

# Spinous Process Combined with a Titanium Mesh Cage as a Bone Graft in the Stability Reconstruction of Lumbar or Lumbosacral Spinal Tuberculosis

**Hongqi Zhang**

Department of Spine Surgery and Orthopedics, Xiangya Hospital, Central South University, Changsha

**Lige Xiao**

Department of Spine Surgery and Orthopedics, Xiangya Hospital, Central South University, Changsha

**mingxing Tang**

Department of Spine Surgery and Orthopedics, Xiangya Hospital, Central South University, Changsha

**Guanteng Yang** (✉ [ygtspine@163.com](mailto:ygtspine@163.com))

Department of Spine Surgery and Orthopedics, Xiangya Hospital, Central South University, Changsha

---

## Research Article

**Keywords:** Titanium mesh cage, Spinous process bone graft, Spinal tuberculosis, Posterior-only approach, Intervertebral bone grafting

**Posted Date:** August 23rd, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-817359/v1>

**License:**   This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

---

**Version of Record:** A version of this preprint was published at Frontiers in Surgery on April 4th, 2022. See the published version at <https://doi.org/10.3389/fsurg.2022.818926>.

# Abstract

**Background.** To investigate the clinical efficacy of one-stage posterior debridement using the spinous process (SP) combined with titanium mesh cages (TMCs) as interbody grafts for the treatment of single-segment lumbar or lumbosacral spinal tuberculosis.

**Methods.** From 2010 to 2018, 69 patients who underwent one-stage posterior debridement using grafts and internal fixation within a single lumbar or lumbosacral segment were included in this study. 12 cases using the SP combined with a TMC (SP+TMC, group A), 30 cases using a TMC only (group B), and 27 cases using allografts (group C) were included. Measurements including operative time, blood loss, hospital stay, visual analogue scale (VAS) score, Oswestry Disability Index (ODI), erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), American Spinal Injury Association Impairment (ASIA) grade, final follow-up (FFU) duration and postoperative complications were recorded. Radiological measurements, including the number of segments fixated, the number of pedicle screws used, the Cobb angle, pelvic parameters, and the bony fusion time, were reviewed. All outcomes were analysed using SPSS 25.

**Results.** We found that group A had fewer fixation segments ( $1.67 \pm 0.64$  vs  $2.81 \pm 0.94$ ,  $p < 0.01$ ), fewer pedicle screws implanted ( $5.05 \pm 1.29$  vs  $6.85 \pm 1.37$ ,  $p < 0.01$ ), a shorter operative time ( $166.43 \pm 44.11$  min vs  $205.93 \pm 51.73$  min,  $p < 0.01$ ), reduced blood loss ( $543.81 \pm 230.81$  ml vs  $803.70 \pm 446.78$  ml,  $p < 0.01$ ), and a strikingly lower hospital cost ( $14710.42 \pm 2354.55$  \$ vs  $19260.34 \pm 3310.75$  \$,  $p < 0.01$ ) than group C.

Compared to group B, group A had a lower economic cost ( $16680.23 \pm 3614.73$  \$ vs  $14710.42 \pm 2354.55$  \$,  $p = 0.03$ ). There was no significant difference in bony fusion time among the three groups ( $8.90 \pm 2.11$  months vs  $8.60 \pm 2.39$  months vs  $9.59 \pm 2.04$  months,  $p > 0.01$ ). No significant difference was observed with respect to pre- or postoperative ESR and CRP ( $p > 0.01$ ). There was no significant difference among the 3 groups with respect to the ODI, VAS score or ASIA grade during any period. No differences regarding the hospital stay, rate of complications, loss of PI-LL, correction or loss of Cobb angle were observed among the three groups ( $p > 0.01$ ).

**Conclusion.** Our study demonstrates that compared to a TMC or allograft, the use of the SP combined with a TMC as a bone graft is an effective and reliable approach for the surgical management of one-level lumbar or lumbosacral spinal tuberculosis, leading to good restoration of spinal stability. Furthermore, this approach is an economical structural bone grafting method, especially for patients in developing countries or areas.

## Background

Tuberculosis is a major health problem worldwide, with an estimated 10.0 million new cases each year[1]. Bone tuberculosis is the most common extrapulmonary tuberculosis, and spine tuberculosis (STB) accounts for 50% of all bone tuberculosis cases, with no age or sex being immune from STB[2]. The lumbar region is the most frequently involved site in 38.2%-59.57% of STBs, while 8.0%-8.48% of STBs involve lumbosacral segments[3, 4]. As the onset of STB can be insidious and difficult to diagnose early, a sizable number of patients from developing countries are seen for the first time at an advanced stage of disease[1]. Surgical treatment plays a key role in the management of advanced stage STB patients who present with spinal deformity, severe or progressive neurologic dysfunction, spinal instability, extensive paravertebral, and epidural abscess[5].

With the introduction of the spinal pedicle screw system, a one-stage posterior approach has been increasingly adopted to treat lumbar and lumbosacral STBs by surgeons[6–8]. However, the spinal pedicle screw system only provides temporary stability, with long-term stability primarily relying on bony fusion of the vertebral defect. At present, the most commonly used bone grafts for STB surgery are allogeneic bone grafts (allografts), autogenous iliac bone grafts, and titanium mesh cages (TMCs) filled with allogeneic or autogenous bone[9, 10], each of which has benefits and

limitations. The autogenous iliac bone graft is considered the gold standard due to its high bone fusion rate, but it may result in extra surgical trauma and complications at the donor site[10, 11]. Other autogenous bone methods, such as rib strut or spinous process (SP) and transverse process (TP) bone, have also been applied in one-level thoracic or lumbar tuberculosis[12–14]. For surgery using the posterior approach, the SP is spontaneously exposed during this process, reducing operative time, bleeding, and trauma. However, regarding structural strength and stability, the SP is not as good as a TMC. Considering this, we decided to use the SP combined with a TMC (filled with autogenous cancellous bone granules) for anterior reconstruction.

To date, no study has reported the use of the SP combined with a TMC as a bone graft in the surgical treatment of lumbosacral STB. By retrospectively comparing patients using SP + TMC to traditional TMC bone grafts or allogeneic bone grafts in terms of safety and efficacy, we aimed to evaluate whether SP + TMC could be a possible alternative choice for surgeons. Moreover, since patients in less developed areas are more likely to be affected by STB, individual hospital costs were also reviewed.

## **Methods**

### **Clinical information**

Patients with lumbar and lumbosacral STB who were hospitalized and underwent one-stage posterior surgery in our department from January 2010 to February 2018 were included in this study. The patients were required to meet all of the following inclusion criteria: (1) the level involved was limited from L1 to S1; (2) only one segment was involved, or multiple segments were involved but only one level needed surgical intervention; (3) no evidence of extensive TB abscess was observed; (4) the focal tissue was expected to be completely debrided via posterior approach only; Patients presenting with any of the following conditions were excluded: (1) multilevel lesions needing surgical intervention; (2) deep multiple cold abscesses or an abscess that was primarily localized in the anterior column, which might be beyond the ability of debridement via the posterior approach; (3) other types of spinal disease or a history of spine surgery; and (4) active TB or other contraindications. This study was approved by our hospital and was conducted following the Declaration of Helsinki. All participants signed the informed consent. The benefits and shortcomings of each method were fully explained the patients and their relatives before surgery to, to allow the patients to choose their treatment for themselves.

### **Outcome assessment**

#### **Demographic data**

The following demographic data were collected from each patient: age, sex, residence, occupation, annual individual income in USD, and infected spinal level.

#### **Clinical assessments**

For all patients, the following indexes were recorded at each timepoint (preoperative, before discharge, and at FFU): patient residence and income, average operation time, blood loss, hospital stay and cost, VAS score, ODI, ASIA grade, ESR and CRP.

#### **Radiological assessments**

(1) Fixation segment: fusion of one disc is considered to be one fixation segment; (2) number of pedicle screws (3) Cobb angle in the sagittal plane: the angle between the upper endplate and the inferior endplate of the lesion vertebral body in the sagittal plane is defined as the Cobb angle in our study; (4) pelvic parameters: pelvic tilt (PT), pelvic incidence (PI), sacral Slope (SS), lumbar lordosis (LL), and PI-LL; (5) bone grafting fusion: bone graft fusion was assessed using the radiologic criteria reported by Bridwell et al[15].

## Statistical analysis

The results were recorded and analysed using SPSS software version 25.0 (SPSS Inc., Chicago, IL). Quantitative data are expressed as the mean  $\pm$  standard deviation. ANOVA was used for intergroup comparison of quantitative data, and paired t-tests were used for intragroup comparisons. The chi-square test was performed for intergroup comparisons of nonnormally distributed qualitative data. For normally distributed qualitative data, the Wilcoxon rank sum test and Mann-Whitney rank sum test were used (intragroup and intergroup, respectively).  $p < 0.05$  was considered a significant difference.

## Results

A total of 69 patients were divided into three groups: group A (TMC+SP bone graft: 12 cases, Figure 1), group B (TMC bone graft: 30 cases, Figure 2), and group C (allogeneic bone graft: 27 cases, Figure 3). The mean follow-up times were  $35.29 \pm 6.69$  months,  $34.57 \pm 6.65$  months and  $35.15 \pm 6.46$  months, respectively ( $p=0.92$ ). No significant differences were observed in sex ( $p = 0.57$ ), age ( $p = 0.58$ ), ODI ( $p = 0.87$ ), ODI-FFU ( $p = 0.80$ ), VAS score ( $p = 0.72$ ), VAS-FFU ( $p = 0.78$ ), or hospital stay ( $p = 0.54$ ). No significant difference in ESR or CRP was found at any time point (Table 1). A total of 74%-78% of patients were from rural areas, while 67%-74% of patients were farmers and workers. Regarding income, 87%-92% of patients had an annual individual income less than \$5000 (Table 1).

**TABLE I**

Demographics of study populations

Clinical features	Group A (n=12)	Group B (n=30)	Group C (n=27)	p value	
Age(yr.)	48.52 ±14.32	50.4±13.20	46.67±15.06	0.62	P <sub>AB</sub> =0.52 P <sub>AC</sub> =0.84 P <sub>BC</sub> =0.33
Male sex (no. [%])	6(50%)	15(50%)	17(63%)	0.51	P <sub>AB</sub> =0.87 P <sub>AC</sub> =0.29 P <sub>BC</sub> =0.33
Residence (no. [%])					
Rural	9(75%)	22(74%)	21(78%)		
Urban	3(25%)	8(26%)	6(22%)	0.87	
Occupation					
Farmer	6(50%)	16(53%)	15(56%)		
Worker	2(17%)	6(20%)	5(18%)		
Student	1(8%)	3(10%)	3(11%)		
Others	3(25%)	5(17%)	4(15%)	1	
Annual individual income (US)					
≤\$2000	1(8%)	5(17%)	5(18%)		
\$2000-\$4999	9(75%)	21(70%)	18(67%)		
≥\$5000	2(17%)	4(13%)	4(15%)	0.98	
Infected spinal level					
L1-2	2	3	4		
L2-3	3	7	3		
L3-4	2	5	6		
L4-5	4	9	10		
L5-S1	1	6	4		
Fixation Segment	1.67±0.64	1.83±0.90	2.81±0.94	0.00	P <sub>AB</sub> =0.47 P <sub>AC</sub> ≤0.01 P <sub>BC</sub> ≤ 0.01
Number of pedicle screw	5.05±1.29	5.53±1.73	6.85±1.37	0.00	P <sub>AB</sub> =0.28 P <sub>AC</sub> ≤0.01 P <sub>BC</sub> ≤ 0.01
ODI	0.75±0.16	0.73±0.12	0.73±0.11	0.87	P <sub>AB</sub> =0.62 P <sub>AC</sub> =0.69 P <sub>BC</sub> =0.89

ODI-FFU	0.18±0.05	0.19±0.04	0.19±0.06	0.80	P <sub>AB</sub> =0.68 P <sub>AC</sub> =0.54 P <sub>BC</sub> =0.73
VAS	7.05±1.53	7.27±1.46	6.96±1.26	0.72	P <sub>AB</sub> =0.61 P <sub>AC</sub> =0.83 P <sub>BC</sub> =0.41
VAS-FFU	1.38±0.84	1.53±0.76	1.52±0.79	0.78	P <sub>AB</sub> =0.51 P <sub>AC</sub> =0.57 P <sub>BC</sub> =0.94
Operation blood loss (ml)	543.81±230.81	584.00 ±229.06	803.70±446.78	0.01	P <sub>AB</sub> =0.66. P <sub>AC</sub> □ 0.01 P <sub>BC</sub> =0.01
Operation time (min)	166.43±44.11	189.00±41.64	205.93±51.73	0.02	P <sub>AB</sub> =0.1 P <sub>AC</sub> □ 0.01 P <sub>BC</sub> =0.19
Hospital cost (US)	\$14710.42±2354.55	\$16680.23±3614.73	\$19260.34±33100.75	0.00	P <sub>AB</sub> =0.03 P <sub>AC</sub> □ 0.01 P <sub>BC</sub> □ 0.01
Hospital stays (day)	24.71±8.85	26.20 ±5.95	26.89 ±5.31	0.54	P <sub>AB</sub> =0.48 P <sub>AC</sub> =0.30 P <sub>BC</sub> =0.65
Duration of follow-up (months)	35.29 ±6.69	34.57 ±6.65	35.15 ±6.46	0.92	P <sub>AB</sub> =0.71 P <sub>AC</sub> =0.94 P <sub>BC</sub> =0.74
Mean value of pre-operation					
ESR (mm/h)	67.57 ±28.87	71.33 ±28.60	60.33 ±27.00	0.35	P <sub>AB</sub> =0.65 P <sub>AC</sub> =0.38 P <sub>BC</sub> =0.14
CRP (mg/l)	45.67 ±33.02	50.20 ±26.35	45.71 ±21.79	0.78	P <sub>AB</sub> =0.59 P <sub>AC</sub> =0.99 P <sub>BC</sub> =0.49
Mean value of post-operation					
ESR (mm/h)	60.62 ±28.39	65.90 ±29.11	59.56 ±33.73	0.72	P <sub>AB</sub> =0.53 P <sub>AC</sub> =0.91 P <sub>BC</sub> =0.45
CRP (mg/l)	21.28 ±29.79	26.87 ±28.38	19.82 ±18.42	0.57	P <sub>AB</sub> =0.50 P <sub>AC</sub> =0.83 P <sub>BC</sub> =0.28
Mean value of Final follow-up					
ESR (mm/h)	12.62 ±3.97	12.50 ±4.19	11.48 ±4.15	0.57	P <sub>AB</sub> =0.92 P <sub>AC</sub> =0.35 P <sub>BC</sub> =0.36

CRP (mg/l)	4.43 ±2.04	4.90 ±1.90	4.96 ±2.00	0.62	P <sub>AB</sub> =0.41 P <sub>AC</sub> =0.38 P <sub>BC</sub> =0.91
------------	------------	------------	------------	------	---

---

Abbreviation: FFU Final follow-up

Regarding the number of fixation segments and pedicle screws, both groups A and B had significantly fewer fixation segments and pedicle screws than group C ( $p < 0.001$ ), while no significant difference was found between groups A and B ( $p > 0.01$ , Table 1). As a consequence, the hospital costs of group A and group B were lower than that of group C ( $\$14710.42 \pm 2354.55$  vs  $\$16680.23 \pm 3614.73$  vs  $\$19260.34 \pm 3310.75$ ,  $p < 0.01$ ;  $p_{AC} < 0.01$   $p_{BC} < 0.01$ , respectively). There was a significant difference in hospital cost between groups A and B ( $p_{AB} = 0.03$ ). In terms of operative time, a significant difference was observed among all three groups ( $p = 0.02$ ), with group A ( $166.43 \pm 44.11$  min) having a shorter operative time compared to group C ( $205.93 \pm 51.73$  min,  $p < 0.01$ ). There was no significant difference between groups A and B ( $p = 0.1$ ) or between groups B and C ( $p = 0.19$ ) (Table 1). There was a significant difference in blood loss among the three groups ( $543.81 \pm 230.81$  ml vs  $584.00 \pm 229.06$  ml vs  $803.70 \pm 446.78$  ml;  $p = 0.01$ ,  $p_{AB} = 0.66$ ,  $p_{AC} < 0.01$   $p_{BC} = 0.01$ ).

No significant difference was observed in the preoperative, postoperative, or final follow-up Cobb angles among groups A, B, and C ( $p = 0.99$ ,  $0.71$  and  $0.99$ ). Moreover, there was no significant difference in Cobb angle correction or loss among the three groups ( $p = 0.88$  and  $0.98$ ). The pelvic parameters (PT, PI, SS) of the three groups were not significantly different at any time point (Table 2). The LL of the three groups was not significantly different at the preoperative, postoperative, or final follow-up ( $p = 0.94$ ,  $0.78$  and  $0.81$ , respectively). In addition, the LL correction and loss among the three groups were not significantly different ( $p = 0.68$  and  $0.33$ , respectively). Similarly, the PI-LL of the three groups showed no significant difference in preoperative, postoperative, final follow-up or loss of correction parameters ( $p = 0.38$ ,  $0.19$ ,  $0.14$  and  $0.23$ , respectively). There was no significant difference in bone graft fusion time among the three groups ( $8.90 \pm 2.11$  months vs  $8.60 \pm 2.39$  months vs  $9.59 \pm 2.04$  months,  $p = 0.25$ ) (Table 2).

**TABLE 2**

Radiographic assessments of study populations

Radiographic data	Group A (n=12)	Group B (n=30)	Group C (n=27)	P value
<b>Cobb angle (°)</b>				
Pre-operative	13.43±7.62	13.06 ±9.07	13.07 ±7.58	0.99
Postoperative	11.33 ±8.85	11.84 ±10.46	13.89 ±9.86	0.71
Last follow-up	11.42 ±8.38	11.90 ±10.24	11.39 ±8.59	0.99
Mean Cobb angle correction	6.46 ±4.45	6.70±5.06	7.27±5.17	0.88
Mean Correction loss	3.38±3.90	3.14±3.83	3.33±3.26	0.98
<b>Lumbar lordosis (°)</b>				
Pre-operative	37.71±13.12	39.61±12.63	38.20±15.97	0.94
Postoperative	39.11±9.94	41.29±10.18	38.57±12.36	0.78
Last follow-up	39.12±11.35	42.02±9.50	39.82±14.04	0.81
Mean Lumbar lordosis correction	9.98±5.33	7.74±6.12	9.22±7.89	0.68
Mean Correction loss	5.63±4.15	3.41±3.21	4.54±3.97	0.33
<b>PT (°)</b>				
Pre-operative	13.32±7.11	16.69±8.26	14.41±7.90	0.74
Postoperative	18.25±11.00	10.20±5.94	11.84±6.94	0.49
Last follow-up	14.35±8.80	11.26±6.27	13.51±7.55	0.55
Mean Correction loss	3.24±3.97	2.71±2.98	2.63±2.79	0.85
<b>PI (°)</b>				
Pre-operative	42.59±9.26	46.49±8.97	45.08±8.93	0.88
Postoperative	49.48±13.50	43.79±9.17	42.92±9.89	0.94
Last follow-up	43.18±9.87	43.38±8.19	43.50±10.43	1.00
Mean Correction loss	2.78±2.36	3.46±3.39	2.91±2.65	0.79
<b>SS (°)</b>				
Pre-operative	29.84±4.78	29.80±8.06	31.47±8.21	0.84
Postoperative	31.23±3.51	33.59±8.45	31.45±7.65	0.40
Last follow-up	28.97±6.47	32.12±7.12	30.07±8.27	0.54
Mean Correction loss	3.45±2.84	2.50±2.86	2.77±3.01	0.68
<b>PI-LL (°)</b>				
Pre-operative	10.81±7.84	8.86±8.30	13.34±9.92	0.38
Postoperative	5.97±3.94	6.36±4.89	8.62±4.97	0.19

Last follow-up	7.37±4.60	5.29±4.76	8.90±5.61	0.14
Mean Correction loss	3.53±2.98	1.82±2.06	2.73±2.53	0.23
Bone graft fusion time (months)	8.90 ±2.11	8.60±2.39	9.59 ±2.04	0.25

With respect to neurological status, the ASIA grade showed no difference among the three groups before surgery ( $p = 0.88$ ) or at the last follow-up ( $p = 0.957$ ) (Table 3). As shown in Table 4, there were no significant postoperative complications among the three groups ( $p = 0.81$ ), and all patients were cured after active treatment.

**Table 3**

The neurological function evaluated by the ASIA impairment scale

ASIA scale	Group A (N = 12)	Group B (N = 30)	Group C (N = 27)	P value
	Pre	Pre	Pre	
A	0	0	0	0.883
B	0	0	0	
C	2	5	3	
D	4	12	10	
E	6	13	14	
	FFU	FFU	FFU	0.957
A	0	0	0	
B	0	0	0	
C	0	2	0	
D	2	3	2	
E	10	25	25	

Abbreviation: Pre preoperation, FFU Final follow-up

**Table 4**

Comparison of postoperative complications of study populations

Complications	Group A (N = 12)	Group B (N = 30)	Group C (N = 27)	P value
Systemic complications				
Pulmonary infection	1	2	2	
Hepatic dysfunction	1	1	2	
Renal dysfunction	1	3	2	
Urinary tract infection	1	0	2	
Deep vein thrombosis	0	2	1	
Local complications				
Cerebrospinal fluid linkage	0	1	1	
Sinus formation	1	2	2	
TMC dislocation	0	2	0	
Bone graft absorbed	0	0	1	
Total	5	13	14	0.805

## Discussion

For interbody fusion in patients with tuberculosis spondylitis, autogenous iliac bone has long been considered the best method since it results in good osteogenesis, bone induction, bone conductivity, and biocompatibility[13]. However, the preparation of autogenous iliac bone prolongs the operative time, increasing trauma and the risk of donor site complications. It has been reported that up to 40% of cases suffer from chronic pain and wound infection[16]. There is also a risk of bone absorption[17]. Allogeneic iliac bone may cause a mild chronic inflammatory reaction, which slows the formation and growth of blood vessels and interferes with osteoclast and osteoblast remodelling on the bone contact surface. The bone fusion time is relatively longer than that of autologous bone[18, 19]. Previous studies reported that TMCs provide better structural support for kyphosis and intervertebral height correction than autogenous iliac bone, and it is immune to the degradative enzymes that reside in an infected environment. However, a TMC has a risk of subsiding or displacement, which is related to the contact area, bone strength, and surgery[20, 21]. Recently, several authors have reported on the use of SP bone for the treatment of spinal infection[12, 13, 22]. Zhong et al[12] reviewed 35 cases treated with SP bone in one-level thoracic or lumbar tuberculosis and found that the mean bone fusion time was  $12.90 \pm 3.91$  months. Ke Tang[13] compared SP, transverse process (TP) and iliac bone grafts in single-segment thoracic tuberculosis, and the mean bone fusion times were  $12.90 \pm 3.91$  months,  $6.75 \pm 1.55$  months, and  $5.52 \pm 1.64$  months, respectively. According to their reports, the use of the SP could be suitable for strutting the bone defect space, representing an additional choice for surgeons in segmental stability construction. However, because using a single SP as a bone graft conveys a risk of delayed bony fusion or even non-union, the author suggested prolonged brace treatment.

In our study, we chose the SP combined with a TMC for reconstruction of the anterior and middle columns of the spine. Usually, we first implant the shaped SP followed by the TMC (filled with autogenous cancellous bone granules). Finally, we tighten the titanium rod with proper pressure and confirm that the TMC and SP are in good positions. Since this is the

first report on one-level lumbar and lumbosacral STB treated with SP + TMC methods, we compared it to TMCs (group B) and allografts (group C) regarding three aspects: safety, efficacy, and cost-effectiveness.

## 1. Safety

There were 12 patients (group A) who underwent SP + TMC bone grafts with a significant improvement in the VAS score and ODI at the FFU, at which time CRP and ESR had returned to normal. All patients achieved bone fusion at a mean time of  $8.90 \pm 2.11$  months, and all patients with neurological defects were improved at the FFU, indicating that the STB was cured. Moreover, there was no significant difference in postoperative complications compared to other groups. The above data indicates the safety of SP + TMC graft methods in lumbar and lumbosacral STB surgery.

## 2. Efficacy

Our study found that SP + TMC (group A) exhibited lower fixation segments, fewer pedicle screw implants ( $5.05 \pm 1.29$  vs  $6.85 \pm 1.37$   $p_{AC} < 0.01$ ), shorter operation time ( $166.43 \pm 44.11$  min vs  $205.93 \pm 51.73$  min  $p_{AC} < 0.01$ ), and reduced intraoperative blood loss ( $543.81 \pm 230.81$  ml vs  $803.70 \pm 446.78$  ml  $p_{AC} < 0.01$ ) compared to the allograft (group C). The underlying reason for this phenomenon could be that because allogeneic iliac bone has a weaker osteoinduction ability, surgeons tend to choose a more stable fixation scheme, i.e., lengthening the fixed segment when using allogeneic iliac bone in bone fusion. The postoperative and FFU radiological assessments between the two groups showed no significant difference in Cobb angle or LL correction and maintenance, while the pelvic parameters and PI-LL showed no obvious sagittal imbalance in any group. Although there was no significant difference in bone graft fusion time among the three groups ( $8.90 \pm 2.11$  months vs  $8.60 \pm 2.39$  months vs  $9.59 \pm 2.04$  months,  $p = 0.25$ ) (Table 2), compared to previous reports, the SP + TMC group had a significantly shorter time of bone fusion than the SP-only group[12, 13]. Moreover, the postoperative and follow-up data showed that the SP + TMC group achieved the same satisfying clinical results in relatively short segment fixation compared to the allograft group with long segment fusion.

## 3. Cost-effectiveness

In the past five years, the global total budget for TB has continually increased, reaching \$994 million USD in 2020, and the rapid increase in the TB budget has caused a heavy economic burden to society[1]. The average annual disposable income per person is approximately \$2000 in rural and urban areas and \$5000 in our areas. In our study, 74%-78% of patients came from rural areas. Regarding careers, 67%-74% of patients were farmers and workers with insufficient health insurance. A total of 87%-92% of patients had an annual individual income of less than \$5000. For these people, it is of great significance to reduce the cost of treatment on the premise of ensuring the safety and efficacy of the operation. Since the mean hospital cost was  $\$14710.42 \pm 2354.55$  in group A,  $\$16680.23 \pm 3614.73$  in group B, and  $\$19260.34 \pm 33100.75$  in group C, there was a significant decrease in hospital cost in group A compared to groups B ( $p = 0.03$ ) and C ( $p < 0.01$ ). SP + TMC provides a method with high cost-effectiveness for patients in developing countries and areas. The reduction in cost is primarily due to the decrease in the fixation segment, the reduced number of pedicle screws and the use of allogeneic bone and titanium mesh cages.

From the above comparisons, we found that for single-segment lumbar and lumbosacral STBs, TMCs reduce the fixed segments and achieves the same effect as long segment fixation combined with allogeneic bone grafts. Additionally, the combination of SP bone reduces the cost of hospitalization. The reasons for these observations could be as follows: 1. A TMC provides immediate stability, and its rigid characteristics can tolerate compression forces well. 2. A TMC can be tailored to fit the bone graft area, increasing the contact area and weight-bearing surfaces. 3. The SP, as an autogenous bone graft, has advantages with respect to osteogenesis, bone healing, bone conduction, and osteoinduction. 4. The SP is present in the surgical exposure area in the posterior approach, which can reduce time, bleeding, and trauma for an allogeneic iliac bone. 5. The SP, a cortical bone, has improved structural integrity and can effectively fill the defect space.

## Conclusion

Our study revealed that compared to TMC and allograft treatment, the SP combined with a TMC as a bone graft may represent an effective and economical approach for the surgical management of one-level lumbar or lumbosacral spinal TB, leading to good spinal stability restoration. This approach is a reliable structural bone grafting method, especially for developing countries or areas.

## Abbreviations

SP spinous process, TMCs combined with titanium mesh cages, VAS visual analogue scale, ODI Oswestry Disability Index, ESR erythrocyte sedimentation rate, CRP C-reactive protein, ASIA American Spinal Injury Association Impairment grade, FFU final follow-up, STB spine tuberculosis, TP transverse process, PT pelvic tilt, PI pelvic incidence, SS sacral Slope, LL lumbar lordosis.

## Declarations

## Ethics approval and consent to participate

Our research was approved by the ethics department of Xiangya Hospital, Central South University, Changsha, China. We have consensus with all participants. We also followed the Declaration of Helsinki and relevant policies in china.

## Consent for publication

Written informed consent was acquired from each of the patients or their parents and legal guardians to authorize treatment, imageology findings, and photographic documentation. The patients or their parents and legal guardians consented to the publication of their pictures as well as their anonymous and clustered data.

## Availability of data and material

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Competing interests

The authors declare that they have no competing interests.

## Funding

This study was supported by the National Natural Science Foundation of Hunan (2019JJ80014, 2020JJ5919). No benefit in any form has been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

## Authors' contributions

HZ designed the study. LX and MT performed the data collection, statistical analysis and data interpretation. GY contributed to manuscript writing. GY and LX contributed to patient enrollment and follow-up. All authors read and approved the final manuscript.

## Acknowledgements

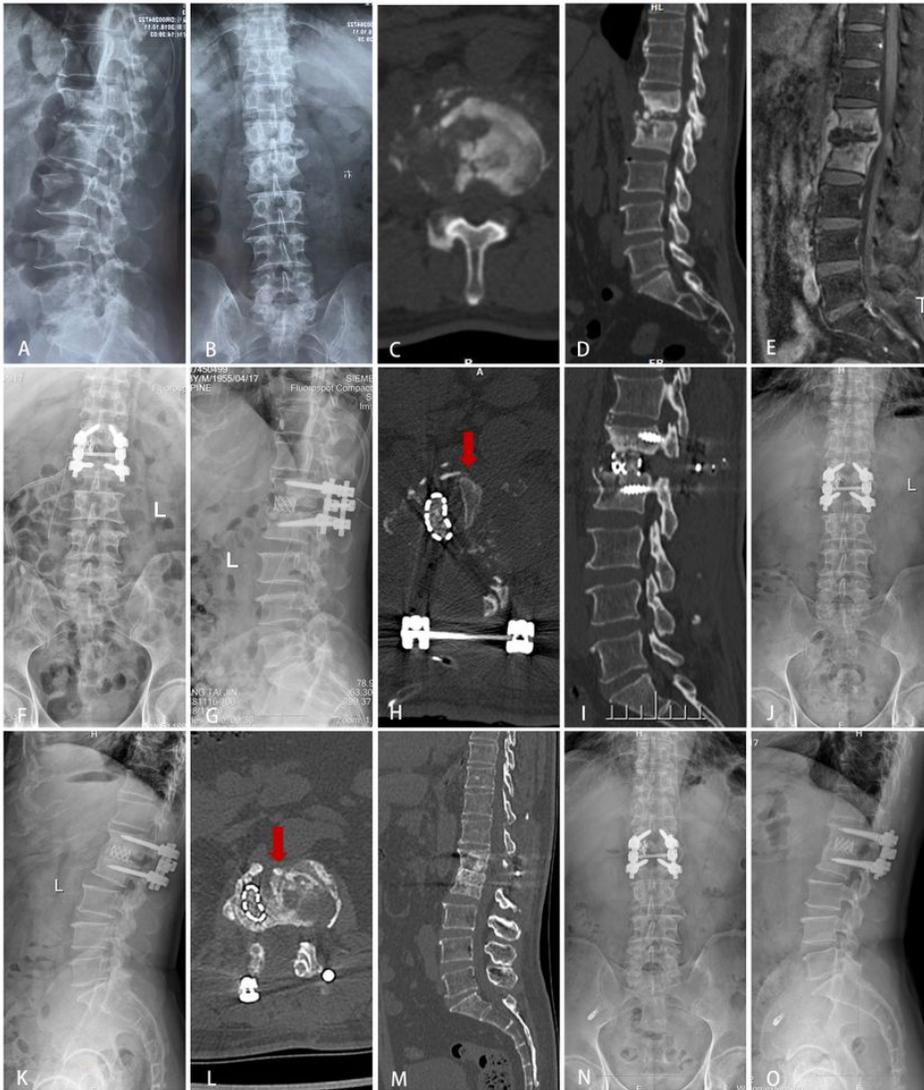
The authors thank all the staff of the Department of Spine Surgery, Xiangya Hospital, Central South University for their dedicated assistance in patient sample collection.

## References

1. Global Tuberculosis Report 2020, World Health Organization (WHO). 2020
2. Jain AK, S Rajasekaran, KR Jaggi, and VP Myneedu, Tuberculosis of the Spine. *J Bone Joint Surg Am*, 2020. **102**(7): p. 617–628 DOI:10.2106/JBJS.19.00001
3. Liu Z, J Wang, GZ Chen, et al., Clinical Characteristics of 1378 Inpatients with Spinal Tuberculosis in General Hospitals in South-Central China. *Biomed Res Int*, 2019. **2019**: p. 9765253 DOI:10.1155/2019/9765253
4. Shi T, Z Zhang, F Dai, et al., Retrospective Study of 967 Patients With Spinal Tuberculosis. *Orthopedics*, 2016. **39**(5): p. e838-43 DOI:10.3928/01477447-20160509-03
5. Fisahn C, F Alonso, GA Hasan, et al., Trends in Spinal Surgery for Pott's Disease (2000–2016): An Overview and Bibliometric Study. *Global Spine J*, 2017. **7**(8): p. 821–828 DOI:10.1177/2192568217735827
6. Wang YX, HQ Zhang, W Liao, et al., One-stage posterior focus debridement, interbody graft using titanium mesh cages, posterior instrumentation and fusion in the surgical treatment of lumbo-sacral spinal tuberculosis in the aged. *Int Orthop*, 2016. **40**(6): p. 1117–24 DOI:10.1007/s00264-016-3161-z
7. Zhang H, K Zeng, X Yin, et al., Debridement, internal fixation, and reconstruction using titanium mesh for the surgical treatment of thoracic and lumbar spinal tuberculosis via a posterior-only approach: a 4-year follow-up of 28 patients. *J Orthop Surg Res*, 2015. **10**: p. 150 DOI:10.1186/s13018-015-0292-7
8. Zhang HQ, MZ Lin, JS Li, et al., One-stage posterior debridement, transforaminal lumbar interbody fusion and instrumentation in treatment of lumbar spinal tuberculosis: a retrospective case series. *Arch Orthop Trauma Surg*, 2013. **133**(3): p. 333–41 DOI:10.1007/s00402-012-1669-2
9. He Z, Y Ou, B Hou, J Wei, and X Mu, A meta-analysis of the safety and effectiveness of titanium mesh versus bone graft alone for the treatment of thoracolumbar tuberculosis. *Eur Spine J*, 2020. **29**(7): p. 1505–1517 DOI:10.1007/s00586-019-06260-2
10. Chen Y, D Chen, Y Guo, et al., Subsidence of titanium mesh cage: a study based on 300 cases. *J Spinal Disord Tech*, 2008. **21**(7): p. 489–92 DOI:10.1097/BSD.0b013e318158de22
11. Wang YX, HQ Zhang, M Li, et al., Debridement, interbody graft using titanium mesh cages, posterior instrumentation and fusion in the surgical treatment of multilevel noncontiguous spinal tuberculosis in elderly patients via a posterior-only. *Injury*, 2017. **48**(2): p. 378–383 DOI:10.1016/j.injury.2016.12.025
12. Zhong W, X Liang, K Tang, et al., Midterm surgical results of the lamina with spinous process in treating one-level thoracic or lumbar tuberculosis: a retrospective study. *Sci Rep*, 2020. **10**(1): p. 22036 DOI:10.1038/s41598-020-79209-x
13. Tang K, J Li, T Huang, et al., Clinical efficacy of three types of autogenous bone grafts in treatment of single-segment thoracic tuberculosis: A retrospective cohort study. *Int J Med Sci*, 2020. **17**(17): p. 2844–2849 DOI:10.7150/ijms.47309

14. Xu S, G Wang, J Yang, et al., [The autologous bundled multi-segment rib graft reconstruction for bone defects after thoracic spinal tuberculosis debridement]. *Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi*, 2017. **31**(10): p. 1225–1230 DOI:10.7507/1002-1892.201612117
15. Bridwell KH, LG Lenke, KW McEnery, C Baldus, and K Blanke, Anterior fresh frozen structural allografts in the thoracic and lumbar spine. Do they work if combined with posterior fusion and instrumentation in adult patients with kyphosis or anterior column defects? *Spine (Phila Pa 1976)*, 1995. **20**(12): p. 1410–8
16. Arrington ED, WJ Smith, HG Chambers, AL Bucknell, and NA Davino, Complications of iliac crest bone graft harvesting. *Clin Orthop Relat Res*, 1996(329): p. 300–9 DOI:10.1097/00003086-199608000-00037
17. Zeng Y, Y Fan, F Luo, et al., Tricortical iliac crest allograft with anterolateral single rod screw instrumentation in the treatment of thoracic and lumbar spinal tuberculosis. *Sci Rep*, 2020. **10**(1): p. 13037 DOI:10.1038/s41598-020-70007-z
18. Govender S and AH Parbhoo, Support of the anterior column with allografts in tuberculosis of the spine. *J Bone Joint Surg Br*, 1999. **81**(1): p. 106–9 DOI:10.1302/0301-620x.81b1.9316
19. Epstein NE, Iliac crest autograft versus alternative constructs for anterior cervical spine surgery: Pros, cons, and costs. *Surg Neurol Int*, 2012. **3**(Suppl 3): p. S143-56 DOI:10.4103/2152-7806.98575
20. Zhang HQ, M Li, YX Wang, et al., Minimum 5-Year Follow-Up Outcomes for Comparison Between Titanium Mesh Cage and Allogeneic Bone Graft to Reconstruct Anterior Column Through Posterior Approach for the Surgical treatment of Thoracolumbar Spinal Tuberculosis with Kyphosis. *World Neurosurg*, 2019. **127**: p. e407-e415 DOI:10.1016/j.wneu.2019.03.139
21. Wang B, G Lv, W Liu, and I Cheng, Anterior radical debridement and reconstruction using titanium mesh cage for the surgical treatment of thoracic and thoracolumbar spinal tuberculosis: minimum five-year follow-up. *Turk Neurosurg*, 2011. **21**(4): p. 575–81 DOI:10.5137/1019-5149.JTN.4639 – 11.1
22. Su B, K Tang, W Liu, et al., One-stage posterior debridement, autogenous spinous process bone graft and instrumentation for single segment lumbar pyogenic spondylitis. *Sci Rep*, 2021. **11**(1): p. 3065 DOI:10.1038/s41598-021-82695-2

## Figures



**Figure 1**

Typical cases of group A (SP+TMC bone graft) A 63-year-old male was diagnosed as having tuberculous spondylitis after an eight months history of severe back pain. The infection had been resistant to chemotherapy for four months. A-E Pre-operative X-ray, MRI and CT showed that the lesion around the vertebral body of L1/2 developed an abscess with marked bony destruction. The abscess involved in the spinal canal with cord compromise resulted in neurologic deficit. F-J Post-operative X-ray and CT showed complete resolution of epidural abscess and decompression of neural component. Interbody graft using titanium mesh cages and spinous process were placed satisfactorily. K-O Final follow-up radiographs showed good bone fusion



**Figure 2**

Typical cases of group B (TMC bone graft) A 49-year-old female was diagnosed as having tuberculous spondylitis after a six months history of low back pain. The infection had been resistant to chemotherapy for one months. A-E Pre-operative X-ray, MRI and CT showed that the lesion around the vertebral body of L3/4 developed an abscess with marked bony destruction. F-I Post-operative X-ray and CT showed complete resolution of epidural abscess and decompression of neural component. Interbody graft using two titanium mesh cages were placed satisfactorily. J-M one year follow up showed good bone fusion. N-O Final follow-up radiographs showed good bone fusion and no obvious of displacement or subsidence of titanium mesh cage.



**Figure 3**

Typical cases of group C (allogeneic bone graft) A 55-year-old male was diagnosed as having tuberculous spondylitis after a one-year history of severe low back pain. The infection had been resistant to chemotherapy for three months. A-E Pre-operative X-ray, MRI and CT showed that the lesion around the vertebral body of L4/5 developed an abscess with marked bony destruction. F-I Post-operative X-ray and CT showed complete resolution of epidural abscess and decompression of neural component. Interbody graft using two allogeneic bones were placed satisfactorily. J-M one year follow up showed good bone fusion. N-O Final follow-up radiographs showed good bone fusion and no obvious of bone absorption or fractures.