Comparison between bundled multi-segment rib graft and titanium mesh bone graft in the treatment of thoracic and lumbar spinal tuberculosis

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Thoracic and lumbar spinal tuberculosis; Autogenous rib graft; Titanium mesh bone graft; Spinal fusion
Abstract
Background: To investigate the two different methods including bone grafting with bundled multi-segment ribs and titanium mesh bone grafting through posterior approach in patients with thoracic and lumbar spinal tuberculosis.

Methods: 38 patients with thoracic spinal tuberculosis in our hospital were divided into group A (19 cases of titanium mesh bone grafting) and group B (19 cases of bone grafting with bundled multi-segment ribs). The transverse costal process approach was firstly initiated, then the necrotic tissue of tuberculosis lesions was removed thoroughly. Finally, titanium mesh bone grafting and bone grafting with bundled multi-segment ribs was applied, respectively.

Results: The data demonstrated that 12 to 24 months of follow-up revealed that the operation time of Titanium mesh bone grafting in group A was 21.2±2.3 min, and that of bundled rib bone grafting in group B was 7.2±2.4 min. Compared to group A, the time in group B was significantly shorter. The amount of bleeding in group A not distinct from that in group B. There was no significant difference in Cobb angle. The fusion time in the two groups was similar. There was no significant difference in Oswestry dysfunction index between the two groups at the last follow-up.

Conclusions: Bone grafting with bundled multi-segment ribs could stable the function quickly after thoracic tuberculosis lesion clearance, indicating as an alternative and development prospects of bone graft strategy.

Background
Tuberculosis has increased significantly in recent years, with cases of spinal tuberculosis also increasing year by year. Spinal tuberculosis accounts for about 1%–2% of all tuberculosis infections and 75% of osteoarticular tuberculosis[1–3]. If the treatment is not timely, the disability rate is higher. Patients often suffer from kyphosis and neurological impairment due to the collapse of the vertebral body and the destruction of the intervertebral disc. The incidence of thoracic tuberculosis in spinal tuberculosis is higher, ranking only second to lumbar tuberculosis. The complications caused by thoracic tuberculosis are serious and most likely lead to paraplegia, so people have always been concerned[2, 4].
Previous studies have shown that most patients with spinal tuberculosis can be successfully alleviated or even cured by anti-tuberculosis drugs [5, 6]. However, due to individual differences or insensitivity to anti-tuberculosis drugs, the use of the drugs is limited. Surgical intervention has become an important way to treat serious spinal tuberculosis. Surgical treatment of spinal tuberculosis requires thorough removal of tuberculosis lesions, curettage of dead bones, and bone graft in the bone defect area[5] [7, 8]. Bone transplantation provides stability to the spine structure, and autologous bone grafting is the “gold standard” for bone transplantation. Currently, the most commonly used bone grafting methods for thoracic tuberculosis are titanium mesh bone grafting and autologous rib bone grafting. However, there are few reports on the systematic comparative analysis of these two different bone grafting methods[5, 8–10]. In this study, we compared preoperative and postoperative clinical indicators between bone grafting with bundled multi-segment ribs and titanium mesh bone grafting in 38 patients with thoracic spinal tuberculosis.

Methods
1.1 Ethics statement
This study was approved by the Institutional Review Board of the First Affiliated Hospital and was conducted according to the principle of the declaration. All participants provided their written informed consent to participate in this study prior to their data being stored in the hospital database and used for research purposes.

1.2 Patient Data
Thirty-eight patients with thoracic and lumbar spinal tuberculosis at the Orthopaedic Department of our hospital were divided into group A (19 cases of titanium mesh bone graft) and group B (19 cases of bone graft with bundled multi-segment ribs). These patients met the following criteria: 1) patients with obvious pain in the chest and back combined with neurological symptoms of the spinal cord, which were diagnosed by preoperative imaging examination and postoperative pathological examination, genetic determination, and tuberculosis culture; 2) patients who can tolerate the surgery as evaluated by the Anesthesiology Department; 3) patients with surgical indications for one-stage debridement, bone graft fusion, and posterior internal fixation.

1.3 Surgical methods
1.3.1 Preoperative and perioperative management

Both groups were treated with regular anti-tuberculosis drugs for more than 3 weeks. Generally, HRZE four-drug regimen was adopted, and second-line anti-tuberculosis drugs should be adjusted as appropriate in patients with gastrointestinal intolerance or severe liver damage. Blood, liver and kidney functions, blood routine, erythrocyte sedimentation rate, C-reactive protein, and other inflammatory indicators should be closely observed, and hypoproteinemia and anemia should be corrected actively to strengthen systemic nutritional support.

1.3.2 Surgical procedures

Both groups of patients underwent general anesthesia and were placed in a prone position. The C-arm machine was positioned to mark the diseased vertebral body, and the spinous processes were opened about 5 cm apart from the diseased vertebrae. The longitudinal incision was made in an arc-shaped incision to reveal the lamina and articular processes. The required pedicle screw was placed with the perspective aid of the C-arm, and the connecting rod was installed on one side. The intervertebral space was opened, followed by removal of the transverse process of the diseased vertebrae and separation of the soft tissue on the connected ribs of the diseased vertebrae. The ribs were then cut, and the parietal pleura along the diseased vertebral surface was carefully separated with the periosteal stripper. Next, the lesion tissue was completely scraped off and repeatedly rinsed with hydrogen peroxide, saline, and povidone-iodine dilution until the fresh bone was revealed. Decompression should be performed if spinal cord compression is present. The bone grafting methods of the two groups were listed as follows.

In group A, the lower edge of the iliac crest (i.e. among the gluteal muscle, abdominal muscle, and attachment of lumbar muscle) was cut to reach the iliac bone, which was dissected under the periosteum close to the bone surface. The internal and external plates of the iliac bone were dissected, and an iliac bone block of the appropriate size was cut directly from the iliac bone with a bone knife. The titanium mesh was then trimmed according to the size of the bone defect, and then the granular bone was filled into the titanium mesh. The titanium mesh bone graft was placed at the bone defect using the method of “implantation”, and the internal fixation was adjusted again. The
appropriate pressure was applied to promote the stability and fusion of the bone[5].

In group B, the ribs were cut and folded for 2–3 segments and bundled with absorbable sutures (Johnson-Johnson VICRYL PLUS sutures) (Supplementary Fig. 1). The bone defect area was plugged in after pruning the appropriate size of bone grafts. After bone grafting, the screw tail cap was loosened, proper pressure was applied, the tail cap was tightened, and the connecting rod was placed. Streptomycin powder was placed after the lesion and bone defect area were rinsed with isoniazid. Finally, 1 to 2 drainage tubes were placed, followed by suture layer by layer to close the incision.

1.3.3 Postoperative treatment

After the operation, patients were required to stay in bed for 3 weeks. Meanwhile, patients were encouraged to do functional exercises of chest, waist, back, and limbs in bed (without weight). After 3 weeks, patients were required to take protective braces to get out of bed. Anti-tuberculosis drugs were continued to take after the operation, and liver and kidney function and inflammation indexes were regularly reviewed. Anti-tuberculosis drugs were maintained for 18 to 24 months. The X-ray films were reexamined at 1 month, 3 months, 6 months, 1 year, and 2 years after the operation, and computed tomography (CT) and magnetic resonance imaging (MRI) of the diseased vertebrae were reexamined at 3 months, 6 months, 1 year, and 2 years after the operation.

1.4 Analytical indicators

The following indicators were accurately recorded in the two groups. First, time spent on bone grafting after tuberculosis removal (including autogenous bone removal). Second, blood loss during operation. Third, correction of thoracic kyphosis deformity angle after operation and loss of kyphosis deformity angle after the last follow-up. Fourth, fusion time of bone graft (using Zenya Ito fusion standard). Fifth, spinal nerve recovery. It was assessed before treatment, 3 months after treatment, 6 months after treatment, and the last follow-up. The spinal cord function was graded into 5 grades according to the Frankel classification [8, 10, 11]. Class A: the sensorimotor function was completely lost below the injury plane; Class B: the motor function completely disappeared below the injury plane, with only some sensations existing; Class C: the sensation below the injury plane was normal, and the muscle strength was 2 to 3; Class D: the sensation existed at the injury plane, and muscle
strength was 4; Class E: the sensorimotor function was normal. Finally, spine function that was evaluated by the Oswestry Disability Index (ODI) before treatment, 3 months after treatment, 6 months after treatment, and last follow-up. The patient responded to nine questions about pain, daily activities, self-care ability, walking, sitting, standing, sleep, travel, and social activities. Each question has six options, scoring 0-5 points, with 0 points indicating non-dysfunction and 5 points indicating the most serious dysfunction. Then ODI was calculated as scores/45 × 100%[10-13].

1.5 Statistical Analysis
All the data were processed using the SPSS 17.0 statistical software and carried out by the medical staff outside the treatment group. The follow-up measurements were expressed as (x ± s). T-test was used for statistical analysis, P < 0.05 was considered as statistically significant.

Results
2.1 Comparison of postoperative complications between the two groups
No significant difference was found in the age, sex, and lesion involvement segmental index between the two groups (P > 0.05) (Table 1).

In the two groups, one case had a wound infection with wound edge necrosis, and the other one had a sinus tract healing failure at the drainage tube. All of them were healed after re-debridement. There were no serious complications in other cases. During the follow-up period, the imaging examination showed that spinal internal fixation was in a good position and the bone graft fusion was satisfactory (Fig. 1). Routine blood test, erythrocyte sedimentation rate, and C-reactive protein all reached the normal index range. No recurrence of tuberculosis was observed after drug withdrawal.

2.2 Comparison of perioperative indicators between the two groups
The time spent on bone grafting in group A (21.2 ± 2.3 min) was significantly longer than that in group B (7.2 ± 2.4 min). The amount of bleeding during operation in group A and group B was 512 ± 40 mL and 502 ± 48 mL, respectively, with no significant difference between the two groups (Table 1).

2.3 Comparison of Cobb angle between the two groups
Before surgery, there was no significant difference in the Cobb angle between group A (35.1 ± 4.8°) and group B (35.2 ± 4.5°). After surgery, the Cobb angles of groups A and B were 15.1 ± 3.6° and 15.3 ± 3.1°, respectively, and there was no significant difference between groups. At the last follow-up, the Cobb angle in group A was 17.3 ± 3.6° with an average loss of 1.8°. The Cobb angle in group
B was 17.2 + 3.1° with an average loss of 1.9°, with no significant loss of Cobb angle between the two groups (P > 0.05) (Table 2).

2.4 Comparison of bone fusion time between the two groups
The fusion time of bone grafting was 7.1 ± 0.4 months in the group A and 7.2 ± 0.4 months in the group B. There was no statistical difference between group A and group B (P > 0.05) (Table 1).

2.5 Comparison of spinal function between the two groups
Frankl grade and Oswestry dysfunction index were significantly improved after 3 months and 6 months of surgery, as well as at the last follow-up (P < 0.05) (Tables 3 and 4). These results indicate that the spinal cord and nerve function of the two groups recovered to a certain extent after the operation.

Discussion
The purpose of spinal tuberculosis surgery is to remove tuberculosis tissue as possible, restore spinal stability and correct spinal deformity, and relieve spinal cord and nerve root compression[14–20]. However, after the complete removal of the lesions and the curettage of the dead bones, it will inevitably lead to the destruction of the vertebral body structure, which in turn affects the stability of the spine. Autologous bone grafting provides stabilization of the spine structure, and bone graft fusion is important for the correction of spinal deformity after the removal of the lesion, the repair of the bone defect, and the reconstruction of the spinal stability [5].

The most widely used method for bone grafting of spinal tuberculosis is bulk bone grafting, often using autologous iliac bone block, autologous ribs, fibula, etc. Clinically, the use of the iliac bone graft is more common because it has a high mechanical strength with three-sided cortical bone, which can effectively provide strong support for the bone defect area and maintain the stability of the spine before bone graft fusion [6, 7]. Moreover, the autologous iliac bone block has a high fusion rate, good tissue compatibility, and no risk of other diseases, and is an ideal material for bone graft fusion. However, there are many complications in the iliac bone grafting, including increased blood loss, additional incision, injury of superior gluteal nerve and artery, postoperative infection, hematoma, intestinal hernia, and delayed fracture. Even if no complication occurs, it will increase the operation time, leave scars on the donor site, and affect the aesthetics[18–23].
Titanium mesh bone graft has a stronger axial stress loading effect than iliac bone, rib, and fibula, and its fusion rate is equivalent to that of the fibula. Titanium mesh can be intercepted arbitrarily in length and is porous in the periphery. Small bones in the lumen can be closely connected with the bone in the non-decompression area through the surrounding wall pore and the upper or lower cavity pore, thus ensuring the area required for bone fusion. However, titanium mesh bone graft also has many disadvantages, especially the displacement of titanium mesh and its sinking to the vertebral body. Even though expanding the implanted bed in the lesion may be an alternative strategy, it will destroy the stability of the spine to a certain extent, and increase the bone grafting time and the amount of bleeding [22].

We have applied bundled multi-segment bone grafting for thoracic tuberculosis since 2010. It has the following advantages. First, the rib taken is the part that needs to be removed during the operation, and no additional surgical incision is needed, leading to the shortened operation time and decreased surgical trauma. Second, the rib as an autogenous bone has the characteristics of fast fusion, strong osteogenesis and induction. Third, the multi-segment ribs are firmly bundled with absorbable sutures to prevent early detachment of rib bone graft. Fourth, bundling multiple ribs together can greatly increase the contact area with the bone graft bed and prevent the bone from sinking. Fifth, bundling the multi-segment ribs together to make them a whole, which can freely change the length-width ratio of the bone graft and thus increase the supporting force to prevent the fracture of the single rib bone graft due to insufficient strength and maintain the angle of correction of kyphosis deformity after the operation. Finally, it can effectively avoid complications, such as infection and rejection caused by using allogenic bone.

However, there are still some limitations in this study. The number of cases used in this study is relatively small. Besides, a larger number of patients and longer follow-ups would be required. Studies involving combined anterior and posterior approaches are also necessary.

In conclusion, we found that there was no significant difference in the bone fusion time, bleeding volume, correction of deformity angle, loss of Cobb angle, and recovery of spinal cord nerve function between bundled multi-segment rib bone graft and titanium mesh bone graft. The operation time of
bundled multi-segment rib bone graft was significantly shorter than that of iliac bone graft. Rib bone graft, having early stabilization function after clearance of tuberculosis lesions, was convenient to obtain with less incidence of complications. Therefore, bone graft with bundled multi-segment ribs is a good alternative to treat spinal tuberculosis.

**Conclusions**
We analyzed and compared the preoperative and postoperative clinical indicators of bone graft with bundled multi-segment ribs and titanium mesh bone graft, and further confirmed the feasibility and potential advantages of bone graft with bundled multi-segment ribs in the prospects of bone graft fusion.

**Declarations**

*Abbreviations*

Not applicable.

*Ethics approval and consent to participate*

The present study was approved by the Ethics Committee of Hospital of Integrated Traditional Chinese and Western Medicine in Zhejiang Province (Hangzhou Red Cross Hospital).

*Consent for publication*

Written informed consent was obtained from all participants.

*Availability of data and material*

The analyzed data sets generated during the study are available from the corresponding author on reasonable request.

*Competing interests*

The authors declare that they had no competing interests.

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*Authors’ contributions*

YFW designed the study, collected the data and drafted the manuscript. QZ collected and analyzed
the data. MFZ and YHJ helped to collect the data. SYS conceived and designed the study and helped to draft the manuscript. All authors read and approved the final manuscript.

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Tables
Table 1. The clinical data of the two groups

| Group | Patients | Age | Gender | Segment | PRC | POC | ESR | Blood (mL) | Bone graft (min) | Fusion (min) |
|-------|----------|-----|--------|---------|-----|-----|-----|------------|-----------------|--------------|
| A     | 1        | 45  | woman  | T5-6    | 39.1| 15.1| 27  | 650        | 21              | 8            |
|       | 2        | 53  | man    | T5-6    | 10.6| 9.5 | 33  | 530        | 25              | 7            |
|       | 3        | 38  | woman  | T6-7    | 21.5| 14.3| 41  | 480        | 21              | 8            |
|       | 4        | 47  | man    | T7-8    | 39.5| 15.2| 33  | 700        | 19              | 6            |
|       | 5        | 24  | man    | T5-6    | 41.3| 16.9| 45  | 650        | 18              | 7            |
|       | 6        | 29  | woman  | T7-8    | 28.5| 14.1| 42  | 560        | 22              | 6            |
|       | 7        | 68  | man    | T5-6    | 38.3| 12.3| 18  | 550        | 23              | 7            |
|       | 8        | 66  | woman  | T7-8    | 39.7| 16.4| 24  | 350        | 18              | 8            |
|       | 9        | 58  | man    | T6-7    | 36.1| 18.3| 40  | 400        | 22              | 7            |
|       | 10       | 43  | woman  | T5-7    | 27.3| 11.4| 38  | 450        | 24              | 6            |
|       | 11       | 29  | man    | T8-9    | 38.4| 14.9| 47  | 450        | 17              | 8            |
|       | 12       | 59  | woman  | T8-9    | 37.1| 14.5| 55  | 400        | 19              | 8            |
|       | 13       | 65  | man    | T8-9    | 39.4| 16.5| 13.5| 380       | 18              | 7            |
|       | 14       | 55  | woman  | T10-11  | 40.6| 16.3| 38  | 800        | 25              | 8            |
|       | 15       | 45  | man    | T7-9    | 42.4| 18.3| 70  | 460        | 24              | 7            |
|       | 16       | 37  | woman  | T8-9    | 39.1| 15.5| 34  | 450        | 22              | 7            |
|       | 17       | 67  | man    | T9-10   | 38.3| 17.3| 39  | 500        | 19              | 6            |
|       | 18       | 44  | man    | T9-10   | 35.0| 16.3| 22  | 470        | 20              | 6            |
|       | 19       | 60  | man    | T-7-8   | 35.2| 14.4| 10  | 490        | 22              | 8            |
| B     | 1        | 29  | man    | T7-8    | 11.5| 9.1 | 18  | 630        | 6               | 7            |

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|   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|
| 1 |   |   |   |   |   |   |
| 2 |  46 | man | T9-10 | 39.5 | 16.2 | 33 | 490 | 7 | 9 |
| 3 |  37 | woman | T6-7 | 28.5 | 10.5 | 44 | 480 | 10 | 8 |
| 4 |  66 | man | T7-8 | 39.7 | 17.2 | 48 | 610 | 6 | 6 |
| 5 |  58 | man | T5-6 | 27.3 | 11.5 | 45 | 760 | 8 | 6 |
| 6 |  48 | man | T6-7 | 37.1 | 13.2 | 37 | 560 | 6 | 7 |
| 7 |  71 | man | T5-6 | 40.6 | 17.2 | 29 | 520 | 8 | 7 |
| 8 |  68 | woman | T7-8 | 39.1 | 16.1 | 24 | 350 | 7 | 8 |
| 9 |  54 | woman | T6-7 | 39.1 | 16.2 | 68 | 400 | 6 | 7 |
|10 |  34 | woman | T5-6 | 21.5 | 11.3 | 36 | 450 | 9 | 6 |
|11 |  57 | man | T8-10 | 41.3 | 16.5 | 47 | 430 | 5 | 8 |
|12 |  56 | woman | T8-9 | 38.3 | 17.3 | 25 | 400 | 8 | 7 |
|13 |  48 | man | T8-9 | 36.1 | 16.2 | 13.5 | 380 | 7 | 9 |
|14 |  68 | woman | T8-9 | 38.4 | 18.9 | 44 | 680 | 6 | 6 |
|15 |  29 | man | T7-9 | 39.4 | 17.2 | 65 | 460 | 8 | 7 |
|16 |  38 | man | T8-9 | 42.4 | 19.8 | 32 | 450 | 9 | 7 |
|17 |  48 | woman | T6-7 | 39.1 | 16.3 | 21 | 500 | 7 | 8 |
|18 |  66 | man | T9-10 | 35.2 | 16.4 | 19 | 500 | 6 | 7 |
|19 |   | man | T6-7 | 35.0 | 16.2 | 40 | 480 | 8 | 9 |

Table 2. Comparison of Cobb angle between the two groups

| Group | Pre-operation | Post-operation | Last follow-up |
|-------|---------------|----------------|---------------|
| Group A | 35.1 ± 4.8° | 15.1 ± 3.6° | 17.3 ± 3.6° |
| Group B | 35.2 ± 4.5° | 15.3 ± 3.1° | 17.2 ± 3.1° |

Table 3. Comparison of spinal nerve recovery between the two groups
| Frank grade | Rib bone graft fusion (n = 19) | Titanium mesh fusion (n=19) | P |
|-------------|-------------------------------|-----------------------------|---|
| Pre-therapy |                               |                             | 0.904 > 0.05 |
| B           | 3                             | 4                           |   |
| C           | 7                             | 7                           |   |
| D           | 9                             | 8                           |   |
| Post-therapy (3 months) |                   |                             | 0.923 > 0.05 |
| B           | 2                             | 3                           |   |
| C           | 4                             | 5                           |   |
| D           | 7                             | 6                           |   |
| E           | 6                             | 5                           |   |
| Post-therapy (6 months) |             |                             | 0.987 > 0.05 |
| B           | 1                             | 1                           |   |
| C           | 2                             | 2                           |   |
| D           | 5                             | 6                           |   |
| E           | 11                            | 10                          |   |
| Last follow up |                             |                             | 0.793 > 0.05 |
| B           | 0                             | 1                           |   |
| C           | 1                             | 1                           |   |
| D           | 2                             | 2                           |   |
| E           | 16                            | 15                          |   |
Table 4. Comparison of ODI between the two groups

| Group   | n   | Before operation | After the Operation (3 months) | After the Operation (6 months) | Last follow up |
|---------|-----|------------------|-------------------------------|-------------------------------|----------------|
| Group A | 1   | 78.7±9.0         | 32.9±6.3                      | 20.1±6.7                      | 11.7±7.0       |
|         | 9   |                  |                               |                               |                |
| Group B | 1   | 79.5±8.2         | 32.5 ± 6.4                    | 22.4 ± 5.8                    | 11.9 ± 6.4     |
|         | 9   |                  |                               |                               |                |
| $P$     | 0.05| 0.05            | 0.05                          | 0.05                          |                |

Figures
Figure 1

Typical cases: Bundled multi-segment rib bone graft case. a1. Preoperative anterior and lateral X-ray shows thoracic 6 vertebral bone destruction; a2. Postoperative anterior and lateral X-ray shows the good position of rib bone graft; a3. Postoperative CT shows the good position of the rib bone graft. Titanium mesh bone graft case. b1. Preoperative anterior and lateral X-ray shows thoracic 8 and 9 vertebral bone destruction; b2. Postoperative anterior and lateral X-ray shows good positioning of titanium mesh bone graft; b3. Postoperative CT shows the good position of titanium mesh bone graft.
Figure 2

Schematics of bone graft with bundled multi-segment ribs.