating pediatric TLJ TB patients [8].

Herein, we conducted a multicenter retrospective analysis to compare the safety, clinical outcomes, and complications associated with posterior-anterior and posterior-only surgical approaches in treating pediatric TLJ TB patients aged 3–10 years. Our findings could offer a theoretical basis and clinical reference for managing such patients.

Methods

Patient population

Herein, pediatric TLJ TB patients treated with debridement, fusion, and instrumentation were recruited from two hospitals in China between May 2008 and February 2022, and their clinical data were reviewed retrospectively.

The inclusion criteria were as follows: (1) Age ≤ 10 years; (2) Patients with active TLJ TB as confirmed through clinical manifestations, imaging, biochemical tests, and pathological examinations; (3) Patients with ≤ 2 involved segments; (4) Patients in whom conservative treatment proved ineffective; (5) Patients who underwent the posterior-anterior (Group A) or posterior-only (Group B) treatments; (6) Patients who had a follow-up period of ≥ 2 years; and (7) Patients with complete medical and imaging records. Patients who did not meet the above criteria were excluded from the study.

The Ethics Committee of Honghui Hospital, Xi'an Jiaotong University, approved this study, and a signed informed consent form was obtained through the patients' guardians.

Preoperative management

The patients were first subjected to various clinical investigations, including chest X-ray, spinal X-ray, Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Erythrocyte Sedimentation Rate (ESR), C-Reactive Protein (CRP), T-cell Spot (T-Spot) test, TB antibodies, and hepatic and renal functions. Before surgery, all patients underwent 2–4 weeks of conventional chemotherapy [ethambutol (15 mg/kg/d) + pyrazinamide (20–30 mg/kg/d) + rifampicin (5–10 mg/kg/d) + isoniazid (5–10 mg/kg/d)]. Generally, patients can only undergo surgery when their appetite improves without low fever, anemia and hypoproteinemia are corrected, and ESR and CRP levels are significantly lower. Nonetheless, emergency surgery would be performed if any patient's neurologic functions deteriorated while under medication.

Surgical procedures

Following general anesthesia induction, patients were placed in the prone position. An incision was then made along the dorsal median line before performing a strict subperiosteal dissection on the laminae and articular processes. The surgical screw size was selected based on the patient's age and the transverse diameter of the pedicle on the anteroposterior radiograph. Appropriate pedicle screws were then placed in the upper and lower two vertebrae of the affected segment, with short screws implanted in the vertebra whenever possible. Patients

aged < 5 years were fixed using 4.0 mm pedicle screws and 3.2/3.5 mm titanium rods, whereas those aged > 5 years were fixed using 5.0/5.5 mm pedicle screws and 4.75 mm CoCrMo/5.5 mm titanium rods.

For group A patients, the connecting rods were first installed before correcting the deformity using the cantilever technique. Subsequently, an appropriate amount of allogeneic bone grains was used to decorticate and graft the posterior structures of the involved segments. The patient was then changed to the lateral position before performing the thoracoabdominal procedure. To obtain healthy bone surfaces and achieve adequate spinal cord decompression, necrotic bone, abscesses, destroyed intervertebral discs, and granulation tissue were completely removed. Finally, an appropriately sized freeze-dried allogenic iliac-derived strut bone (Allogenic Bone Grafts, OsteoRad, Taiyuan, Shanxi Province, China) was sourced and implanted into the defect area for anterior reconstruction.

For group B patients, immobilization was first performed on the less severe side using a temporary rod to avoid the spinal instability-induced Spinal Cord Injury (SCI) during decompression and debridement. Partial or total laminectomy was performed depending on the degree of spinal stenosis. The articular and transverse processes were then removed, with dissection around the medial rib and pediculectomy performed if necessary. Subsequently, various curettes were employed to remove the TB lesions, which included necrotic discs, dead bone, granulation tissue, and pus, through the intervertebral foraminal until the bone surface bled. For a more thorough debridement, a silicone catheter was then inserted into the abscess cavity, alternating between pressurized flushing and negative pressure suction. Following that, the temporary rod was replaced on the operated side, and the other side of the lesion was subjected to the same procedure. Subsequently, bilateral contoured rods were installed to correct the deformity through the cantilever technique. A suitable allogenic strut bone was then implanted in the defect area for reconstruction before tightening the bone graft gap through appropriate compression. Finally, posterior bone grafting was performed using autogenous bone combined with allogeneic bone particles.

For all patients, the lesion and wound drains were placed correctly before closing the incision. Intraoperatively obtained necrotic tissues were sent for pathogenic culture and histopathologic examination.

Postoperative management

All patients were intravenously treated with antibiotics for 2–3 days to prevent incision infection. At a total volume < 30 ml/day, the drain was removed, and a thoracolumbar X-ray was performed. The patients were then allowed to walk around as much as they could under brace protection. At two months postoperatively, pyrazinamide and ethambutol were discontinued, with the remaining anti-TB medications continued until one year postoperatively. Furthermore, hepatoprotective drugs were added to prevent pharmacological liver injury.

Follow-up

Patients were followed up at 1, 3, 6, 9, and 12 months post-discharge, and then once a year. At each follow-up, the thoracolumbar X-ray was performed, along with CT/MRI if necessary. Furthermore, routine blood tests, as well as CRP and ESR assessments, were performed regularly to observe TB activity. Patients' liver and renal functions were also monitored during chemotherapy. At each follow-up, the Visual Analogue Scale (VAS) and Oswestry Disability Index (ODI) scores, kyphosis angles, Frankel grades, and ESR and CRP values were accurately recorded. The Bridwell [9] and Frankel grading systems [10] were used to evaluate the bony fusion and patients' neurological dysfunction levels, respectively.

Statistical analysis

All statistical analyses were performed using SPSS 23.0 software (SPSS, Chicago, Illinois, USA). Categorical variables were expressed as frequencies or rates, whereas continuous variables were presented as Mean ± Standard Deviation (SD). Differences in CRP, ESR, VAS, and ODI values, as well as kyphosis angles, before and after surgery, were compared using the paired t-test. Each variable's inter-group variances were compared using the independent sample t-test/x^2 test. Changes in the Frankel grades during the preoperative and postoperative periods, as well as at final follow-up, were compared using the Wilcoxon signed rank test, and inter-group differences were examined using the Mann-Whitney test. Results or differences with $p < 0.05$ were considered statistically significant.

Results

General information

A total of 52 patients (age range = 3–10 years, mean age = 6.8 ± 2.2 years; males = 22; females = 30) were retrieved. Group A comprised 14 males and 10 females (mean age = 7.0 ± 2.2 years), whereas group B comprised 16 males and 12 females (mean age = 6.6 ± 2.3 years). The average height and weight of the children in the two groups were 116.9 ± 13.1 vs.114.8 ± 13.4 cm and 21.8 ± 4.8 vs.21.1 ± 5.1 kg, respectively. In addition, group A had thirteen single-segment cases and 11 double-segment cases, whereas group B had 19 single-segment cases and 9 double-segment cases. (Table 1)

Across all procedures, groups A and B had average operation durations and blood loss values of

Table 1 Patients' basic information

	Group A (*n* = 24)	Group B (*n* = 28)	*P* value
Sex (M/F)	14/10	16/12	0.931
Age (years)	7.0 ± 2.2	6.6 ± 2.3	0.535
Body height (cm)	116.9 ± 13.1	114.8 ± 13.4	0.579
Weight (kg)	21.8 ± 4.8	21.1 ± 5.1	0.619
Infected segment (one/two)	13/11	19/9	0.312
Operation time (min)	293.3 ± 43.0	192.3 ± 55.1	<0.001
Blood loss (ml)	442.1 ± 99.6	355.4 ± 86.4	0.001
Time to stand (days)	12.3 ± 4.8	8.6 ± 4.9	0.010
Hospitalization (days)	19.2 ± 4.8	15.4 ± 4.7	0.006
Follow-up time (months)	39.0 ± 28.5	36.1 ± 18.1	0.659

M: Male; F: Female

Table 2 Inflammatory indicator in two groups

	Group A	Group B	*P* value
ESR(mm/h)			
Preoperative	61.3 ± 10.8	64.6 ± 11.6	0.300
Post-op 6 months	11.5 ± 3.8*	13.3 ± 4.4*	0.123
Post-op 1 year	4.5 ± 2.0*	4.1 ± 2.3*	0.523
CRP (mg/L)			
Preoperative	50.5 ± 12.9	52.7 ± 12.1	0.519
Post-op 6 months	10.6 ± 3.4*	11.2 ± 3.7*	0.549
Post-op 1 year	3.3 ± 2.2*	3.0 ± 1.8*	0.553

ESR: Erythrocyte Sedimentation Rate; CRP: C-Reactive Protein

*:post-op 6 months or post-op 1 year vs. preoperative $P<0.001$.

293.3±43.0 vs.192.3±55.1 min ($P<0.001$) and 442.1±99.6 vs.355.4±86.4 ml ($P=0.001$), respectively. Compared to group A patients, group B patients showed significantly lower mean durations for patients to start standing (12.3±4.8 vs.8.6±4.9 days, $P=0.010$) and hospitalization (19.2±4.8 vs.15.4±4.7 days, $P=0.006$). Furthermore, groups A and B had mean follow-up times of 39.0±28.5 and 36.1±18.1 months, respectively. (Table 1)

Inflammatory indicators

Before treatment, the mean CRP and ESR values in groups A and B were 50.5±12.9 vs.52.7±12.1 mg/L ($P=0.519$) and 61.3±10.8 vs. 64.6±11.6 mm/h ($P=0.300$), respectively, both of which decreased significantly at six months postoperatively, later returning to normal at one year postoperatively. (Table 2)

Radiological assessment

Preoperatively, groups A and B had average kyphosis angles of 31.4±7.5° and 33.0±6.1°, respectively, which were significantly reduced correspondingly to 5.2±3.9° and 4.5±2.0° postoperatively. At the final follow-up, the average kyphosis angles of groups A and B were 8.9±13.2° and 7.1±3.6°, respectively, with overall corresponding correction rates of 72.0±35.1 vs.77.9±12.5 ($P=0.408$). Moreover, compared to the preoperative values, all patients showed a significant improvement in kyphosis angles both postoperatively and at the last follow-up. (Table 3)

Table 3 Kyphosis angle in two groups

	Group A	Group B	*P* value
Kyphosis angle (°)			
Preoperative	31.4 ± 7.5	33.0 ± 6.1	0.389
Postoperative	5.2 ± 3.9*	4.5 ± 2.0*	0.357
Final follow-up	8.9 ± 13.2*	7.1 ± 3.6*	0.490
Correction rate 1 (%)	83.2 ± 11.2	86.3 ± 6.5	0.224
Correction rate 2 (%)	72.0 ± 35.1	77.9 ± 12.5	0.408
Correction loss rate (%)	11.2 ± 26.3	8.4 ± 10.1	0.597

Correction rate 1 = 100%(preoperative-postoperative)/preoperative; Correction rate 2 = 100%(preoperative-final follow-up)/preoperative; Correction loss rate = 100%(final follow-up- postoperative)/preoperative

*: postoperative or final follow-up vs. preoperative $P<0.001$

Table 4 Function scores in two groups

	Group A	Group B	*P* value
VAS			
Preoperative	6.3 ± 1.2	6.2 ± 1.1	0.639
Postoperative	3.7 ± 1.2*	3.4 ± 1.0*	0.357
Final follow-up	0.6 ± 0.9*	0.5 ± 0.7*	0.683
Frankel grade (A/B/C/D/E)			0.747
Preoperative	0/3/10/9/2	0/4/9/15/0	0.929
Postoperative	0/1/3/10/10*	0/1/5/13/9*	0.489
Final follow-up	0/0/0/5/19*	0/0/0/4/24*	0.538
ODI (%)			
Preoperative	79.4 ± 11.5	80.6 ± 10.9	0.682
Postoperative	43.7 ± 10.4*	41.7 ± 7.9*	0.444
Final follow-up	15.4 ± 5.7*	14.0 ± 5.4*	0.398

VAS: Visual Analog Scale; ODI: Oswestry Disability Index

*: postoperative or final follow-up vs. preoperative $P<0.001$

Neurologic function scores

Compared to the preoperative scores, all patients showed significant improvement in back pain post-surgery, which almost completely disappeared at the last follow-up, with no statistically significant differences between the two groups. No patient showed aggravation of neurological deficits. Compared to preoperative neurologic deficits, both groups showed substantial improvements in the Frankel grades postoperatively and at the last follow-up, with no significant differences. At the last follow up, groups A and B showed improved Frankel grades by levels 1.4 and 1.5 ($P=0.901$), respectively. Similarly, the two groups showed no statistically significant differences in ODI scores preoperatively (79.4±11.5% vs. 80.6±10.9%), postoperatively (43.7±10.4% vs. 41.7±7.9%), and at the final follow-up (15.4±5.7 vs. 14.0±5.4%). (Table 4)

Complications

Three group A patients suffered pleural tears during surgery, which were later repaired. Two of the three patients developed pleural effusions postoperatively, which

improved following aggressive medical interventions, and the other patient experienced no discomfort. Furthermore, three group B patients experienced transient intercostal neuralgia postoperatively. On the other hand, one group A patient experienced cerebrospinal fluid leakage, which was treated through prolonged drainage. Additionally, two group A patients and one group B patient developed superficial infections in their wounds, which healed well following local debridement and antibiotic treatment. Notably, all patients' wounds healed without sinus formation or chronic infections. Moreover, there was no internal fixation failure or TB recurrence. All patients exhibited solid bone fusion at the last follow-up, with one group A patient showing a slight graft displacement during follow-up. The patient later requested internal fixation removal at two years postoperatively due to back discomfort. However, the patient's kyphosis progressed; hence, he underwent a posterior fixation, osteotomy, and corrective surgery. (Table 5)

Discussion

Spinal TB, a severe orthopedic condition with a global prevalence, often presents with low fever, back pain, kyphosis, and neurological dysfunction [11]. Unlike adult spinal TB, which manifests as intervertebral space infection, the characteristic features of pediatric spinal TB include vertebral destruction, a potentially more significant kyphosis (even in cases of cured TB), and a residual mild kyphosis that may evolve into severe deformity (without surgical intervention) as the spine grows [12, 13]. It is noteworthy that TLJ lesions are highly likely to undergo morphological changes, increasing the risk of deformity deterioration [14]. In addition to impacting aesthetics, severe kyphosis could also lead to psychological problems, impaired cardiorespiratory function, and delayed paralysis, degrading patients' QoL and imposing a huge socioeconomic burden. To date, various surgical approaches have been introduced to address this disease, from traditional anterior-only to the more widely used posterior-anterior and posterior-only approaches. However, the surgery strategy for TLJ TB remains controversial. Few studies have compared the safety and efficacy of the latter two procedures mentioned above in the treatment of children with TLJ TB. Therefore, exploring an optimal surgical intervention for pediatric TLJ TB patients is imperative to ensure effective debridement, defect reconstruction, kyphosis correction, and prevention of deformity aggravation with minimal surgical trauma and complications.

Table 5 Complications

	Group A	Group B
Pleural tears	3	0
Pleural effusions	2	0
Intercostal neuralgia	0	3
Cerebrospinal fluid leakage	1	0
Superficial wound infection	2	1
Sinus or chronic infection	0	0
Internal fixation failure	0	0
Graft displacement	1	0

The anterior surgical approach offers the benefits of direct and extensive access to the anterior column for debridement. Numerous studies involving adult spinal TB patients have demonstrated that anterior debridement, bone grafting, and internal fixation could yield satisfactory long-term results [15, 16]. Nonetheless, this approach was found to be ineffective in curbing kyphosis progression in pediatric patients post-surgery [17]. Additionally, Schulitz et al. [7] reported that the anterior approach compromised the anterior growth and impeded spinal remodeling capabilities. Moreover, posterior element overgrowth has been established to be a major factor contributing to kyphosis progression after anterior fusion in children [17].

In light of the aforementioned shortcomings of the anterior-only surgical approach, anterior debridement combined with posterior instrumentation has been recommended for stabilizing the spine and preventing loss of correction. Huang et al. [18] treated 15 pediatric spinal TB patients using the anterior decompression + posterior instrumentation combination approach. According to the results, the average loss of correction was only 4° at 30.3 months postoperatively. It is also noteworthy that anterior decompression preceded posterior fixation in their study. Conversely, scholars in other studies preferred posterior fixation first, followed by anterior debridement and bone grafting [19, 20]. Notably, immediate stabilization of the spine could be achieved via posterior fixation while appropriately distracting the collapsed space. In addition to providing an avenue for indirect spinal cord decompression, this intervention also expands the operating space and facilitates anterior debridement and strut graft insertion. Zhang et al. [21] performed a two-stage procedure on 14 children with lumbar TB, using posterior instrumentation, anterior debridement, and fusion. According to the results, there was only a 2° loss of correction, with satisfactory improvement in neurological function and no internal fixation failure occurrence in ≥3 years of follow-up. Interestingly, we obtained similar results in ≥two years of follow-up after treating 24 pediatric TLJ TB patients using a one-stage posterior-anterior approach (Fig. 1). Nonetheless, it is noteworthy that the posterior-anterior procedure has been associated with high trauma, long operative periods, and multiple surgical complications.

Modern spinal surgical approaches are evolving towards minimally invasive techniques. This transition could be attributed to the fact that pediatric spinal

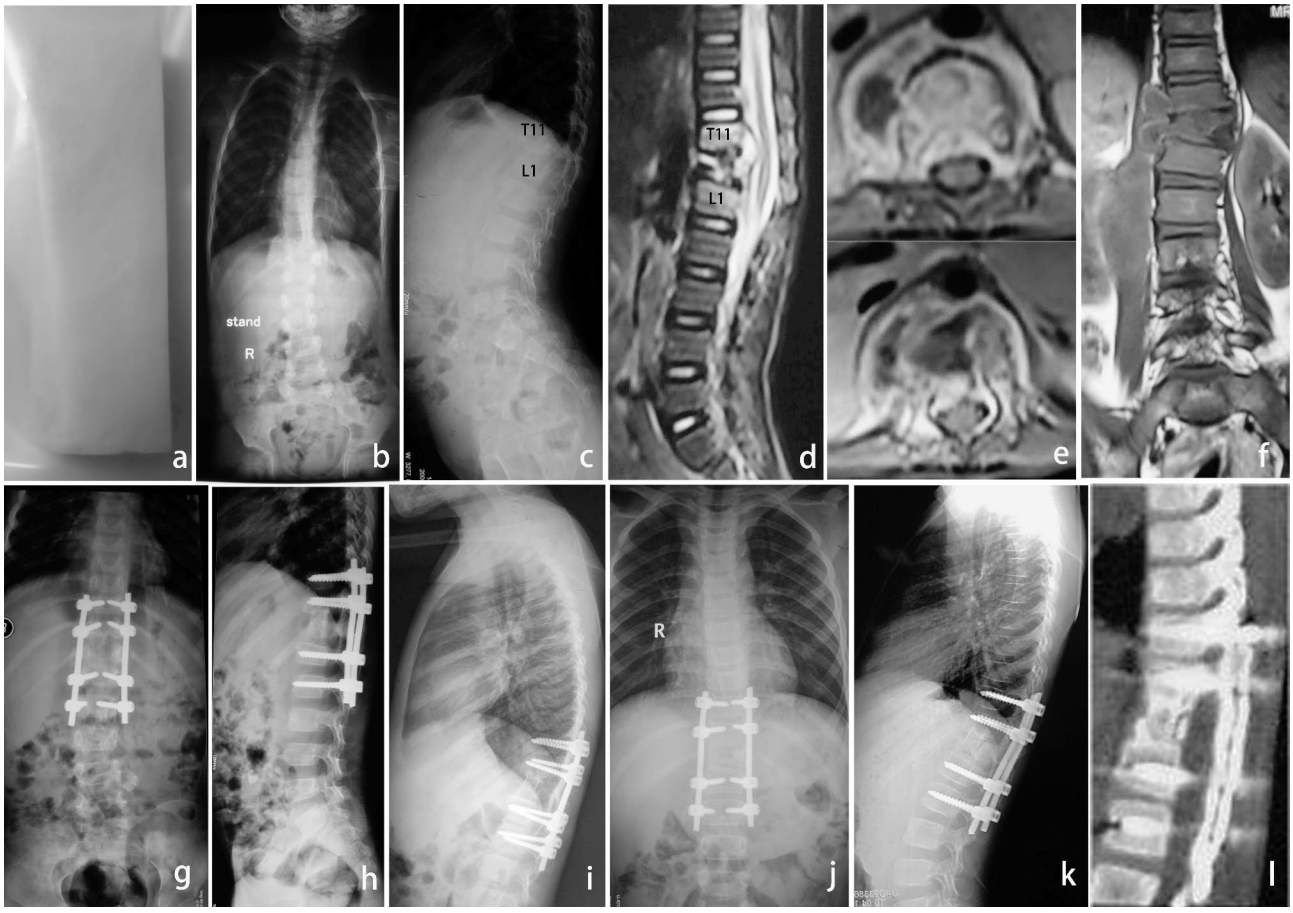

Fig. 1 (**a**) Allogenic strut bone; (**b-f**) Preoperative images of a 7-year-old boy showing severe destruction of the T12 vertebral body with kyphosis, spinal cord compression, and abscesses; (**g-h**) Posterior instrumentation, anterior debridement, and fusion were performed using allogenic strut bone; postoperative X-ray showed favorable kyphosis correction; (**i**) Twenty-month postoperative X-ray showing a good internal fixation position; (**j, k**) Coronal and sagittal alignment were satisfactorily maintained 28 months postoperatively; and (**l**) A solid fusion was obtained

TB patients in poor general health conditions could be at great risk under prolonged anesthesia and significant trauma. Consequently, shortening the surgical duration, reducing blood loss, and minimizing trauma and complications while achieving Enhanced Recovery After Surgery (ERAS) has gained significant attention among spinal surgeons. Compared to the posterior-anterior approach, the posterior-only procedure offers the benefits of simplicity and minimal invasiveness as it facilitates effective internal fixation, decompression, debridement, and bone grafting via a single incision and position, avoiding entry into the thoracic cavity and dissection of the mediastinum. Herein, the posterior-only approach demonstrated notable advantages over the posterior-anterior technique regarding the surgical duration and blood loss amount. Furthermore, patients who underwent the posterior-only procedure had fewer complications, with earlier ambulatory resumption, quicker recovery, and a shorter hospital stay.

Yin et al. [22] treated 27 pediatric spinal TB patients with percutaneous drainage combined with low-dose chemotherapy. According to the results, patients' ESR values returned to normal, and their neurological functions significantly improved over a 31-month follow-up period. Nonetheless, this method could not correct kyphosis. In our hospital, we often treat patients with relatively confined abscesses with direct posterior surgery, whereas pediatric patients with larger abscesses are often subjected to percutaneous catheter drainage under local anesthesia. Herein, a small dose of saline (20 ml) containing isoniazid (0.2 g) was irrigated during drainage before performing the posterior-only procedure.

Since patients with a long medical history often experience spontaneous facet fusion, resulting in rigid deformity, fixation alone may result in unsatisfactory correction, even causing screws to pull out in some cases. In this regard, it is noteworthy that the posterior-only approach allows for adequate resection of the posterior spinal structures, facilitating kyphosis correction. Applying temporary rods could initially restore the local sagittal alignment, achieving immediate spinal stability and offering safety assurance for decompression. Although

this procedure may sacrifice some of the posterior structures, we observed no segmental instability before bony fusion because pedicle screws, through three-column fixation, combined with anterior structural bone grafting, provided sufficient spinal stability.

Moreover, applying an appropriate distraction force to the screws expands the anterior lesion space allowing for a 270° or 360° circumferential decompression of the spinal cord through the unilateral or bilateral transpedicular space. Although concerns have also been raised on the possibility of the posterior-only approach carrying TB bacteria to the posterior portion of the spine, causing intraspinal or central infection, consistent with previous reports [23, 24], this risk did not occur in our patients. This finding highlights the appropriateness of the posterior-only approach to neural decompression in patients with intraspinal abscesses [25]. Following debridement, the anterior and posterior spinal structures were fully relaxed, allowing for adequate kyphosis correction through the cantilever technique. In our hospital, we often apply appropriate pressure to screws to tighten the graft-bone interface, preventing strut bone displacement. Herein, we performed an intervertebral bone graft with additional posterior short-segment fusion to ensure equal growth of the spine after effective correction and subsequently prevent an increase in kyphosis during growth. Using the one-stage posterior approach, Zhang et al. [26] treated seven TLJ TB patients with kyphosis aged 9–12 years and in poor general health conditions. According to the results, kyphosis correction and neurologic recovery were satisfactory, with no TB recurrence. Notably, we achieved equally good results using the posterior-only approach in 28 younger children with TLJ TB (Fig. 2).

Autologous bone is currently considered the gold standard for treating bone defects [27]. However, autologous strut bone for young children is limited in both supply and supportive strength. Furthermore, although titanium mesh has demonstrated favorable results in defect reconstruction for pediatric spinal TB, it is noteworthy that potentially metal-toxic implants should not be used in children during active growth [28]. In this regard, we recommend the use of the commercially available allogeneic strut bone derived from the human iliac bone (Fig. 1a). This material is sterilized, demineralized, lyophilized, and irradiated, significantly reducing the risk of immunogenicity and disease transmission while preserving the bone's original mechanical characteristics. Besides aiding in avoiding the trauma and donor site complications associated with autologous bone harvesting, the use of this material also reduces blood loss and saves on surgical duration. Moreover, the strut bone can be trimmed based on individual bone defects, and its elasticity modulus is comparable to that of the vertebral body, with smooth edges and adequate bone contact surfaces, preventing postoperative subsidence. Herein, one patient developed strut bone displacement during follow-up, which we attributed to a mismatch between the graft size and the bone defect, as well as the eventual inability to utilize the screw-rod for intervertebral space compression in the posterior-anterior approach (Fig. 3f and g). Nonetheless, our findings demonstrated that the strut bone has a strong biocompatibility and could be remodeled as the spine grows, ultimately resulting in solid fusion.

According to research, children with healed spinal TB experience considerable morphological changes in both the fusion mass and the unaffected segments above and below the lesion, a phenomenon more prevalent in the TLJ region [14]. Herein, one patient underwent internal fixation removal two years postoperatively due to a foreign body sensation in the back. Unfortunately, the patient exhibited a significant kyphosis progression during the subsequent follow-up (Fig. 3h-j). In this regard, since pedicle screws do not negatively impact spinal growth [29], we recommend that pediatric spinal TB patients should undergo internal fixation removal after their bones have matured.

To the best of our knowledge, this study is the first to conduct a comparative analysis of the clinical outcomes of the posterior-anterior and posterior-only surgical approaches in treating pediatric TLJ TB patients aged 3–10 years based on multicenter data. However, there were some limitations. First, this was a retrospective study with a limited sample size and follow-up time. Consequently, prospective Randomized Controlled Trials (RCTs) with large samples should be conducted in the future, with pediatric TLJ TB patients being followed up closely post-surgery until skeletal maturity. Second, the patients included in this study had lesions involving ≤ 2 segments, necessitating additional research on the difference in efficacy between the posterior-anterior and posterior-only approaches in treating children with lesions involving ≥ 3 segments.

Conclusion

In children with TLJ TB involving ≤ 2 segments, both the one-stage posterior-anterior and single posterior approaches effectively removed lesions and decompressed the spinal cord, restored spinal stability, corrected kyphosis, and prevented deformity deterioration. However, the one-stage posterior instrumentation, debridement, and reconstruction using allogeneic strut bone were more effective in shortening the surgical duration, reducing trauma and complications, and promoting rapid postoperative recovery, making it a safe and highly preferable minimally invasive approach for treating pediatric TLJ TB patients.

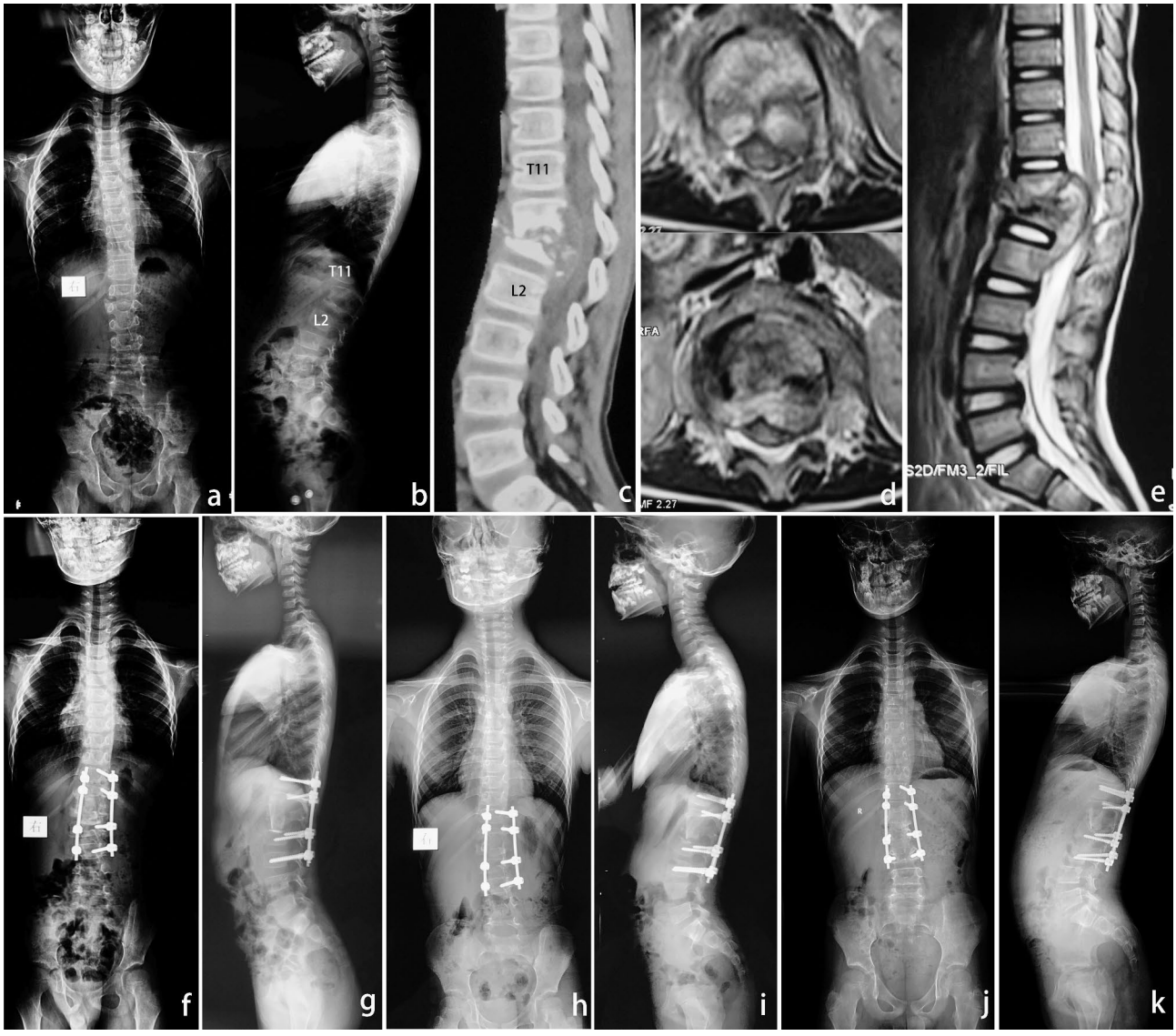

Fig. 2 (**a-e**) Preoperative images of a 5-year-old boy showing T12/L1 involvement, as well as the protrusion of dead bone fragments into the spinal canal; (**f, g**) A posterior-only approach was performed; (**h, i**) Six-month postoperative radiographs showing a good position of the internal fixation and strut bone; and (**j, k**) X-rays showing no obvious loss of correction 40 months postoperatively, with a solid fusion

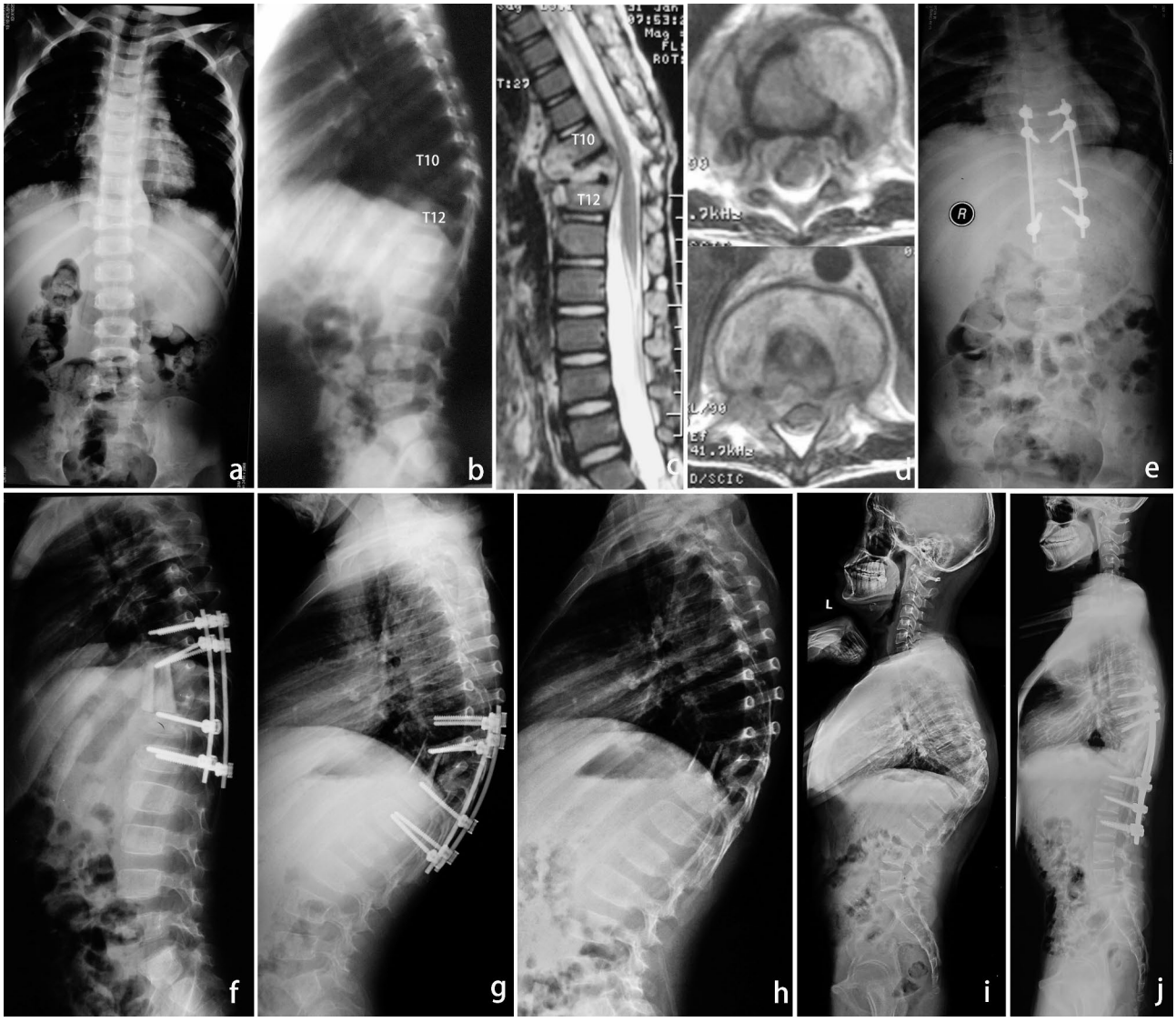

Fig. 3 (**a-d**) Preoperative images of a 6-year-old boy showing severe destruction of the T11 vertebral body with kyphosis; (**e, f**) A posterior-anterior surgical approach was performed; (**g**) Three-month postoperative radiographs showing strut bone displacement with loss of correction; (**h**) Although the TB was cured two years post-surgery, the patient requested internal fixation removal due to back discomfort; and (**i, j**) Significant kyphosis progression was observed at 163 months postoperatively and posterior osteotomy and corrective surgery was performed

Abbreviations

CRP	C-Reactive Protein
CT	Computed Tomography
ESR	Erythrocyte Sedimentation Rate
ERAS	Enhanced Recovery After Surgery
F	Female
MRI	Magnetic Resonance Imaging
M	Male
ODI	Oswestry Disability Index
QoL	Quality of Life
RCTs	Randomized Controlled Trials
SCI	Spinal Cord Injury
TLJ	Thoracolumbar Junction
TB	Tuberculosis
T-Spot	T-cell Spot
VAS	Visual Analog Scale

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Author contributions
Jingyu Wang conceived the study design and drafted the manuscript. Jingyu Wang and Xueying Zhang supervised the material preparation and data collection, and prepared Figs. 1, 2 and 3. Xiaobin Wang performed the statistical analysis and interpreted the results. Jing Li, Hua Hui and Dingjun Hao contributed to the revision. All authors read and approved the final manuscript.

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Data availability
The datasets used and analysed in this study are available from the corresponding author on reasonable request.

Declarations

Ethics approval
All methods were performed in accordance with the relevant guidelines and regulations of the Helsinki declaration and were approved by the Ethics Committee of Honghui Hospital, Xi'an Jiaotong University.

Consent to publish
Not applicable.

Competing interests
All authors declare that they have no competing interests.

Consent to participate
Informed consent was obtained from all guardians of patients included in the study.

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